(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 033 393 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
22.01.2014 Bulletin 2014/04

(21) Application number: **06838501.2**

(22) Date of filing: **29.11.2006**

(51) Int Cl.:
H04L 27/26 $^{(2006.01)}$

(86) International application number:
PCT/US2006/045578

(87) International publication number:
WO 2007/145660 (21.12.2007 Gazette 2007/51)

(54) ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING USING SUBSYMBOL PROCESSING

ORTHOGONAL-FREQUENZMULTIPLEX MIT SUBSYMBOLVERARBEITUNG

MULTIPLEXAGE ORTHOGONAL À REPARTITION FRÉQUENTIELLE UTILISANT LE TRAITEMENT DE SOUS-SYMBOLES

(84) Designated Contracting States:
CH FI FR GB LI SE

(30) Priority: **14.06.2006 US 813667 P**

(43) Date of publication of application:
11.03.2009 Bulletin 2009/11

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(56) References cited:
EP-A- 1 357 718

- **MULLER S H ET AL: "A novel peak power reduction scheme for OFDM" PERSONAL, INDOOR AND MOBILE RADIO COMMUNICATIONS, 1997. WAVES OF THE YEAR 2000. PIMRC '97., THE 8TH IEEE INTERNATIONAL SYMPOSIUM ON HELSINKI, FINLAND 1-4 SEPT. 1997, NEW YORK, NY, USA,IEEE, US, vol. 3, 1 September 1997 (1997-09-01), pages 1090-1094, XP010247616 ISBN: 0-7803-3871-5**

Printed by Jouve, 75001 PARIS (FR)

Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to signal processing, and more specifically to orthogonal frequency division multiplexing techniques used in signal transmission and reception:

Description of the Related Art

[0002] Orthogonal frequency division multiplexing (OFDM) is a signal processing technology well known in the field of communications. In general, OFDM operates by dividing a frequency spectrum into smaller subbands (a.k.a. subcarriers) and modulating these sub carriers with data symbols.

[0003] **FIG. 1** shows a simplified block diagram of one implementation of a prior-art OFDM transmitter **100.** Transmitter **100** receives digital input data and converts the data into analog OFDM signals for transmission. Conversion of the data occurs through sequential steps of data symbol mapping **102**, inverse fast Fourier transform (IFFT) processing **104**, cyclic prefix appending **106**, digital-to-analog conversion (DAC) **108**, and spectral shaping **110**.

[0004] Data symbol mapping block **102** receives binary bits of data, which are divided into groups of finite length. One or more data symbols *a[n]* are created for each group of bits, using any one of a number of modulation techniques commonly known in the art, such as differential quadrature phase-shift-keying (DQPSK) or quadrature amplitude modulation (QAM). The length of each group and thus the number of input data bits per data symbol is determined by the modulation technique employed.

[0005] IFFT **104** subsequently applies each set of N data symbols *a[n]* to a set of N subcarriers, which are numbered from 0 to N-1, where one data symbol *a[n]* is paired with each subcarrier. The subcarriers employed by OFDM are arranged orthogonally to one another, so that each subcarrier can be distinguished without intersymbol interference. Each set k of N data symbol *a[n]* and subcarrier pairs is then converted by IFFT **104** from frequency-domain representations into a time-domain OFDM symbol S_k, consisting of N *samples* $S_k[i]$, where i equals 0 to N-1. The discrete model for each OFDM symbol S_k may be expressed by Equation (1) as follows:

$$S_k[i] = S_k\left(i\frac{T}{N}\right) = \sum_{n=0}^{N-1} a[n] e^{j\frac{2\pi}{N}ni} w[i] = \sum_{n=0}^{N-1} a[n] c[i,n] \tag{1}$$

where $\frac{T}{N}$ is the sample period, $w[i]$ is a discrete window function, and $c[i,n] = e^{j\frac{2\pi}{N}ni} w[i]$ denotes the finite length complex exponential sequence of the subcarriers.

[0006] The OFDM symbols S_k are then prepared for transmission. First, a cyclic prefix is inserted at the beginning of each OFDM symbol S_k by cyclic prefix appending **106.** This prefix enables the receiver to cope with signal echoes that result from multipath reflections. Next, the OFDM symbols and prefixes are converted from digital format to analog format using digital-to-analog converter (DAC) **108**. Finally, the analog output from DAC **108** undergoes spectral shaping by spectral shaping block **110** to produce an OFDM signal for transmission.

[0007] As an example of the production of a prior-art OFDM signal, assume that IFFT **104** receives 384 data symbols *a[n]*, where n = 0,...,383, and employs N=128 subcarriers. Since one data symbol *a[n]* in each set of $\underline{N}$ data symbols *a [n]* is assigned to each subcarrier, the number of OFDM symbols S_k generated is equal to 3 (384 data symbols *a[n]* divided by 128 subcarriers). The grouping of data symbols *a[n]* in the frequency domain is shown in Table L As shown in Table I, in a prior-art OFDM system, data symbols *a[0]* to *a[127]* are assigned to OFDM symbol S_0, data symbols *a [128]* to *a[255]* are assigned to OFDM symbol S_1, and data symbols *a[256]* to *a[383]* are assigned to OFDM symbol S_2.

TABLE I. GROUPING OF DATA SYMBOLS *a[n]* IN THE FREQUENCY DOMAIN OF A PRIOR-ART OFDM SIGNAL

Subcarrier Index	**0**	**1**	**2**	**3**	**...**	**127**
OFDM Symbol 0 (S_0)	*a[0]*	*a[1]*	*a[2]*	*a[3]*	...	*a[127]*

(continued)

TABLE I. GROUPING OF DATA SYMBOLS *a[n]* IN THE FREQUENCY DOMAIN OF A PRIOR-ART OFDM SIGNAL						
OFDM Symbol 1 (S_1)	*a[128]*	*a[129]*	*a[130]*	*a[131]*	...	*a[255]*
OFDM Symbol 2 (S_2)	*a[256]*	*a[257]*	*A[258]*	*a[259]*	...	*a[383]*

[0008] Table II shows the grouping of samples $S_k[i]$, where k= 0, 1, 2 and i = 0,...,127, in the time domain after conversion by FFT **104**. In a prior-art OFDM system, the samples $S_k[i]$ of each OFDM symbol S_k remain grouped together, and the OFDM symbols S_k are transmitted in succession. In other words, samples $S_0[0]$ to $S_0[127]$ of OFDM symbol S_0 are transmitted before samples $S_1[0]$ to $S_1[127]$ of OFDM symbol S_1, which are transmitted before samples $S_2[0]$ to $S_2[127]$ of OFDM symbol S_2.

TABLE II. GROUPING OF SAMPLES $S_k[i]$ IN THE TIME DOMAIN OF A PRIOR-ART OFDM SIGNAL

	OFDM Symbol S_0						**OFDM Symbol S_1**						**OFDM Symbol S_2**					
Sample Index	**0**	**1**	**2**	**3**	**...**	**127**	**128**	**129**	**130**	**131**	**...**	**255**	**256**	**257**	**258**	**259**	**...**	**383**
Trans-mitted Data	$S_0[0]$	$S_0[1]$	$S_0[2]$	$S_0[3]$	...	$S_0[127]$	$S_1[0]$	$S_1[1]$	$S_1[2]$	$S_1[3]$	...	$S_1[127]$	$S_2[0]$	$S_2[1]$	$S_2[2]$	$S_2[3]$	...	$S_2[127]$

[0009] **FIG. 2** shows a frequency-domain representation of prior-art OFDM symbol S_0 described in the example above. Each subcarrier, represented by a single waveform, is assigned one data symbol *a[n]*. Additionally, note that the subcarriers are spaced apart so that the peak of each subcarrier corresponds to a zero level of every other subcarrier. This is representative of the orthogonal nature of the set of subcarriers.

[0010] **FIG. 3** shows a simplified block diagram of one implementation of a prior-art OFDM receiver **300**, which reverses the operations performed by OFDM transmitter **100.** Receiver **300** receives analog OFDM signals and extracts the original digital data. Extraction occurs through sequential steps of matched filtering **302**, analog-to-digital conversion (ADC) **304**, cyclic prefix removal **306**, fast Fourier transform (FFT) processing **308**, and data symbol demapping **310**.

[0011] First, the received OFDM signal is down-converted into a baseband analog signal at the receiver's RF front end. The baseband analog signal is filtered by matched filtering block **302** and converted to digital format by ADC **304**. Next, synchronization and channel estimation may be performed (not shown). Then, cyclic prefix removal block **306** removes the cyclic prefixes from the time-domain OFDM symbols S_k.

[0012] FFT **308** receives digital OFDM symbols S_k and extracts the *N* subcarriers from each to obtain data symbols *a[n]*, according to Equation (2) as follows:

$$a[n] = \sum_{i=0}^{N-1} S_k[i] e^{-j\frac{2\pi}{N}ni} w[n] \qquad (2)$$

Finally, data symbols *a[n]* are demapped into the original binary bits using data symbol demapping block **310** which demodulates the data symbols in accordance with the modulation technique employed by data symbol mapping **102 of FIG. 1**.

[0013] Müller, et al., "A Novel Peak Power Reduction Scheme for OFDM," Proc. of the Int. Symposium on Personal, Indoor and Mobile Radio Communications, pp. 1090-1094, Sept. 1997, teaches an OFDM system that applyies *V* IDFTs to *V* frequency-domain subblocks, wherein all of the subcarrier positions in each subblock that are already represented in another subblock are set to zero. After applying the *V* IDFTs, the resulting *V* time-domain subblocks multiplied by rotation factors and are combined by summing the subsymbols to generate an OFDM symbol. Thus, the first samples of the *V* time-domain subsymbols are summed to generate a first sample of the OFDM symbol, the second samples of the *V* time-domain subsymbols are summed to generate a second sample of the OFDM symbol, and so on. Multiplying by the rotation factors helps reduce the peak-to-average power ratio of the resulting OFDM symbol. Further, summing the *V* time-domain subsymbols results in an OFDM symbol that has the same number of samples as each *V* time-domain subsymbol. European patent application number EP-1357718-A2 teaches a similar method of generating OFDM symbols.

SUMMARY OF THE INVENTION

[0014] In one aspect, the invention is a method according to claim 1.

