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TO WHOM IT MAY CONCERN

I, Mathias Kruck of German Business Consultants (Asia) Pte Ltd, state as follows:

I am fully conversant of the German and English languages and hereby confirm that the attached translation of PCT application PCT/EP 97/01090 is an accurate translation of the German original attached hereto.

Singapore, 14th December 1998

Mathias Kruck

96TK 1089DEP

METHOD AND SYSTEM FOR THE OFDM MULTICARRIER TRANSMISSION OF DIGITAL BROADCASTING SIGNALS

The invention concerns a method for the OFDM multicarrier transmission of digital broadcasting signals, in particular for digital audio broadcasting and for digital value-added services according to Claim 1, a digital OFDM multicarrier transmission system for carrying out the method, as well as a digital OFDM multicarrier transmitter and a digital OFDM multicarrier receiver suitable for use in a digital OFDM multicarrier transmission system.

The DAB (digital audio broadcasting) transmission system was developed over the past few years for terrestrial digital audio broadcasting. The known system is suitable for transmitting high-quality audio programs to mobile, portable, and stationary receivers. It is also generally possible to transmit additional data at relatively low data rates over the DAB transmission system, for example information accompanying the program or traffic information. Multiple audio programs and data services are combined into a so-called DAB ensemble and broadcast together at a transmit frequency using a selected coded orthogonal frequency division multiplexing (COFDM) method. The known DAB transmission system can currently be used to transmit a maximum effective net data rate of 1728 Kbps. Due to rapid developments in the multimedia field, there is great interest in transmitting so-called added-value services, such as video programs, at higher data rates, which can exceed the current effective net data rate of 1728 Kbps. However, the conventional DAB system is unsuitable, in particular, for mobile reception of higher-speed data, since the error protection mechanism used is too ineffective.

The object of the present invention is therefore to further develop the existing DAB transmission system so that added-value services, such as video programs, can be transmitted at

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higher data rates without impairing the transmission quality.

The present invention achieves this object with the steps described in Claim 1 and with the features of Claims 8, 17, and 20.

The subclaims describe advantageous embodiments and improvements.

The main idea behind the present invention is to provide a digital OFDM multicarrier transmission system that is based on the existing DAB transmission system with improved system performance. At the same time, attention was paid to the ability to use known hardware components from the existing DAB transmission system when designing the digital OFDM multicarrier transmission system, making it possible to easily incorporate the present invention into an existing DAB transmission system. To keep things simple, the transmission system according to the present invention is called the X-DAB transmission system. "X-DAB" stands for extended (or enhanced) digital audio broadcasting system. To prevent misunderstandings at the outset, note that the X-DAB transmission system can be used to advantageously transmit high-speed data signals, such as video signals, to mobile receivers along with audio programs, even though this cannot be done with a conventional DAB transmission system at a sufficient level of quality.

With the method according to the present invention for the OFDM multicarrier transmission of digital broadcasting signals, at least one source data stream, which is split into several frames of a predetermined length, is generated, just like with the known DAB system. In order to considerably improve system performance compared to the DAB transmission system, the source data stream is broken down into N parallel data substreams, each of which is supplied to a separate channel encoder having a predetermined code rate. Each channel

encoder supplies an encoded, preferably convolution-encoded, sequence of M bits at its output. The bits of the N encoded parallel data substreams are each combined into an N-tuple, i.e., a group or a vector of N bits, and mapped to a complex symbol of a 2^N-PSK symbol alphabet. This encoded modulation technique is essentially known. The most important difference compared to the existing DAB transmission system is that the X-DAB transmission system processes complex symbols or their N-bit addresses instead of individual bits immediately after channel encoding of the source data stream. It has been determined that the improved system characteristics are, in fact, due to this measure. Consequently, complex symbols, and not individual bits, are combined into blocks of a predetermined size. As with the known DAB transmission system, in which, however, bits are mapped to complex symbols only after blocks are generated, the complex symbols in each block are each assigned to different subcarriers. An analog OFDM signal is then generated from the complex symbols in each block and transmitted to receiving equipment.