[0015] In another aspect, the invention is an apparatus according to claim 8.

[0016] In a further aspect, the invention is a method according to claim 9.

[0017] In yet another aspect, the invention is an apparatus according to claim 15.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Other aspects, features, and advantages of the present invention will become more fully apparent from the following detailed description, the appended claims, and the accompanying drawings in which like reference numerals identify similar or identical elements.

FIG. 1 shows a simplified block diagram of one possible implementation of a prior-art OFDM transmitter;

FIG. 2 graphically illustrates a frequency-domain representation of an exemplary prior-art OFDM signal;

FIG. 3 shows a simplified block diagram of one possible implementation of a prior-art OFDM receiver;

FIG. 4 shows a simplified block diagram of a combined-OFDM transmitter according to one embodiment of the present invention;

FIG. 5 graphically illustrates one implementation of a grouping pattern of frequency-domain data symbols according to one embodiment of the present invention;

FIG. 6 graphically illustrates one implementation of an interleaving pattern of time-domain samples according to one embodiment of the present invention;

FIG. 7 shows a simplified block diagram of a combined-OFDM receiver according to one embodiment of the present invention; and

FIG. 8 graphically illustrates the imaging that occurs in the frequency domain of an upsampled combined-OFDM signal according to one embodiment of the present invention.

DETAILED DESCRIPTION

[0019] Certain embodiments of the present invention relate to combined-OFDM methods and apparatuses for practicing these methods. In one such embodiment, data symbols *a*[*n*] are divided into groups, where each group is converted into an OFDM subsymbol using an inverse fast Fourier transform. Then, multiple OFDM subsymbols are combined to produce a combined-OFDM symbol.

[0020] **FIG. 4** shows a simplified block diagram of a combined-OFDM transmitter **400** according to one embodiment of the present invention. Transmitter **400** receives digital input data and converts the data into analog combined-OFDM signals for transmission. Conversion of the data occurs through sequential steps of data symbol mapping **402**, data symbol grouping **412**, inverse fast Fourier transform (IFFT) processing **404**, OFDM subsymbol combining **416**, cyclic prefix appending **406**, digital-to-analog conversion (DAC) **408**, and spectral shaping **410.**

[0021] In prior-art transmitter **100** of **FIG. 1,** IFFT **104** receives a set of N data symbols $a[n]$ from data symbol mapping block **102** and assigns the N data symbols $a[n]$ to N subcarriers. The N data symbol $a[n]$ and subcarrier pairs are then converted from frequency-domain representations into a time-domain OFDM symbol S_k. According to the embodiment of **FIG. 4,** transmitter **400** has data symbol mapping block **402,** which performs operations analogous to those of data symbol mapping block **102** of prior-art transmitter **100.** Additionally, transmitter **400** has M instances of IFFT **404,** $M > 1$, each instance utilizing N subcarriers. A set of N data symbols $a[n]$ is divided into M groups by data symbol grouping **412.** Each group m, numbered consecutively from 0 to M-1, is then transmitted to a separate instance of IFFT **404.** Division of data symbols $a[n]$ amongst the M groups is performed according to a grouping pattern. This pattern is described further in the example below.

[0022] Each instance of IFFT **404** receives one group m of $\frac{N}{M}$ data symbols $a[n]$ and assigns the $\frac{N}{M}$ data symbols to the N subcarriers. Since the number $\frac{N}{M}$ of data symbols $a[n]$ in each group m is smaller than the number N of subcarriers per IFFT **404**, not every subcarrier is assigned a data symbol $a[n]$ for modulation. Thus, the number N_m of modulated subcarriers per **IFFT'404** is equal to $\frac{N}{M}$. Each IFFT **404** then converts the N subcarriers (i.e. the N_m modulated subcarriers and $(N - N_m)$ unmodulated subcarriers) from frequency-domain representations into a time-domain OFDM subsymbol S_m. As such, M instances of IFFT **404** produce M time-domain OFDM subsymbols S_m, each subsymbol S_m consisting of N samples. The discrete model for each OFDM subsymbol S_m, may be expressed by Equation (3) as follows:

$$S_m[i] = \sum_{n=0}^{N_m-1} a_m[n] c_m[i,n] \tag{3}$$

where $i = 0,\ldots, N-1$, $a_m[n]$ are the data symbols in OFDM subsymbol m, and the finite length complex exponential sequence for each group of modulated subcarriers N_m is $c_m[i,n] = e^{j\frac{2\pi}{N}(m+Mn)i} w[i]$. Note that this grouping sequence varies depending on the grouping pattern used.

[0023] Next, OFDM subsymbol combining **416** receives M OFDM subsymbols, each containing N samples, from the M instances of IFFT **404.** According to this embodiment, the (N x M) total samples are combined using an interleaving pattern, to create one type of combined-OFDM symbol, herein referred to as an interleaved-OFDM (IOFDM) symbol. This interleaving pattern is discussed further in the example below. The resulting IOFDM symbol is expressed in Equation (4) below:

$$X_k(q) = \sum_{m=0}^{M-1} \sum_{i=0}^{N-1} S_m[i] \delta[q - m - iM] \tag{4}$$

where δ[.] denotes a unit impulse sequence. This unit impulse sequence varies depending on the OFDM subsymbol combining (e.g., interleaving) pattern used.

[0024] The IOFDM symbols X_k are then prepared for transmission. Similar to prior-art transmitter **100** of **FIG. 1**, transmitter **400** performs cyclic prefix appending **406**, digital-to-analog conversion (DAC) **408**, and spectral shaping **410**.

[0025] As an example of an IOFDM signal according to this embodiment, assume that data symbol grouping block **412** receives 128 data symbols $a[n]$, n = 0,..., 127, and each instance of IFFT **404** employs N=128 subcarriers. Also, assume that the number M of groups is chosen to be 4. The 128 data symbols $a[n]$ may be divided into M groups by data symbol grouping block **412** as shown in Table III.

TABLE III. GROUPING OF DATA SYMBOLS *a[n]* IN THE FREQUENCY DOMAIN OF AN IOFDM SIGNAL ACCORDING TO ONE EMBODIMENT

Subcarrier Index	**0**	**1**	**2**	**3**	**4**	**...**	**127**
OFDM Subsymbol 0 (S_0)	$a[0]$				$a[4]$	...	
OFDM Subsymbol 1 (S_1)		$a[1]$				...	
OFDM Subsymbol 2 (S_2)			$a[2]$			...	
OFDM Subsymbol 3 (S_3)				$a[3]$		...	$a[127]$

According to this grouping pattern, the first data symbol $a[0]$ is assigned to subcarner 0 in OFDM subsymbol S_0, the second data symbol $a[1]$ is assigned to subcarrier 1 in the second OFDM subsymbol S_1, the third data symbol $a[2]$ is assigned to subcarrier 2 in the third OFDM subsymbol S_2, and the fourth data symbol $a[3]$ is assigned to subcarrier 3 in the fourth OFDM subsymbol S_3. This grouping pattern is continued beginning with the fifth data symbol $a[4]$ being assigned to subcarrier 4 in the first OFDM subsymbol S_0 and concluding with the last data symbol $a[127]$ being assigned to subcarrier 127 in the fourth OFDM subsymbol S_3.

[0026] **FIG. 5** further demonstrates the data symbol grouping pattern described in the example above. This frequency-domain representation shows each modulated subcarrier N_m, represented by a single waveform. **FIGS. 5 (a), (b), (c),** and **(d)** show the first modulated subcarriers of OFDM subsymbols S_0, S_1, S_2, and S_3, respectively. **FIG. 5 (e)** shows the frequency-domain representation of the corresponding IOFDM symbol. Note that $P(f)$ is the frequency response of spectral shaping block 410.

[0027] After conversion from frequency-domain representations into time-domain OFDM subsymbols S_m by the 4 instances of IFFT **404**, samples $S_m[i]$ may be interleaved as shown in Table IV to produce an IOFDM symbol X_k.

TABLE IV. GROUPING OF SAMPLES *$S_m[i]$* IN THE TIME DOMAIN ACCORDING TO ONE EMBODIMENT

	IOFDM Symbol $X_k(q)$, q = 0,..., 511															
Sample Index *q*	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**...**	**508**	**509**	**510**	**511**
Trans-mitted Data	$S_0[0]$	$S_1[0]$	$S_2[0]$	$S_3[0]$	$S_0[1]$	$S_1[1]$	$S_2[1]$	$S_3[1]$	$S_0[2]$	$S_1[2]$	$S_2[2]$	$S_3[2]$	...	$S_0[127]$	$S_1[127]$	$S_2[127]$	$S_3[127]$

Note that one sample $S_m[i]$ is created for each subcarrier, even if the subcarrier is not assigned a data symbol $a[n]$. In this interleaving pattern, sample $S_0[0]$, is followed by samples $S_1[0]$, $S_2[0]$, and $S_3[0]$. Following $S_3[0]$, the pattern continues beginning with $S_0[1]$ and followed by $S_1[1]$, $S_2[1]$, and $S_3[1]$. This interleaving pattern is repeated for all samples $S_m[i]$.

[0028] **FIG. 6** further demonstrates the interleaving pattern described in the example above. **FIGS. 6 (a), (b), (c** and

(d) represent OFDM subsymbols S_0, S_1, S_2, and S_3, respectively. **FIG. 6 (e)** represents the interleaved OFDM symbol X_k.

[0029] According to the exemplary IOFDM symbol given above, 512 samples $X_k[q]$, where q = 0,...,511, are transmitted for each set of 128 data symbols *a[n]*. This is in contrast to the example provided for prior-art OFDM transmitter **100** in the background section, where each set of 128 data symbols is transmitted using 128 OFDM samples. Thus, the IOFDM symbol duration of this example is 4 times longer than the OFDM symbol duration of the corresponding prior-art example. On the other hand, an IOFDM symbol X_k is more robust against noise effects during transmission than the corresponding prior-art OFDM symbol S_k. In addition, the sample period (T/N) of the IOFDM symbol X_k is the same as the sample period of the prior-art OFDM symbol S_k. Thus, the bandwidth of the IOFDM symbol X_k is the same as that of the OFDM symbol S_k.

[0030] **FIG. 7** shows a simplified block diagram of one implementation of a combined-OFDM receiver **700**, which reverses the operations performed by combined-OFDM transmitter **400**. Receiver **700** receives analog combined-OFDM signals and extracts the original digital data. Extraction occurs through sequential steps of matched filtering **702**, analog-to-digital conversion (ADC) **704**, cyclic prefix removal **706**, OFDM subsymbol separating **714**, fast Fourier transform (FFT) processing **708**, data symbol de-grouping and equalization **718**, and data symbol de-mapping **710.**

[0031] First, receiver **700** down-converts the received signal into a baseband analog signal at the receiver's RF front end. Then, similar to prior-art receiver **300** of **FIG. 3**, receiver **700** performs matched filtering **702**, analog-to-digital conversion ADC **704,** and cyclic prefix removal **706**. Additionally, synchronization and channel estimation may be performed (not shown).

[0032] OFDM subsymbol separating block **714** separates (e.g., deinterleaves) the digital IOFDM symbols X_k to recover the M OFDM subsymbols S_m. The M OFDM subsymbols S_m are subsequently transmitted to the M instances of FFT **708**. Each instance of FFT **708** extracts N subcarriers from the corresponding OFDM subsymbol S_m to obtain the corresponding group m of data symbols *a[n]*. The M groups of data symbols *a[n]* are then equalized and de-grouped by data symbol de-grouping and equalization block **718**. Finally, data symbols *a[n]* are de-mapped into the original binary bits using conventional data symbol de-mapping block **710**.

[0033] Various embodiments of the present invention may be envisioned in which alternative grouping patterns are employed. In the IOFDM example above, data symbols *a[n]* were grouped using an interleaving pattern. Another grouping pattern using interleaving may be employed for the above IOFDM example in which the first two data symbols (*a [0]* and *a[1])* are assigned to subcarriers 0 and 1 in OFDM subsymbol S_0, the third and fourth data symbols (*a[2]* and *a[3]*) are assigned to subcarriers 2 and 3 in OFDM subsymbol S_1, the fifth and sixth data symbols (*a[4]* and *a[5])* are assigned to subcarriers 4 and 5 in OFDM subsymbol S_2, and the seventh and eighth data symbols (*a[6]* and *a[7]*) are assigned to subcarriers 6 and 7 in OFDM subsymbol S_3. This process is then continued beginning with the ninth and tenth data symbols *a[8]* and *a[9]* being assigned to subcarriers 8 and 9 in OFDM subsymbol S_0 and concluding with data symbols *a[126]* and *a*[*127*] being assigned to subcarrier 126 and 127 in OFDM subsymbol S_3. A vast number of alternative grouping patterns may be envisioned within the scope of this invention.

[0034] Various embodiments of the present invention may also be envisioned in which alternative combining patterns using interleaving are employed. In one such alternative to the IOFDM example above, OFDM subsymbol combining block **416** may assign two consecutive samples $S_m[i]$ to IOFDM symbol *X(k)* at a time. In other words, OFDM subsymbol combining block **416** may assign $S_0[0]$ and $S_0[1]$, followed by $S_1[0]$ and $S_1[1]$, followed by $S_2[0]$ and $S_2[1]$, followed by $S_3[0]$ and $S_3[1]$ to IOFDM symbol *X*(*k*). This process is then repeated beginning with $S_0[2]$ and ending with $S_3[127]$. A vast number of alternative combining patterns using interleaving may be envisioned within the scope of this invention.

[0035] Furthermore, the above mentioned examples demonstrate one type of combined-OFDM symbol, referred to as an IOFDM symbol. In another type of combined-OFDM symbol, subsymbols S_k can be appended to each other without interleaving, such that, samples $S_0[0]$ to $S_0[127]$ of subsymbol S_0 are followed by samples $S_1[0]$ to $S_1[127]$ of subsymbol S_1, which are followed by samples $S_2[0]$ to $S_2[127]$ of subsymbol S_2, which are followed by samples $S_3[0]$ to $S_3[127]$ of subsymbol S_3. The order in which subsymbols S_k are appended may also vary.

[0036] Further embodiments of the present invention may be envisioned in which the combined-OFDM symbol duration is the same as the corresponding prior-art OFDM symbol duration. In such embodiments, OFDM subsymbols S_m or combined-OFDM symbols X_k are upsampled by upsamplers **414** or **418,** respectively, to increase the data rate. For instance, in the IOFDM example above, the 128 samples $S_m[i]$ may be upsampled by 4 (i.e., upsampled by M), so that the total number of modulated samples transmitted per IOFDM symbol increases from 128 to 512. As a result of upsampling, imaging in DAC **408** produces a larger signal bandwidth. The resulting upsampled IOFDM signal may be represented by Equation (5) as follows:

$$x(t)=\sum_{q}x[q]\delta(t-qT_C)*p(t)=\sum_{m=0}^{M-1}\sum_{i=0}^{N-1}s_m[i]p(t-mT_C-iMT_C) \qquad (5)$$

where *p(t)* is the impulse response of the spectral shaping filter, and $T_C = \frac{T}{MN}$ is the new sample period. **FIG. 8** graphically demonstrates this imaging in the frequency domain. Note that the modulated subcarriers are repeated at higher frequencies. This phenomenon increases the overall signal bandwidth. Additionally, in order to accommodate upsampling, receiver **700** has downsamplers **712** or **716**, which downsample either the combined-OFDM symbols X_k or the OFDM subsymbols S_m of the received signal, respectively.

[0037] The present invention has been described using a number of data symbols *a[n]* that is equal to the number *N* of subcarriers; however, the present invention is not so limited. The number of data symbols *a[n]* may be fewer than the number *N* of subcarriers. Therefore, the number $N_{m'}$ of subcarriers modulated with data symbols *a[n]* per IFFT **404** could be less than $\frac{N}{M}$. The excess unmodulated subcarriers could then be used for other purposes such as implementation as guard channels or pilot channels.

[0038] Additional embodiments of the present invention may be envisioned in which the number *M* of groups varies. In the above-mentioned IOFDM example, the number *M* of groups (i.e., 4) was chosen based on the number *N* (i.e., 128) of subcarriers such that the number N_m of modulated subcarriers per group (i.e., $\frac{N}{M}$) is an integer (i.e., 32). While it is preferred that the number of data symbols per group N_m be an integer, it is not necessary. For example, the number *M* of groups could be 3, in which case each group would not necessarily have the same number of data symbols *a[n]*. Additionally, by increasing the number *M* of groups, and employing upsampling, the width of the overall frequency spectrum is increased. Selecting a number *M* of groups that is equal to the number *N* of subcarriers allows for the greatest possible spectrum spreading. Alternatively, as the number *M* of groups is decreased, the frequency spectrum width is decreased. Selecting the number *M* of groups such that M=1, results in the production of a prior-art OFDM signal. Combined OFDM, therefore, provides a means to construct a variable spreading ratio system according to different applications and/or channel conditions. This spectrum spreading ability allows combined OFDM to be suitable for use in ultra-wideband (UWB) applications. Additionally, due to the wider spectrum of the combined-OFDM signal, lower power operation can be achieved, thereby easing issues of interference compliance.

[0039] In yet other embodiments, the number of IFFT blocks in transmitter **400** and FFT blocks in receiver **700** may vary. For instance, in the above-mentioned IOFDM example, transmitter **400** might have only one shared IFFT block that receives the *M* groups of data symbols *a[n]* in succession and converts the *M* groups in succession into *M* subsymbols S_m in a time-multiplexed manner.

[0040] Other elements of OFDM are supported by this invention. For example, this invention may be implemented using coded OFDM (COFDM). Additionally, piconet channelization methods such as code division multiple access (CDMA) and frequency division multiple access (FDMA) can be used in conjunction with combined OFDM so that multi-piconet performance can be improved.

[0041] The present invention has been described as a transmitter and a receiver; however, the present invention may also be implemented as a transceiver. Furthermore, receivers, transmitters, and transceivers may be implemented in a wide variety of applications, including any suitable consumer product or other suitable apparatus. Such apparatuses include devices such as cellular phones and cellular phone base stations.

[0042] The present invention may be implemented as (analog, digital, or a hybrid of both analog and digital) circuit-based processes, including possible implementation as a single integrated circuit (such as an ASIC or an FPGA), a multi-chip module, a single card, or a multi-card circuit pack. As would be apparent to one skilled in the art, various functions of circuit elements may also be implemented as processing blocks in a software program. Such software may be employed in, for example, a digital signal processor, micro-controller, or general-purpose computer.

[0043] The present invention can be embodied in the form of methods and apparatuses for practicing those methods. The present invention can also be embodied in the form of program code embodied in tangible media, such as magnetic recording media, optical recording media, solid state memory, floppy diskettes, CD-ROMs, hard drives, or any other machine-readable storage medium, wherein, when the program code is loaded into and executed by a machine, such as a computer, the machine becomes an apparatus for practicing the invention. The present invention can also be embodied in the form of program code, for example, whether stored in a storage medium, loaded into and/or executed by a machine, or transmitted over some transmission medium or carrier, such as over electrical wiring or cabling, through fiber optics, or via electromagnetic radiation, wherein, when the program code is loaded into and executed by a machine, such as a computer, the machine becomes an apparatus for practicing the invention. When implemented on a general-purpose processor, the program code segments combine with the processor to provide a unique device that operates analogously to specific circuits.

[0044] The present invention can also be embodied in the form of a bitstream or other sequence of signal values electrically or optically transmitted through a medium, stored magnetic-field variations in a magnetic recording medium, etc., generated using a method and/or an apparatus of the present invention.

[0045] Unless explicitly stated otherwise, each numerical value and range should be interpreted as being approximate as if the word "about" or "approximately" preceded the value of the value or range.

[0046] It will be further understood that various changes in the details, materials, and arrangements of the parts which have been described and illustrated in order to explain the nature of this invention may be made by those skilled in the art without departing from the scope of the invention as expressed in the following claims. For example, various equalization techniques commonly known in the art may be employed in receiver **700**. As another example, methods other than cyclic prefix appending might be employed, including use of a zero pad.