To avoid transmission errors caused by the time-discriminating characteristics of a mobile radio channel, the complex symbols are time-interleaved prior to block generation. Note that individual bits, and not complex symbols, are time-interleaved in the known DAB transmission system. To eliminate signal impairment caused by a frequency-discriminating mobile radio channel, the complex symbols in each block are frequency-interleaved after block generation, which is also the case in a known DAB broadcasting system. The goal of time- and frequency-interleaving is to transmit adjacent signal elements as far apart from each other as possible, thereby avoiding grouping errors in adjacent information elements.

The complex symbols in each block undergo an essentially known differential modulation on each subcarrier.

In contrast to the known DAB transmission system, in which the

subcarriers in each block undergo a 4-PSK modulation, the X-DAB transmission system according to the present invention carries out a 2^N-PSK modulation on the subcarriers, with N being set to a value greater than or equal to 3. Although the present invention uses a higher modulation method than the known DAB transmission system (at least 8-PSK), the system quality does not deteriorate, as would be expected, with a constant signal-to-noise ratio on the receiver side. This is due to the symbol mapping function, which is performed earlier than in the known DAB transmission system.

In addition to improved system characteristics, the digital OFDM multicarrier transmission system according to the present invention is characterized by its downward compatibility with the conventional DAB system. Downward compatibility means that the X-DAB transmission system according to the present invention can be embedded into an existing DAB transmission system, making it possible to transmit DAB programs and X-DAB programs in a shared transmission frame. The ability of the two transmission systems to coexist is achieved by using the same parameters for the OFDM method, including those for frequency interleaving and differential modulation. In order to minimize the additional hardware and software needed for implementing the OFDM multicarrier transmission system according to the present invention, the convolution encoder, convolution decoder, time interleaver, and time deinterleaver known from the DAB system are also used.

A receiving device, which is initially designed like a DAB receiver, is provided for receiving an OFDM signal. The known modules include an OFDM demodulator with an A/D converter and a device for performing a discrete Fourier transform[1] of the OFDM signal, a differential demodulator, and a frequency deinterleaver. Instead of converting the OFDM signal to a bit stream and subsequently supplying it to a device for removing

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[1] **Translator's Note: The German should read Fourier-Transformation, rather than Fourier-Information.**

the block structure, as in the case of known DAB receivers, the complex symbols themselves are supplied to a device which eliminates the block structure. The stream of complex symbols is supplied to a demultiplexer for time-division demultiplexing of the complex symbols from different source data streams. A time deinterleaver reverses the time interleaving of the complex symbols. In contrast to a known DAB receiver, the data streams undergo channel decoding on the complex symbol level, and not bit-by-bit. For this purpose, the complex receiving symbols are applied to N parallel-connected metric calculators. A convolution decoder is connected downstream from each metric calculator. The convolution decoder outputs are fed back to the metric calculators via assigned complementary convolution encoders according to a selected symbol mapping rule executed on the transmitter side, such as a natural mapping or pragmatic mapping rule. The decoded data substreams are present at the output of each convolution decoder. The individual data substreams are supplied to a source decoder for further processing.

The invention is explained in greater detail below on the basis of one embodiment in conjunction with the attached drawings.

Figure 1 shows the block diagram on the transmitter side of a known DAB transmitter to which a digital OFDM multicarrier transmitter according to the present invention is connected;

Figure 2 shows a three-stage encoding modulator according to Figure 1;

Figure 3 shows a three-stage decoder for an encoded 8-PSK modulation that can be used in an OFDM multicarrier receiver according to the present invention;

Figure 4 shows the layout of a transmission frame, applied to

the output of an OFDM signal generator, in which both DAB and X-DAB programs can be transmitted;

Figure 5 shows a natural mapping rule executed by the symbol mapper;

Figure 6 shows an alternative mapping rule, known as pragmatic mapping, which can be executed by the symbol mapper.