[0047] The use of figure numbers and/or figure reference labels in the claims is intended to identify one or more possible embodiments of the claimed subject matter in order to facilitate the interpretation of the claims. Such use is not to be construed as necessarily limiting the scope of those claims to the embodiments shown in the corresponding figures.

[0048] It should be understood that the steps of the exemplary methods set forth herein are not necessarily required to be performed in the order described, and the order of the steps of such methods should be understood to be merely exemplary. Likewise, additional steps may be included in such methods, and certain steps may be omitted or combined, in methods consistent with various embodiments of the present invention.

[0049] Although the elements in the following method claims, if any, are recited in a particular sequence with corresponding labeling, unless the claim recitations otherwise imply a particular sequence for implementing some or all of those elements, those elements are not necessarily intended to be limited to being implemented in that particular sequence.

[0050] Reference herein to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment can be included in at least one embodiment of the invention. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment, nor are separate or alternative embodiments necessarily mutually exclusive of other embodiments. The same applies to the term "implementation."

Claims

1. A method for modulating a set of data symbols into a combined modulated symbol, the method comprising:

a) dividing (412) the set of data symbols into M groups of data symbols, $M>1$;
b) transforming (404) each group of data symbols into a time-domain subsymbol to produce M time-domain subsymbols, wherein:

the transformation of each group of data symbols is based on a set of subcarriers, of which only a subset of the subcarriers is modulated by the group of data symbols;
each data symbol in each group modulates a different subcarrier in a corresponding subset of the subcarriers; and
no two subsets of subcarriers have a subcarrier in common; and **CHARACTERIZED BY** the method further comprising:

c) combining (416) the M time-domain subsymbols to form the combined modulated symbol such that the combined modulated symbol has a duration that is longer than each time-domain subsymbol.

2. The invention of claim 1, wherein the total number of subcarriers in the M subsets of subcarriers is equal to the number of subcarriers in the set of subcarriers.

3. The invention of claim 1, wherein step b) comprises, for each subset of modulated subcarriers, transforming both the subset of modulated subcarriers and one or more unmodulated subcarriers to form the corresponding time-domain subsymbol.

4. The invention of claim 3, wherein for each group of data symbols, the sum of 1) the number of the modulated subcarriers and 2) the number of the one or more unmodulated subcarriers is equal to the total number of subcarriers in the set.

5. The invention of claim 1, wherein:

each time-domain subsymbol is represented by a plurality of time-domain samples; and
step c) comprises interleaving the time-domain samples of the *M* subsymbols to form a sequence of interleaved time-domain samples for the combined modulated symbol.

6. The invention of claim 1, wherein step c) comprises generating an upsampled combined modulated symbol by either i) upsampling (414) the *M* time-domain subsymbols prior to the combining or ii) upsampling the combined modulated symbol after the combining.

7. The invention of claim 1, wherein:

the transformation is an inverse fast Fourier transformation (IFFT);
each time-domain subsymbol is an OFDM subsymbol; and
the combined modulated symbol is a combined OFDM symbol.

8. Apparatus comprising a transmitter (400) for modulating a set of data symbols into a combined modulated symbol, the transmitter comprising:

a data symbol grouper (412) adapted to divide the set of data symbols into *M* groups of data symbols, *M*>1;
one or more transforms (404) adapted to transform each group of data symbols into a time-domain subsymbol, wherein:

the transformation of each group of data symbols is based on a set of subcarriers, of which only a subset of the subcarriers is modulated by the group of data symbols;
each data symbol in each group modulates a different subcarrier in a corresponding subset of the subcarriers; and
no two subsets of subcarriers have a subcarrier in common; and_**CHARACTERIZED BY** the transmitter further comprising:

a subsymbol combiner (416) adapted to combine the *M* time-domain subsymbols to form the combined modulated symbol such that the combined modulated symbol has a duration that is longer than each time-domain subsymbol.

9. A method for demodulating a combined modulated symbol into a set of demodulated data symbols, **CHARACTERIZED BY** the method comprising:

a) separating (714) the combined modulated symbol into *M* time-domain subsymbols, *M*>1, such that each time-domain subsymbol has a duration that is shorter than the combined modulated symbol;
b) transforming (708) each time-domain subsymbol into a group of demodulated data symbols, wherein:

the transformation of each time-domain subsymbol is based on a set of subcarriers, of which only a subset of the subcarriers is modulated by the group of demodulated data symbols;
each demodulated data symbol in each group modulates a different subcarrier in a corresponding subset of the sub carriers; and
no two subsets of subcarriers have a subcarrier in common; and

c) de-grouping (718) the *M* groups of demodulated data symbols to generate the set of demodulated data symbols.

10. The invention of claim 9, wherein:

the combined modulated symbol comprises a sequence of interleaved time-domain samples; and
step a) comprises de-interleaving the interleaved time-domain samples to obtain the *M* time-domain subsymbols.

11. The invention of claim 9, wherein the total number of subcarriers in the *M* subsets of subcarriers is equal to the number of subcarriers in the set of subcarriers.

12. The invention of claim 9, wherein step b) comprises, for each subset of modulated subcarriers, transforming both the subset of modulated subcarriers and one or more unmodulated subcarriers to form the corresponding group of demodulated data symbols.

13. The invention of claim 12, wherein for each group of demodulated data symbols, the sum of 1) the number of the modulated subcarriers and 2) the number of the one or more unmodulated subcarriers is equal to the total number of subcarriers in the set.

14. The invention of claim 9, wherein:

the transformation is a fast Fourier transformation (FFT);
each time-domain subsymbol is an OFDM subsymbol; and
the combined modulated symbol is a combined OFDM symbol.

15. Apparatus comprising a receiver (700) for demodulating a combined modulated symbol into a set of demodulated data symbols, **CHARACTERIZED BY** the receiver comprising:

a subsymbol separator (714) adapted to separate the combined modulated symbol into *M* time-domain subsymbols, *M*>1, such that each time-domain subsymbol has a duration that is shorter than the combined modulated symbol;
one or more transforms (708) adapted to transform each time-domain subsymbol into a group of demodulated data symbols, wherein:

the transformation of each time-domain subsymbol is based on a set of subcarriers, of which only a subset of the subcarriers is modulated by the group of demodulated data symbols;
each demodulated data symbol in each group modulates a different subcarrier in a corresponding subset of the subcarriers; and
no two subsets of subcarriers have a subcarrier in common; and

a data symbol de-grouper (718) adapted to de-group the *M* groups of demodulated data symbols to generate the set of demodulated data symbols.

Patentansprüche

1. Verfahren zum Modulieren eines Satzes von Datensymbolen zu einem kombinierten modulierten Symbol, wobei das Verfahren Folgendes umfasst:

a) Aufteilen (412) des Satzes von Datensymbolen in M Gruppen von Datensymbolen, M>1;
b) Transformieren (404) jeder Gruppe von Datensymbolen in ein Zeitbereichssubsymbol, um M Zeitbereichssubsymbole zu erzeugen, wobei:

die Transformation jeder Gruppe von Datensymbolen auf einem Satz von Subträgern basiert, wobei nur eine Untermenge der Subträger durch die Gruppe von Datensymbolen moduliert wird;
jedes Datensymbol in jeder Gruppe einen anderen Subträger in einer entsprechenden Untermenge der Subträger moduliert und
keine zwei Untermengen von Subträgern einen Subträger gemeinsam haben und **DADURCH GEKENNZEICHNET, dass** das Verfahren ferner Folgendes umfasst:

c) Kombinieren (416) der M Zeitbereichssubsymbole, um das kombinierte modulierte Symbol zu bilden, so dass das kombinierte modulierte Symbol eine Zeitdauer aufweist, die länger als jedes Zeitdomänensubsymbol ist.

2. Erfindung nach Anspruch 1, wobei die Gesamtzahl der Subträger in den M Untermengen von Subträgern der Anzahl von Subträgern in dem Satz von Subträgern entspricht.

3. Erfindung nach Anspruch 1, wobei Schritt b) für jede Untermenge von modulierten Subträgern Folgendes umfasst:

Transformieren sowohl der Untermenge der modulierten Subträger als auch eines oder mehrerer nicht-modulierter Subträger, um das entsprechende Zeitbereichssubsymbol zu bilden.

4. Erfindung nach Anspruch 3, wobei für jede Gruppe von Datensymbolen die Summe 1) der Anzahl der modulierten Subträger und 2) der Anzahl des einen oder der mehreren nicht-modulierten Subträger der Gesamtzahl von Subträgern in dem Satz entspricht.

5. Erfindung nach Anspruch 1, wobei:

jedes Zeitbereichssubsymbol durch eine Vielzahl von Zeitbereichsabtastungen dargestellt wird und
Schritt c) das Verschachteln der Zeitbereichsabtastungen der M Subsymbole umfasst, um eine Sequenz von verschachtelten Zeitbereichsabtastungen für das kombinierte modulierte Symbol zu bilden.

6. Erfindung nach Anspruch 1, wobei Schritt c) das Erzeugen eines aufwärtsabgetasteten kombinierten modulierten Symbols entweder durch i) Aufwärtsabtasten (414) der M Zeitbereichssubsymbole vor dem Kombinieren oder ii) Aufwärtsabtasten des kombinierten modulierten Symbols nach dem Kombinieren umfasst.

7. Erfindung nach Anspruch 1, wobei:

die Transformation eine inverse schnelle Fourier-Transformation (IFFT) ist,
jedes Zeitbereichssubsymbol ein OFDM-Subsymbol ist und
das kombinierte modulierte Symbol ein kombiniertes OFDM-Symbol ist.

8. Vorrichtung, die einen Sender (400) zum Modulieren eines Satzes von Datensymbolen zu einem kombinierten modulierten Symbol umfasst, wobei der Sender Folgendes umfasst:

einen Datensymbolgruppierer (412), der dafür ausgelegt ist, den Satz von Datensymbolen in M Gruppen von Datensymbolen, M>1, aufzuteilen;
eine oder mehrere Transformationen (404), die dafür ausgelegt sind, jede Gruppe von Datensymbolen in ein Zeitbereichssubsymbol zu transformieren, wobei:

> die Transformation jeder Gruppe von Datensymbolen auf einem Satz von Subträgern basiert, wobei nur eine Untermenge der Subträger durch die Gruppe von Datensymbolen moduliert wird;
> jedes Datensymbol in jeder Gruppe einen anderen Subträger in einer entsprechenden Untermenge der Subträger moduliert und
> keine zwei Untermengen von Subträgern einen Subträger gemeinsam haben und **DADURCH GEKENNZEICHNET, dass** der Sender ferner Folgendes umfasst:

einen Subsymbolkombinierer (416), der dafür ausgelegt ist, die M Zeitbereichssubsymbole zu kombinieren, um das kombinierte modulierte Symbol zu bilden, so dass das kombinierte modulierte Symbol eine Zeitdauer aufweist, die länger als jedes Zeitdomänensubsymbol ist.