Figure 1 shows the transmitter side of a digital OFDM multicarrier transmission system in which the present invention is implemented. 10 designates, in general, the digital OFDM multicarrier transmitter according to the present invention, referred to below as the X-DAB transmitter. X-DAB transmitter 10 has at least one essentially known device 20 for the encoded modulation of a source data stream. The number of parallel-connected encoding modulators 20 depends on the number of different source data streams to be broadcast by X-DAB transmitter 10. The source data stream coming from a source (not shown), which can be an MPEG video signal with a high data rate, is divided into multiple logical frames of a predetermined length. Each logical frame is mapped to part of a transmission frame, for example the one shown in Figure 4. The example assumes a transmission frame duration of 24 ms, with each frame containing L=76 OFDM symbols. Each OFDM symbol includes 384 subcarriers, each of which carries a complex symbol from a selected symbol alphabet, e.g., an 8-PSK symbol alphabet. To simplify and clarify this representation, Figure 1 shows only one encoding modulator 20. Each encoding modulator 20 contains multiple parallel-connected convolution encoders 32, 34, and 36, all of which are known. The number of parallel-connected convolution encoders depends on the number of data substreams into which a source data stream is to be divided. Dividing each source data stream frame into three data substreams, which can be of different lengths, has proven to be advantageous. The three parallel data substreams of the source data stream, identified below by 0, 1, and 2, are

supplied to convolution encoder 32, convolution encoder 34, and convolution encoder 36 and convolution-encoded at a predetermined code rate. The code rate of each convolution encoder must be selected according to an optimization criterion. In doing this, note that each convolution encoder 32, 34, and 36 introduces enough redundancy into each data substream to facilitate error correction in the receiver. The rate-compatible point convolution codes (RCPC) used in a known DAB transmitter can also generally be used for encoding the information bits of each data substream. This simplifies the development and layout not only of X-DAB transmitter 10, but of an X-DAB receiver as well, because the Viterbi decoder implemented in DAB receivers can also be used in an X-DAB receiver. Each data substream contains a number of bits, the sum of which equals the number of bits in one logical source data stream frame. This only requires that each convolution encoder 32, 34, and 36 generate one encoded data substream with M bits per logical frame. The outputs of convolution encoders 32, 34, and 36 are connected to the inputs of a symbol mapper 40.

Figure 2 shows encoding modulator 20, whose function is explained in detail below. Data substream 0 is applied to convolution encoder 32, data substream 1 to convolution encoder 34, and data substream 2 to convolution encoder 36. Each convolution encoder ensures that one encoded data substream with M bits is present at its output. An essentially known block interleaver can be series-connected to each convolution encoder. In particular, block interleaver 52 follows convolution encoder 32, block interleaver 54 follows convolution encoder 34, and block interleaver 56 follows convolution encoder 36. However, the use of a block interleaver is optional. As shown in Figure 2, the outputs of convolution encoders 32, 34, and 36 are connected to symbol mapper 40 via block interleavers 52, 54, and 56. The bits of each encoded data substream present at the outputs of convolution encoders 32, 34, and 36 are combined successively

into a group or a vector having three bits $b_i^{(0)}$, $b_i^{(1)}$, $b_i^{(2)}$. Symbol mapper 40 is implemented, for example, so that it can map a 3-bit tuple to a complex symbol of an 8-PSK symbol alphabet. Symbol mapper 40 thus performs an 8-PSK modulation function. Encoding modulator 20 provides complex symbols of an 8-PSK symbol alphabet at its output, with the complex symbols themselves or, more suitably their 3-bit addresses, being further processed.

Figures 5 and 6 show two alternative mapping rules for an 8-PSK modulation. Figure 5 shows the natural mapping rule, while Figure 6 shows the pragmatic mapping rule. As explained in greater detail below, the implementation of an X-DAB receiver depends on which mapping rule is selected. The design of three-stage channel encoder 30 and the mapping rule used must be coordinated with one another in relation to an optimization criterion (e.g., the minimum bit error rate that can be achieved after decoding in the receiver). However, this is not the subject of the present invention.

The complex symbols present at the output of symbol mapper 40, which can also be represented as a 3-bit address, are applied to an essentially known time interleaver 60. A special feature of X-DAB transmitter 10 is that time interleaver 60 does not time-interleave individual bits, as in the case of a known DAB transmitter, but rather the individual complex symbols or their 3-bit addresses. If multiple source data streams are to be transmitted simultaneously, multiple parallel branches, also known as X-DAB subchannels, must be provided. Each branch contains one encoding modulator 20 as well as one time interleaver 60 and is connected to the input of an XSC frame multiplexer 70. "XSC" (X-DAB service channel) refers to the service channel of X-DAB transmitter 10 in the transmission frame shown in Figure 4. To the output of XSC frame multiplexer 70 a further frame multiplexer (not shown) can be connected which incorporates processed control data into the transmission frame shown in Figure 4 via a further encoding

modulator 20 (not shown) without a downstream time interleaver 60. As shown in Figure 1, the output of XSC multiplexer 70 is connected to the input of an essentially known block generator 80. Block generator 80 is used to combine the complex symbols representing one OFDM symbol into a block. Blocks which include a predetermined number of complex symbols are present at the output of block generator 80. In the example, each block contains 384 complex symbols, which corresponds to the number of subcarriers in an OFDM symbol. It is important to know that, unlike a known DAB transmitter, block generator 80 does not combine individual bits, but rather complex symbols, i.e., bit groups. The output of block generator 80 can be connected directly to the input of an essentially known frequency interleaver 90. Frequency interleaver 90 is used to eliminate signal noise caused by the frequency-discriminating characteristics of the mobile radio channel. A differential modulator 100 is connected downstream from frequency interleaver 90. Differential modulator 100 is used to modulate the subcarriers of each block containing the complex symbols. Each modulated subcarrier of a block is supplied to an essentially known OFDM signal generator 110. The purpose of OFDM signal generator 110 is to generate the analog OFDM signal from the modulated subcarriers of each block. In other words, OFDM signal generator 110 supplies one OFDM signal per block which can be viewed as a cumulative signal of the individual subcarriers. OFDM signal generator 110 usually includes a device for performing an inverse discrete Fourier transform and a D/A converter. The OFDM signal present at the output of OFDM signal generator 110 can be broadcast to numerous receiving devices via a transmitting device. Note that frequency interleaver 90, differential modulator 100, and OFDM signal generator 110 all operate in much the same manner as the corresponding function units of a known DAB transmitter. It is therefore not necessary to describe these function units in detail.

As shown in Figure 1, X-DAB transmitter 10 is incorporated

into a known DAB transmitter. The known DAB transmitter contains the known components forming a transmitter part 130, in particular a convolution encoder 135 for encoding control data, a convolution encoder 137 for encoding a source data stream, a time interleaver 140, a DAB-MSC frame multiplexer, an additional frame multiplexer 150, a block generator 155, a symbol mapper 160, as well as frequency interleaver 90, differential modulator 100, and OFDM signal generator 110, which are shared by the DAB transmitter and X-DAB transmitter 10. Because the DAB transmitter is generally known, the individual function units are not explained in greater detail here. However, it is important to note that symbol mapper 160 is connected downstream from block generator 155. Consequently, convolution encoder 137, time interleaver 140, and block generator 155 of known DAB transmitter 130, 90, 100, and 110 process the data streams bit-by-bit and not in the form of complex symbols. A block multiplexer 170, which incorporates the blocks of X-DAB transmitter 10 and the blocks of the DAB transmitter into the transmission frames shown in Figure 4 in a predetermined manner, is provided in order to integrate X-DAB transmitter 10 according to the present invention into known DAB transmitter 130, 90, 100, and 110.

Figure 1 also shows a device 120 for generating synchronization data which is also connected to OFDM signal generator 110.

Let us now examine the layout of a transmission frame which can be generated by the DAB and X-DAB transmitters shown in Figure 1. The transmission frame shown in Figure 4 includes, for example, L=76 blocks corresponding to the 76 OFDM symbols. Each transmission frame is divided into three sequential parts: the synchronization channel, which is generated in synchronization channel generator 120 and occupies the first block in the frame; control channel FIC (fast information channel), which occupies blocks 2 through 1+1; and main service channel MSC, which is contained in blocks 1+2 through

L. To keep things simple, the diagram does not show any null symbol in the synchronization channel. In main service channel MSC, the audio programs and data services can be embedded into the subchannels assigned to the various data sources. Because the layout of the synchronization and control channels is advantageously identical in both the DAB transmitter and X-DAB transmitter 10, the information contained therein can be evaluated by a known DAB receiver as well as by an X-DAB receiver according to the present invention. At least part of main service channel MSC is occupied by an XSC channel, which can contain, for example, the higher-speed video data from one or more sources or subchannels to be transmitted by X-DAB transmitter 10. The subchannels to be transmitted in the transmission frame according to the DAB standard are designated DAB-MSC in Figure 4. Because, as mentioned above, the control data is transmitted unchanged in the FIC channel, the known DAB receiver can decode the control data, even if it was generated by X-DAB transmitter 10, and, on the basis of the information contained therein, detect and decode subchannels DAB-MSC transmitted in standard DAB format in the transmission frame. However, it is not possible to decode the XSC channels.