9. Verfahren zum Demodulieren eines kombinierten modulierten Symbols in einen Satz von demodulierten Datensymbolen, **DADURCH GEKENNZEICHNET, dass** das Verfahren Folgendes umfasst:

a) Trennen (714) des kombinierten modulierten Symbols in M Zeitbereichssubsymbole, M> 1, so dass jedes Zeitbereichssubsymbol eine Dauer aufweist, die kürzer als das kombinierte modulierte Symbol ist,
b) Transformieren (708) jedes Zeitbereichssubsymbols in eine Gruppe von demodulierten Datensymbolen, wobei:

> die Transformation jedes Zeitbereichssubsymbols auf einem Satz von Subträgern basiert, wobei nur eine Untermenge der Subträger durch die Gruppe von demodulierten Datensymbolen moduliert wird;
> jedes demodulierte Datensymbol in jeder Gruppe einen anderen Subträger in einer entsprechenden Untermenge der Subträger moduliert und
> keine zwei Untermengen von Subträgern einen Subträger gemeinsam haben; und

c) Entgruppieren (718) der M Gruppen von demodulierten Datensymbolen, um den Satz von demodulierten Datensymbolen zu erzeugen.

10. Erfindung nach Anspruch 9, wobei:

das kombinierte modulierte Symbol eine Sequenz von verschachtelten Zeitbereichsabtastungen umfasst; und
Schritt a) das Entschachteln der verschachtelten Zeitbereichsabtastungen umfasst, um die M Zeitbereichssubsymbole zu erhalten.

11. Erfindung nach Anspruch 9, wobei die Gesamtzahl der Subträger in den M Untermengen von Subträgern der Anzahl von Subträgern in dem Satz von Subträgern entspricht.

12. Erfindung nach Anspruch 9, wobei Schritt b) Folgendes umfasst: für jede Untermenge von modulierten Subträgem, Transformieren sowohl der Untermenge der modulierten Subträger als auch eines oder mehrerer nicht-modulierter Subträger, um die entsprechende Gruppe von demodulierten Datensymbolen zu bilden.

13. Erfindung nach Anspruch 12, wobei für jede Gruppe von demodulierten Datensymbolen die Summe 1) der Anzahl der modulierten Subträger und 2) der Anzahl des einen oder der mehreren nicht-modulierten Subträger der Gesamtzahl von Subträgern in dem Satz entspricht.

14. Erfindung nach Anspruch 9, wobei:

die Transformation eine schnelle Fourier-Transformation (FFT) ist,
jedes Zeitbereichssubsymbol ein OFDM-Subsymbol ist und
das kombinierte modulierte Symbol ein kombiniertes OFDM-Symbol ist.

15. Vorrichtung, die einen Empfänger (700) zum Demodulieren eines kombinierten modulierten Symbols in einen Satz von demodulierten Datensymbolen umfasst, **DADURCH GEKENNZEICHNET, dass** das Verfahren Folgendes umfasst:

einen Subsymbolseparator (714) der dafür ausgelegt ist, das kombinierte modulierte Symbol in M Zeitbereichssubsymbole, M> 1, zu trennen, so dass jedes Zeitbereichssubsymbol eine Dauer aufweist, die kürzer als das kombinierte modulierte Symbol ist,
eine oder mehrere Transformationen (708), die dafür ausgelegt sind, jedes Zeitbereichssubsymbol in eine Gruppe von demodulierten Datensymbolen zu transformieren, wobei:

die Transformation jedes Zeitbereichssubsymbols auf einem Satz von Subträgern basiert, wobei nur eine Untermenge der Subträger durch die Gruppe von demodulierten Datensymbolen moduliert wird;
jedes demodulierte Datensymbol in jeder Gruppe einen anderen Subträger in einer entsprechenden Untermenge der Subträger moduliert und
keine zwei Untermengen von Subträgern einen Subträger gemeinsam haben; und

einen Datensymbolentgruppierer (718), der dafür ausgelegt ist, die M Gruppen von demodulierten Datensymbolen zu entgruppieren, um den Satz von demodulierten Datensymbolen zu erzeugen.

Revendications

1. Procédé de modulation d’un ensemble de symboles de données en un symbole modulé combiné, le procédé comprenant :

a) la division (412) de l’ensemble de symboles de données en *M* groupes de symboles de données, *M*>1 ;
b) la transformation (404) de chaque groupe de symboles de données en un sous-symbole du domaine temporel pour produire *M* sous-symboles du domaine temporel, dans lequel :

la transformation de chaque groupe de symboles de données est basée sur un ensemble de sous-porteuses, un sous-ensemble seulement des sous-porteuses étant modulé par le groupe de symboles de données ;
chaque symbole de données dans chaque groupe modulant une sous-porteuse différente dans un sous-ensemble correspondant des sous-porteuses ; et
aucun deux sous-ensembles de sous-porteuses n’ont de sous-porteuse commune ; et **CARACTERISE EN CE QUE** le procédé comprend en outre :

c) la combinaison (416) des *M* sous-symboles du domaine temporel pour former le symbole modulé combiné de telle sorte que le symbole modulé combiné ait une durée plus longue que chaque sous-symbole du domaine temporel.

2. Invention selon la revendication 1, dans laquelle le nombre total de sous-porteuses dans les *M* sous-ensembles de sous-porteuses est égal au nombre de sous-porteuses dans l'ensemble de sous-porteuses.

3. Invention selon la revendication 1, dans laquelle l'étape b) comprend, pour chaque sous-ensemble de sous-porteuses modulées, la transformation à la fois du sous-ensemble de sous-porteuses modulées et d'une ou plusieurs sous-porteuses non modulées pour former le sous-symbole du domaine temporel correspondant.

4. Invention selon la revendication 3, dans laquelle pour chaque groupe de symboles de données, la somme 1) du nombre de sous-porteuses modulées et 2) du nombre des une ou plusieurs sous-porteuses non modulées est égale au nombre total de sous-porteuses dans l'ensemble.

5. Invention selon la revendication 1, dans laquelle :

chaque sous-symbole du domaine temporel est représenté par une pluralité d'échantillons du domaine temporel ; et
l'étape c) comprend l'entrelacement des échantillons du domaine temporel des *M* sous-symboles pour former une séquence d'échantillons du domaine temporel entrelacés du symbole modulé combiné.

6. invention selon la revendication 1, dans laquelle l'étape c) comprend la génération d'un symbole modulé combiné suréchantillonné soit en i) suréchantillonnant (414) les *M* sous-symboles du domaine temporel avant la combinaison, soit en ii) suréchantillonnant le symbole modulé combiné après la combinaison.

7. invention selon la revendication 1, dans laquelle :

la transformation est une transformation de Fourier rapide inverse (IFFT) ;
chaque sous-symbole du domaine temporel est un sous-symbole OFDM ; et
le symbole modulé combiné est un symbole OFDM combiné.

8. Appareil comprenant un émetteur (400) pour moduler un ensemble de symboles de données en un symbole modulé combiné, l'émetteur comprenant :

un moyen de groupement de symboles de données (412) adapté pour diviser l'ensemble de symboles de données en *M* groupes de symboles de données, *M*>1 ;
un ou plusieurs moyens de transformation (404) adaptés pour transformer chaque groupe de symboles de données en un sous-symbole du domaine temporel, dans lequel:

> la transformation de chaque groupe de symboles de données est basée sur un ensemble de sous-porteuses, un sous-ensemble seulement des sous-porteuses étant modulé par le groupe de symboles de données ;
> chaque symbole de données dans chaque groupe modulant une sous-porteuse différente dans un sous-ensemble correspondant des sous-porteuses ; et
> aucun deux sous-ensembles de sous-porteuses n'ont de sous-porteuse commune ; et **CARACTERISE EN CE QUE** l'émetteur comprend en outre :

un moyen de combinaison (416) adapté pour combiner les *M* sous-symboles du domaine temporel pour former le symbole modulé combiné de telle sorte que le symbole modulé combiné ait une durée plus longue que chaque sous-symbole du domaine temporel.

9. Procédé de démodulation d'un symbole modulé combiné en un ensemble de symboles de données démodulés **CARACTERISE EN CE QUE** le procédé comprend :

a) la séparation (714) du symbole modulé combiné en *M* sous-symboles du domaine temporel, *M* > 1, de telle sorte que chaque sous-symbole du domaine temporel ait une durée plus courte que le symbole modulé combiné ;
b) la transformation (708) de chaque sous-symbole du domaine temporel en un groupe de symboles de données démodulés, dans lequel :

la transformation de chaque sous-symbole du domaine temporel est basée sur un ensemble de sous-porteuses, un sous-ensemble seulement des sous-porteuses étant modulé par le groupe de symboles de données démodulés ;
chaque symbole de données démodulé dans chaque groupe module une sous-porteuse différente dans un sous-ensemble correspondant des sous-porteuses ; et
aucun deux sous-ensembles de sous-porteuses n'ont de sous-porteuse commune ; et

c) le dégroupement (718) des *M* groupes de symboles de données démodulés pour générer l'ensemble de symboles de données démodulés.

10. Invention selon la revendication 9, dans laquelle :

le symbole modulé combiné comprend une séquence d'échantillons du domaine temporel entrelacés ; et
l'étape a) comprend le désentrelacement des échantillons du domaine temporel entrelacés pour obtenir les *M* sous-symboles du domaine temporel.

11. Invention selon la revendication 9, dans laquelle le nombre total de sous-porteuses dans les *M* sous-ensembles de sous-porteuses est égal au nombre de sous-porteuses dans l'ensemble des sous-porteuses.