MSC multiplexer 145, frame multiplexer 150, XSC frame multiplexer 70, and block multiplexer 170 make sure that service blocks DAB-MSC or XSC generated in DAB transmitter part 130 and in X-DAB transmitter 10 are inserted into the transmission frame shown in Figure 4 in a specific order. For example, multiple DAB-MSC blocks are positioned before and after the XSC blocks in main service channel MSC of the transmission frame shown in Figure 4. Following block multiplexing by block multiplexer 170, the above-mentioned frequency interleaving of the complex symbols in each DAB-MSC and XSC block, differential modulation and the generation of the OFDM signals are carried out together for both block types.

Thanks to this downward-compatible implementation of X-DAB transmitter 10 according to the present invention, data blocks generated by either a DAB transmitter or by X-DAB transmitter 10 can be transmitted in the transmission frame shown in Figure 4.

Figure 3 shows, for example, a three-stage decoder 180 for decoding a data stream which was subjected to an encoded 8-PSK modulation on the transmitter side. Three-stage decoder 180 is an important part of a digital OFDM multicarrier receiver according to the present invention, referred to below as X-DAB receiver.

The X-DAB receiver has the same function units as a conventional DAB receiver. This includes an OFDM demodulator, composed of an A/D converter and a device for performing a discrete Fourier transform. A differential demodulator and a frequency deinterleaver are connected downstream from the OFDM demodulator. A device for removing the block structure follows the frequency deinterleaver. A sequence of complex symbols is thus present at the output of this device. The complex symbols pass though a demultiplexer which performs time-division demultiplexing of the complex symbols from different source data streams. A downstream time deinterleaver largely functions as a known time deinterleaver of a known DAB receiver, the main difference being only that it does not process individual bits but rather the complex symbols, i.e., bit groups. Three-stage decoder 180 shown in Figure 3, which performs an encoded 8-PSK modulation, is connected downstream from the time deinterleaver in order to decode the X-DAB blocks. Three-stage decoder 180 needs three parallel-connected metric calculators 190, 195, and 200 in order to recover three data substreams 0, 1, and 2 of the transmitted source data stream. An optional block deinterleaver 205, 215, and 225 can be connected downstream from each metric calculator. Each metric calculator, 190, 195, 200 is connected to a convolution decoder 230, 232, and 234 either directly or via respective

block deinterleavers 205, 215, and 225[2]. The outputs of convolution decoders 230, 232, and 234 are fed back to the metric calculators via assigned, complementary convolution encoders 240 and 245, depending on the mapping rule executed by symbol mapper 40 of X-DAB transmitter 10. If symbol mapper 40 performed pragmatic mapping, convolution decoder 230 is fed back to metric calculator 200 via a complementary convolution encoder 240 and a block interleaver 210. Convolution decoder 232 is also fed back to metric calculator 200 via a complementary convolution encoder 245 and a block interleaver 220. If symbol mapper 40 performed natural mapping, convolution decoder 230 must be connected to metric calculator 195 via complementary convolution encoder 240 and block interleaver 210. Convolution decoder 232, in turn, must be connected to metric calculator 200 via complementary convolution encoder 245 and block interleaver 220. The term "metric" refers to the distance from the complex receiving symbols to the decision threshold adapted to the mapping rules on the complex level, possibly weighted by a reliability or channel status flag.

Mention should be made of a further advantage of the X-DAB transmission system according to the present invention over the known DAB transmission system arising when implementing "local windows" in the transmission frame shown in Figure 4. The OFDM method can be used to set up simultaneous broadcasting networks, which means that the program ensemble is broadcast at the same frequency from adjacent transmitting stations without producing the interference that occurs with a conventional FM broadcasting receiver. In order to emulate a typical FM broadcasting structure with many local programs in a DAB transmission system, a contiguous portion of main service channel MSC of the transmission frame shown in Figure 4 is removed from the single-frequency broadcasting mode, and the local programs are injected into this local window at the

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2 Translator's Note: The German should read Blockdeinterleaver, rather than Blockinterleaver.

individual transmitting sites. The 4-PSK mapping rule of the DAB standard has a disadvantageous effect here. For example, the 4-PSK symbols on the subcarriers of an OFDM symbol may be assigned to two subchannels, i.e., two different data sources. Consequently, it is not possible to delimit the local window within an OFDM symbol without producing interference. For single-frequency broadcasting, therefore, the range of main service channel MSC must always be expanded by filler bits until a complete OFDM symbol is occupied.

The X-DAB transmission system according to the present invention avoids this disadvantage by performing the 2^N-PSK modulation in symbol mapper 40 before time interleaver 60 performs the time interleaving operation, thus establishing a direct connection to the program in question. When implementing local windows, the subchannel limit between single-frequency broadcasting and local programs can thus lie within an OFDM symbol without interfering with single-frequency broadcasting reception. The X-DAB transmission system can therefore be used to implement local windows by making more efficient use of the bandwidth.

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Patent Claims

1. Method for the OFDM multicarrier transmission of digital broadcasting signals, in particular for digital added-value services, with the following steps:
   (a) generate at least one source data stream which is divided into a plurality of frames of a predetermined length;
   (b) break down the source data stream into N parallel data substreams;
   (c) supply each of the N data substreams to a separate channel encoder (32, 34, 36) having a predetermined code rate, with each channel encoder supplying an encoded sequence of M bits;
   (d) combine the bits of the N data substreams encoded in step c) into an N tuple and map them to a complex symbol of a 2^N-PSK symbol alphabet (40);
   (e) combine the complex symbols into blocks of a predefined size;
   (f) assign the complex symbols in each block to different subcarriers;
   (g) generate an analog OFDM signal from the complex symbols in each block and broadcast the OFDM signals to receiving equipment.

2. Method for the OFDM multicarrier transmission of digital broadcasting signals according to Claim 1, characterized in that each data substream is convolution-encoded in step c).

3. Method for the OFDM multicarrier transmission of digital broadcasting signals according to Claim 1 or 2, characterized in that the complex signals generated in step d) are time-interleaved and, after completing step e), frequency-interleaved.

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4. Method for the OFDM multicarrier transmission of digital broadcasting signals according to one of Claims 1 through 3, characterized in that N is set to a value greater than or equal to 3.

5. Method for the OFDM multicarrier transmission of digital broadcasting signals according to one of Claims 1 through 4, characterized in that the complex symbols in step f) undergo a differential modulation on each subcarrier.

6. Method for the OFDM multicarrier transmission of digital broadcasting signals according to Claim 5, characterized in that the complex symbols modulated in step f) undergo an inverse discrete Fourier transform in step g).

7. Method for the OFDM multicarrier transmission of digital broadcasting signals according to one of Claims 1 through 6, characterized in that multiple source data streams are generated, processed according to steps b) through d), and then time-division multiplexed.

8. Digital OFDM multicarrier transmission system for carrying out the method according to one of Claims 1 through 7, including:

a) a transmitter (10) with the following features: at least one set (30) of at least N parallel-connected channel encoders (32, 34, 36) having a predetermined code rate for encoding one data substream each;
a symbol mapper (40), connected to the outputs of the N parallel-connected channel encoders (32, 34, 36), for mapping an N-bit tuple to a complex symbol of a 2^N-PSK symbol alphabet;
a block generator (80) for combining a predetermined number of complex symbols into a block;
a multicarrier modulator (100) for modulating the complex symbols combined into a block;
and a device (110) for generating analog OFDM

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signals from the complex symbols in each block and for broadcasting the analog OFDM signals.

9. Digital OFDM multicarrier transmission system according to Claim 8, characterized by a time interleaver (60), connected downstream from the symbol mapper (40) for time-interleaving the complex symbols, and a frequency interleaver (90), connected between the block generator (80) and the multicarrier modulator (100), for frequency-interleaving the complex symbols in each block.

10. Digital OFDM multicarrier transmission system according to Claim 8 or 9, characterized in that the multicarrier modulator (100) performs a differential modulation on each subcarrier, and in that each channel encoder (32, 34, 36) is a convolution encoder.

11. Digital OFDM multicarrier transmission system according to one of Claims 8 through 10, characterized by a frame multiplexer (70) for multiplexing complex symbols from different source data streams.

12. Digital OFDM multicarrier transmission system according to one of Claims 8 through 11, characterized in that a block interleaver (52, 54, 56) is connected downstream from each channel encoder (32, 34, 36).