12. Invention selon la revendication 9, dans laquelle l'étape b) comprend, pour chaque sous-ensemble de sous-porteuses modulées, la transformation à la fois du sous-ensemble de sous-porteuses modulées et de l'une ou plusieurs des sous-porteuses non modulées pour former le groupe correspondant de symboles de données démodulés.

13. Invention selon la revendication 12, dans laquelle pour chaque groupe de symboles de données démodulés, la somme 1) du nombre de sous-porteuses modulées et 2) du nombre des une ou plusieurs sous-porteuses non modulées est égale au nombre total de sous-porteuses dans l'ensemble.

14. Invention selon la revendication 9, dans laquelle
la transformation est une transformation de Fourier rapide inverse (IFFT) ;
chaque sous-symbole du domaine temporel est un sous-symbole OFDM ; et
le symbole modulé combiné est un symbole OFDM combiné.

15. Appareil comprenant un récepteur (700) pour démoduler un symbole modulé combiné en un ensemble de symboles de données démodulés, **CARACTERISE EN CE QUE** le récepteur comprend :

un séparateur en sous-symboles (714) adapté pour séparer le symbole modulé combiné en *M* sous-symboles, *M* > 1, de telle sorte que chaque sous-symbole du domaine temporel ait une durée plus courte que le symbole modulé combiné ;
un ou plusieurs moyens de transformation (708) adaptés pour transformer chaque sous-symbole du domaine temporel en un groupe de symboles de données démodulés, dans lequel:

la transformation de chaque sous-symbole du domaine temporel est basée sur un ensemble de sous-porteuses, un sous-ensemble seulement des sous-porteuses étant modulé par le groupe de symboles de données démodulés ;
chaque symbole de données démodulé dans chaque groupe module une sous-porteuse différente dans un sous-ensemble correspondant des sous-porteuses ; et
aucun deux sous-ensembles de sous-porteuses n'ont de sous-porteuse commune ; et

un moyen de dégroupement de symboles de données (718) adapté pour dégrouper les *M* groupes de symboles de données démodulés pour générer l'ensemble de symboles de données démodulés.

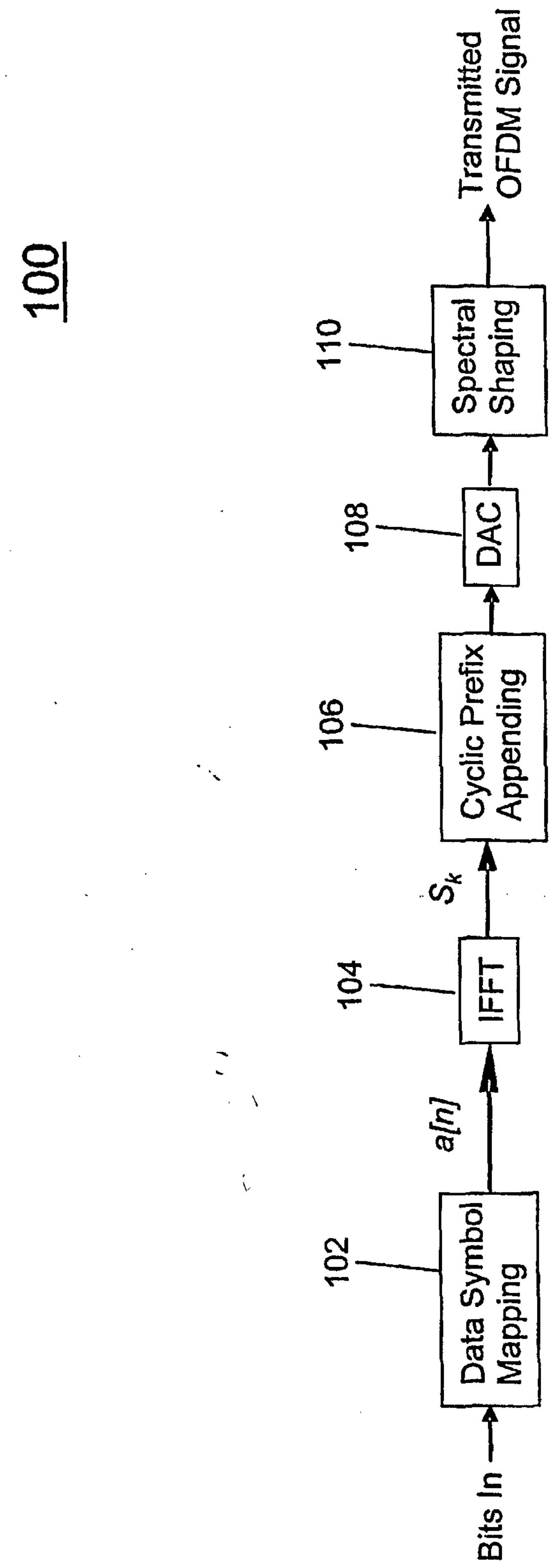

FIG. 1 (Prior Art)

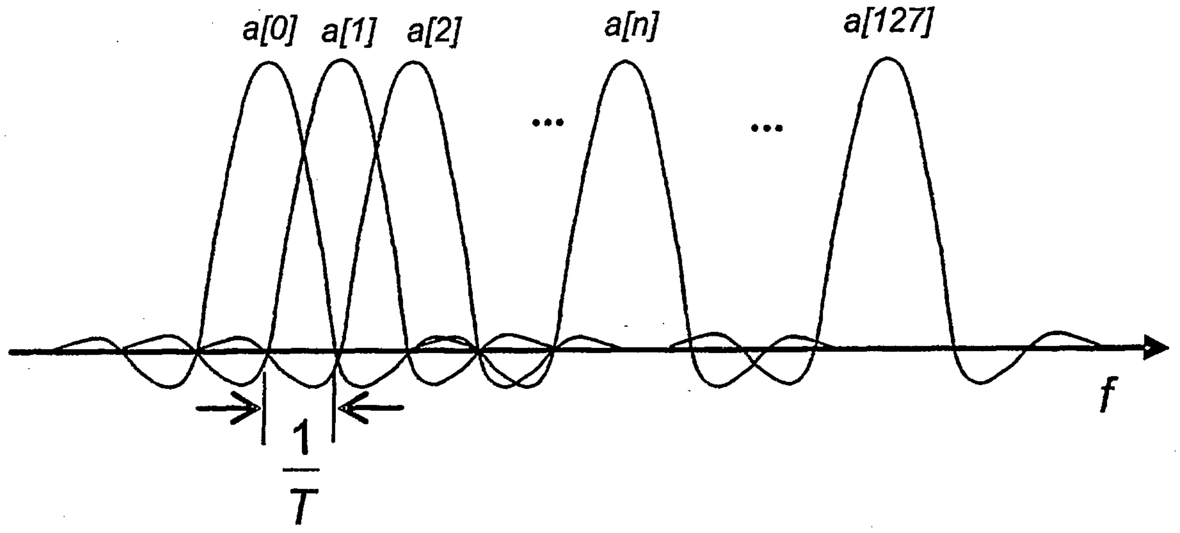

FIG. 2 (Prior Art)

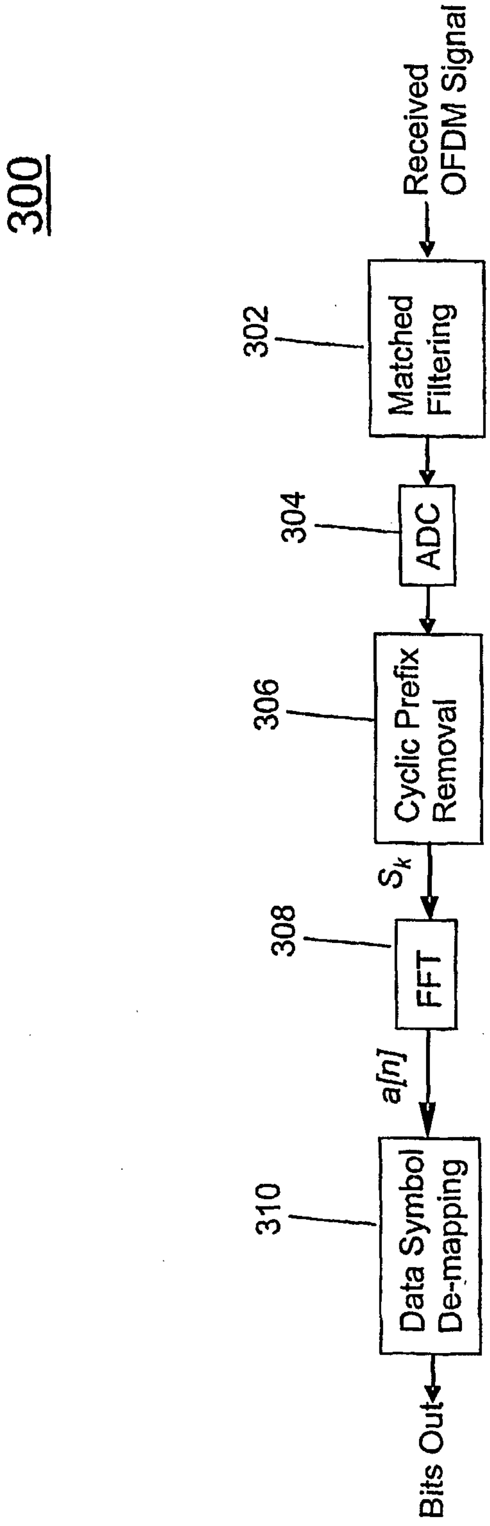

FIG. 3 (Prior Art)