13. Digital OFDM multicarrier transmission system according to one of Claims 8 through 11, characterized by

b) a transmitting part (130), positioned parallel to the transmitter (10), which supplies a blocked 4-PSK symbol stream, like the one produced by a symbol mapper (160) of a known DAB transmitter, and is connected to the frequency interleaver (90) via a block multiplexer (170), to which the block generator (80) of the transmitter (10) is also attached.

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14. Digital OFDM multicarrier transmission system according to one of Claims 8 through 13, characterized in that N is greater than or equal to 3.

15. Digital OFDM multicarrier transmission system according to one of Claims 8 through 14, characterized by

c) a receiver with the following features:
an OFDM demodulator;
a differential demodulator;
a frequency deinterleaver;
a device for removing the block structure;
a demultiplexer for time-division demultiplexing the complex symbols from different source data streams;
a time deinterleaver;
N parallel-connected metric calculators (190, 195, 200) downstream from each of which is connected a separate convolution decoder (230, 232, 234), with the outputs of the convolution decoders (230, 232, 234) being fed back to the respective metric calculators (195, 200) via assigned complementary convolution encoders (240, 245) according to a selected symbol mapping rule.

16. Digital OFDM multicarrier transmission system according to Claim 15, characterized in that a block deinterleaver (205, 215, 225) is connected between each metric calculator (190, 195, 200) and each convolution decoder (230, 232, 234), and a block interleaver (210, 220) is connected between each convolution encoder (240, 245) for re-encoding each data bit stream detected and the respective, downstream metric calculator (195, 200).

17. Digital OFDM multicarrier transmitter for use in a digital OFDM multicarrier transmission system according to one of Claims 8 through 16 with the following features:
at least one set (30) of at least N parallel-connected

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channel encoders (32, 34, 36) having a predetermined code rate for encoding one data substream;
a symbol mapper (40), connected to the outputs of the N parallel-connected channel encoders (32, 34, 36), for mapping an N-bit tuple to a complex symbol of a 2^N-PSK symbol alphabet;
a block generator (80) for combining a predetermined number of complex symbols into a block;
a multicarrier modulator (100) for modulating the complex symbols combined into a block;
and a device (110) for generating analog OFDM signals from the complex symbols in each block and for broadcasting the analog OFDM signals.

18. Digital OFDM multicarrier transmitter according to Claim 17, characterized by a time interleaver (60), connected downstream from the symbol mapper (40), for time-interleaving the complex symbols and a frequency interleaver (90), connected between the block generator (80) and the multicarrier modulator (100), for frequency-interleaving the complex symbols in each block.

19. Digital OFDM multicarrier transmitter according to Claim 17 or 18, characterized in that the multicarrier modulator (100) performs a differential modulation on each subcarrier, and in that each channel encoder (32, 34, 36) is a convolution encoder.

20. Digital OFDM multicarrier receiver for use in a digital OFDM multicarrier transmission system according to one of Claims 8 through 16, characterized by
an OFDM demodulator;
a differential demodulator;
a frequency deinterleaver;
a device for removing the block structure;
a demultiplexer for time-division demultiplexing the complex symbols from different source data streams;

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a time deinterleaver;

N parallel-connected metric calculators (190, 195, 200) downstream from each of which is connected a separate convolution decoder (230, 232, 234), with the outputs of the convolution decoders (230, 232, 234) being fed back to the respective metric calculators (190, 195, 200) via assigned complementary convolution encoders (240, 245) according to a selected symbol mapping rule.

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Abstract

Improvement of an existing DAB transmission system, so that a higher net data rate can be achieved while maintaining the same system quality, or the same system quality can be achieved with a much lower signal-to-noise ratio on the receiver side at the same net data rate.

A symbol mapper (40) is connected directly downstream from a convolution encoder (30) instead of to the block generator (155), as in the case of the DAB system. A multi-stage channel encoder, to which the data substreams of a source data stream are distributed, is used. The source data stream is processed on the complex symbol level and not on the bit level, as in the case of known DAB systems.