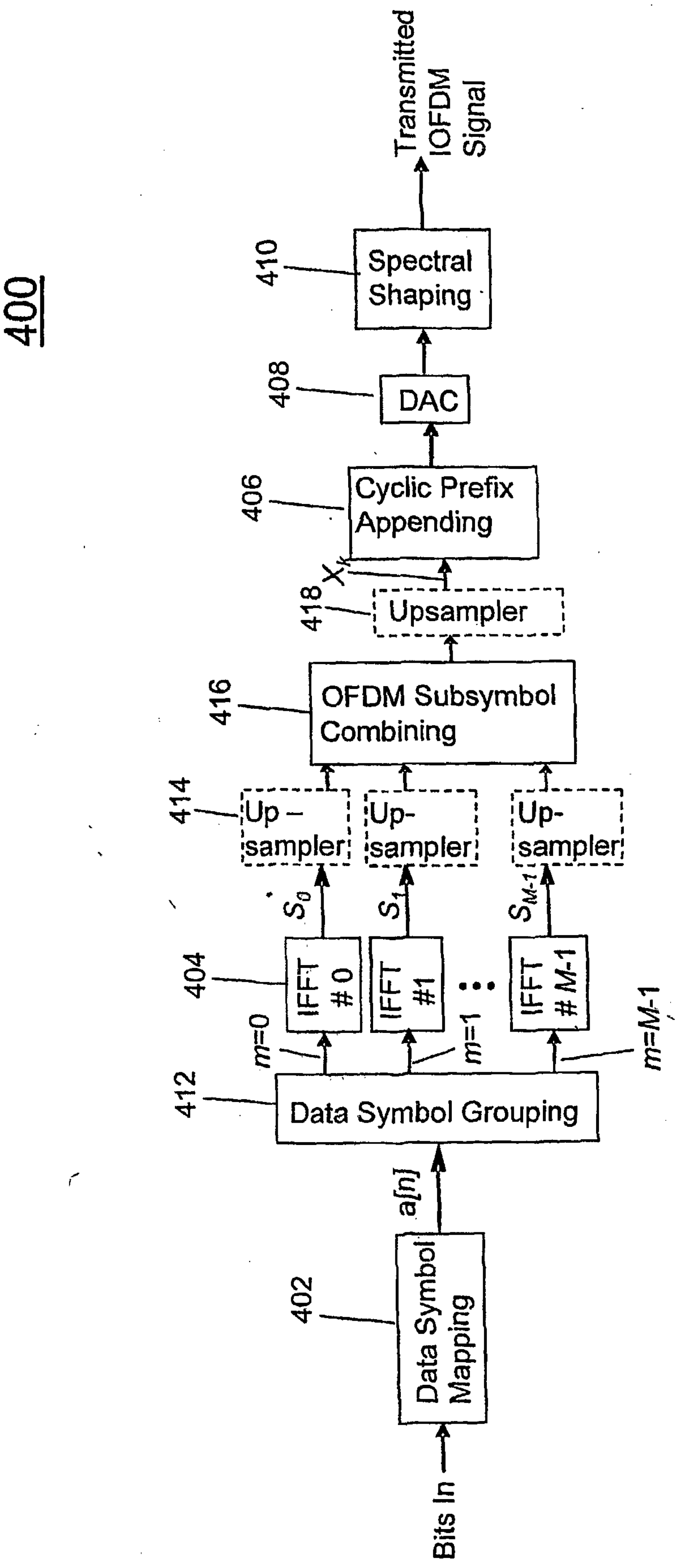
400
Bits In
Data Symbol Mapping
402
a[n]
Data Symbol Grouping
412
m=0
m=1
m=M-1
IFFT # 0
IFFT #1
IFFT # M-1
404
S0
S1
SM-1
Up-sampler
Up-sampler
Up-sampler
414
OFDM Subsymbol Combining
416
Upsampler
418
Xk
Cyclic Prefix Appending
406
DAC
408
Spectral Shaping
410
Transmitted IOFDM Signal

FIG. 4

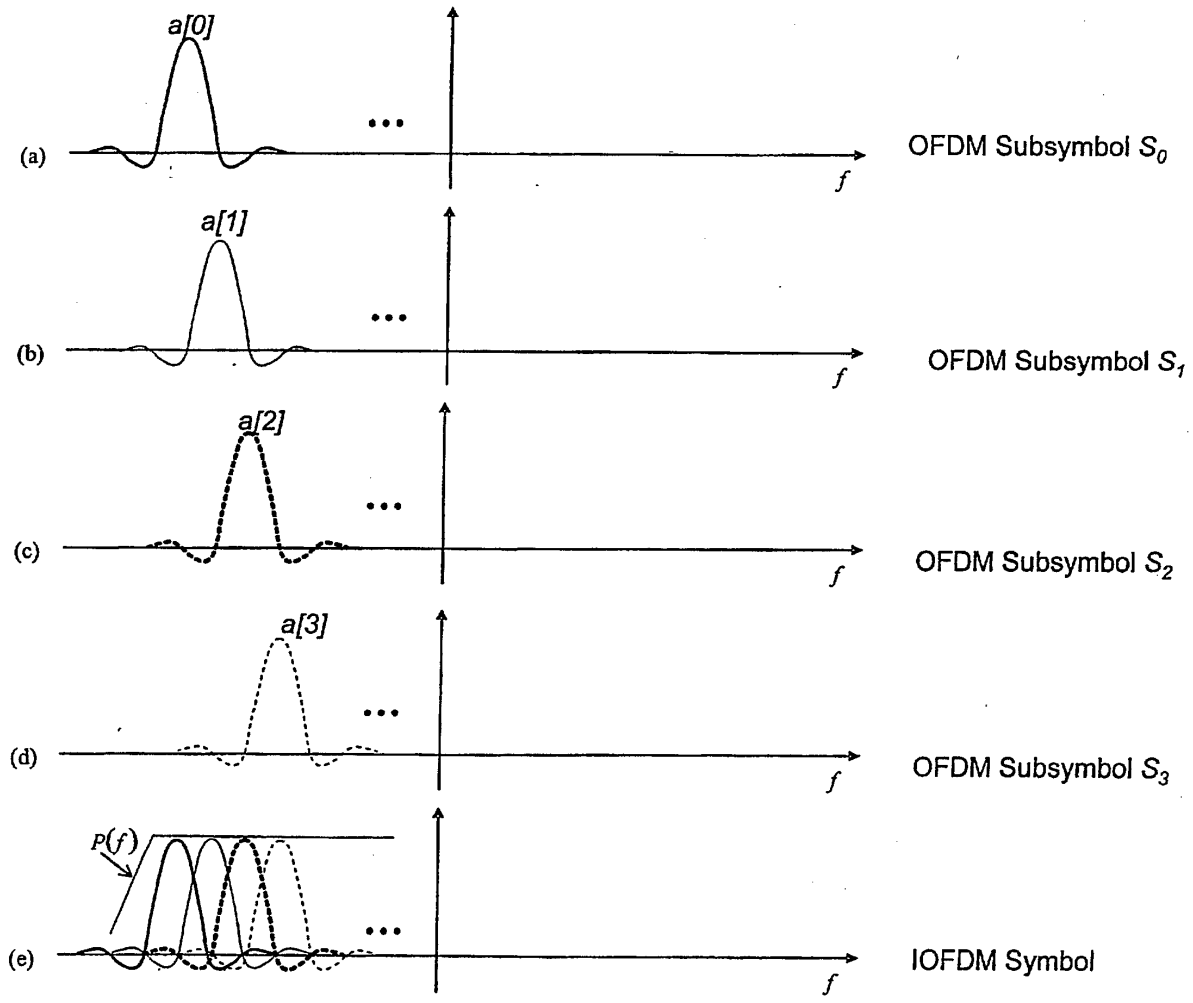
(a)
a[0]
f
OFDM Subsymbol S_0
(b)
a[1]
f
OFDM Subsymbol S_1
(c)
a[2]
f
OFDM Subsymbol S_2
(d)
a[3]
f
OFDM Subsymbol S_3
(e)
P(f)
f
IOFDM Symbol

FIG. 5

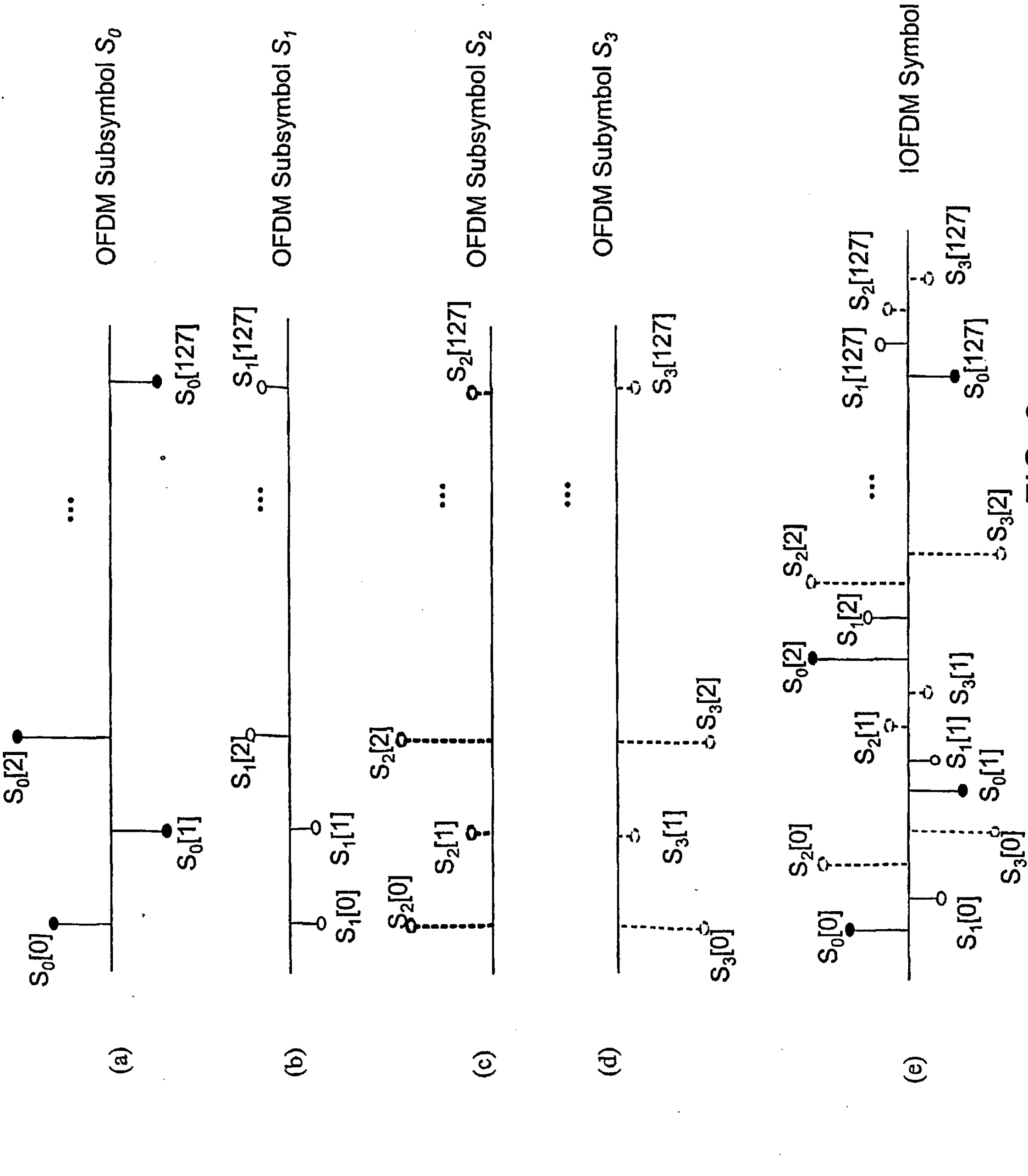
(a)
OFDM Subsymbol S_0
$S_0[0]$
$S_0[1]$
$S_0[2]$
$S_0[127]$
(b)
OFDM Subsymbol S_1
$S_1[0]$
$S_1[1]$
$S_1[2]$
$S_1[127]$
(c)
OFDM Subsymbol S_2
$S_2[0]$
$S_2[1]$
$S_2[2]$
$S_2[127]$
(d)
OFDM Subymbol S_3
$S_3[0]$
$S_3[1]$
$S_3[2]$
$S_3[127]$
(e)
IOFDM Symbol
$S_0[0]$
$S_1[0]$
$S_2[0]$
$S_3[0]$
$S_0[1]$
$S_1[1]$
$S_2[1]$
$S_3[1]$
$S_0[2]$
$S_1[2]$
$S_2[2]$
$S_3[2]$
$S_0[127]$
$S_1[127]$
$S_2[127]$
$S_3[127]$

FIG. 6

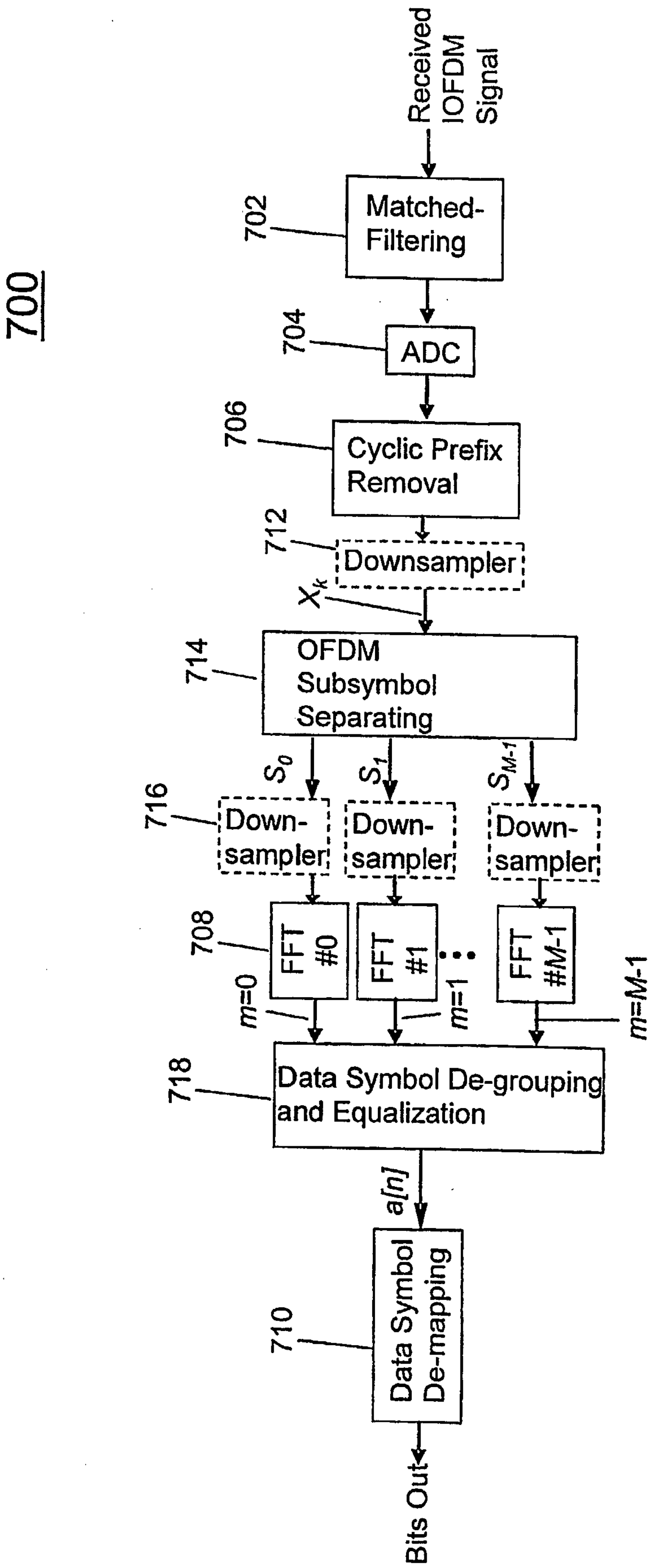
700
Received IOFDM Signal
702
Matched-Filtering
704
ADC
706
Cyclic Prefix Removal
712
Downsampler
X_k
714
OFDM Subsymbol Separating
S_0
S_1
S_{M-1}
716
Down-sampler
Down-sampler
Down-sampler
708
FFT #0
FFT #1
FFT #M-1
m=0
m=1
m=M-1
718
Data Symbol De-grouping and Equalization
a[n]
710
Data Symbol De-mapping
Bits Out

FIG. 7

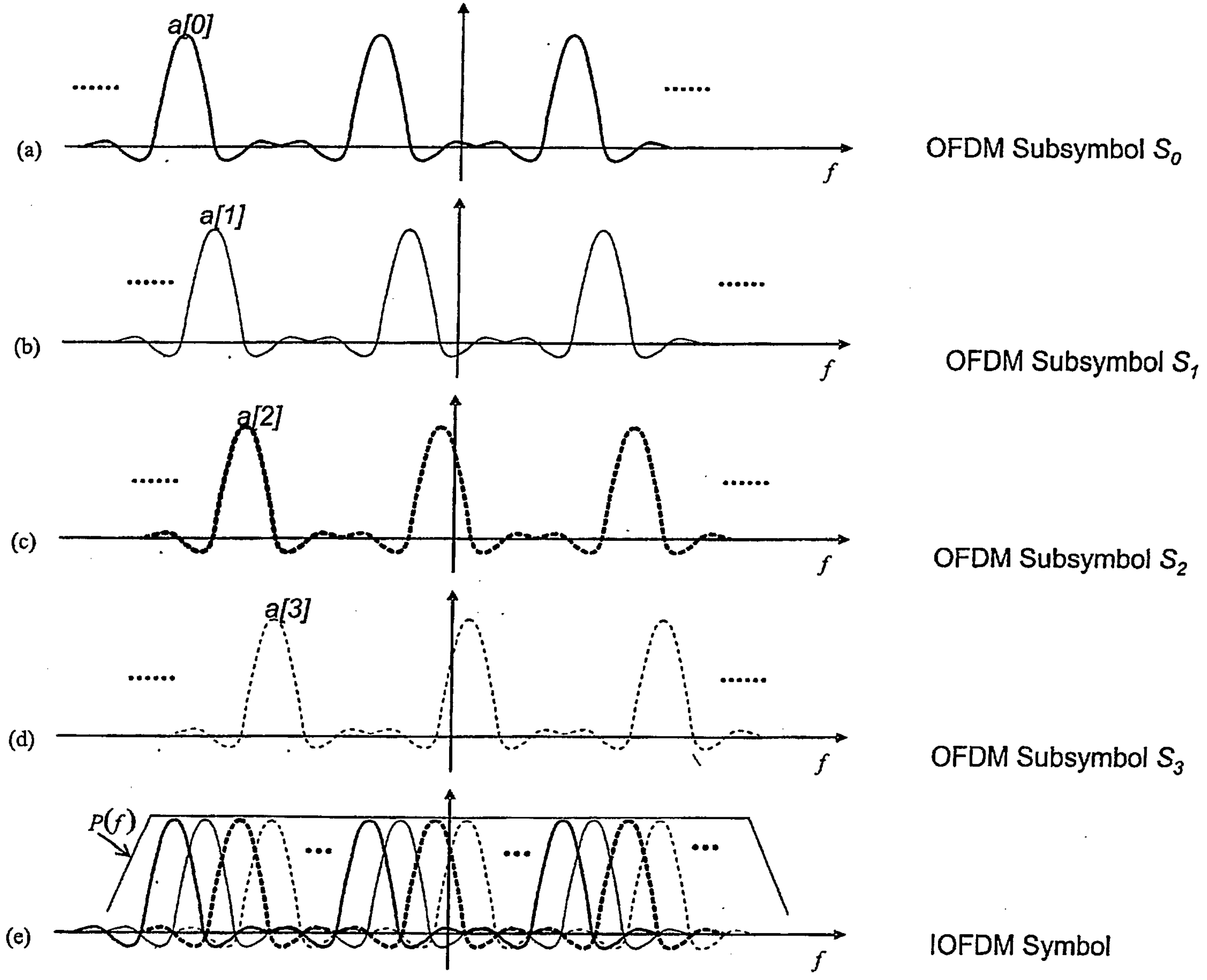
(a)
a[0]
......
......
f
OFDM Subsymbol S_0
(b)
a[1]
......
......
f
OFDM Subsymbol S_1
(c)
a[2]
......
......
f
OFDM Subsymbol S_2
(d)
a[3]
......
......
f
OFDM Subsymbol S_3
(e)
P(f)
...
...
...
f
IOFDM Symbol

FIG. 8

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- EP 1357718 A2 **[0013]**

Non-patent literature cited in the description

- **MÜLLER et al.** A Novel Peak Power Reduction Scheme for OFDM. *Proc. of the Int. Symposium on Personal, Indoor and Mobile Radio Communications,* September 1997, 1090-1094 **[0013]**