(Figure 1)

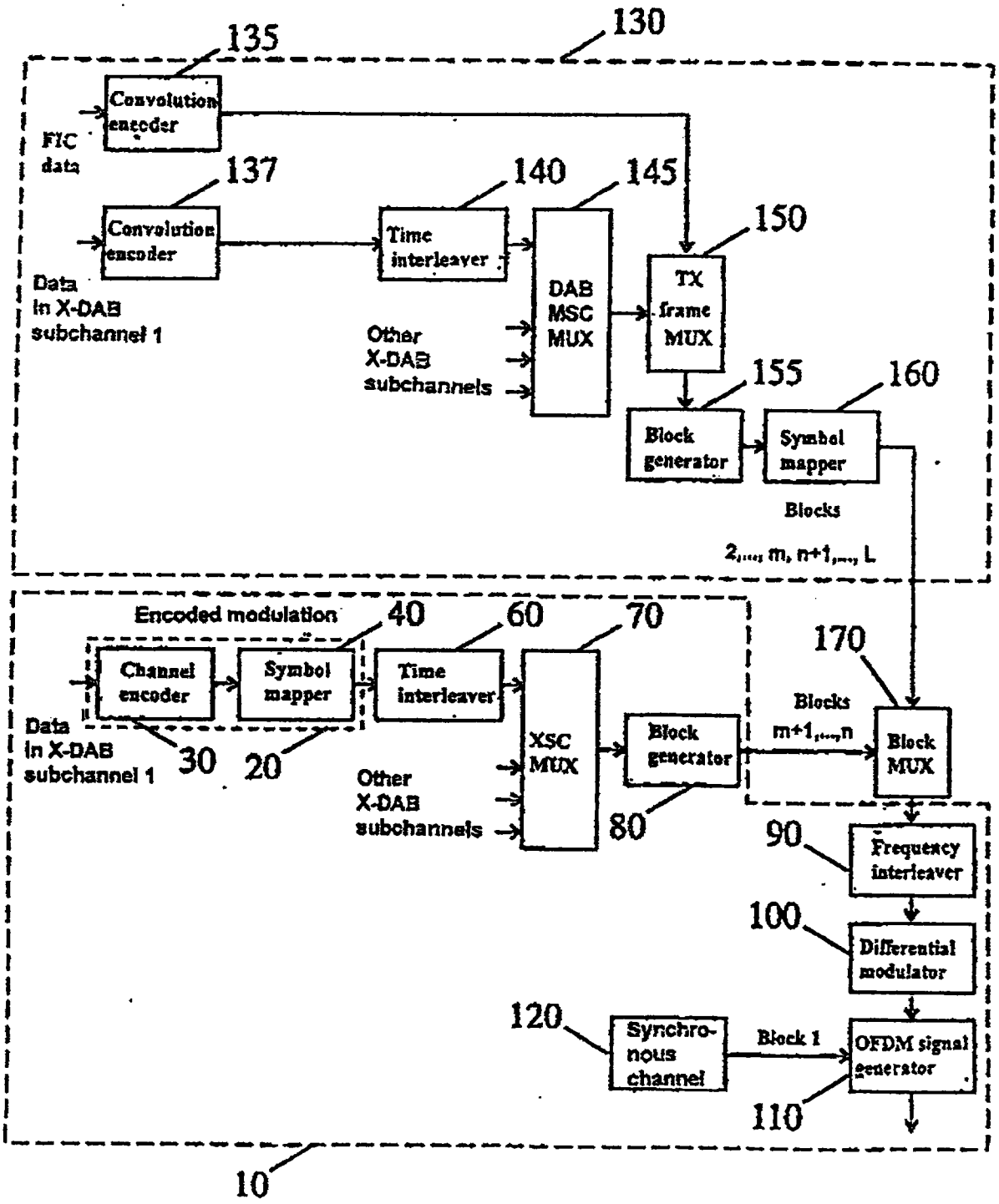

130
135
Convolution encoder
FIC data
137
Convolution encoder
Data in X-DAB subchannel 1
140
Time interleaver
145
DAB MSC MUX
Other X-DAB subchannels
150
TX frame MUX
155
Block generator
160
Symbol mapper
Blocks
2,..., m, n+1,..., L
Encoded modulation
40
Channel encoder
Symbol mapper
30
20
Data in X-DAB subchannel 1
60
Time interleaver
70
XSC MUX
Other X-DAB subchannels
Block generator
80
170
Blocks m+1,...,n
Block MUX
90
Frequency interleaver
100
Differential modulator
120
Synchro-nous channel
Block 1
OFDM signal generator
110
10

Fig. 1

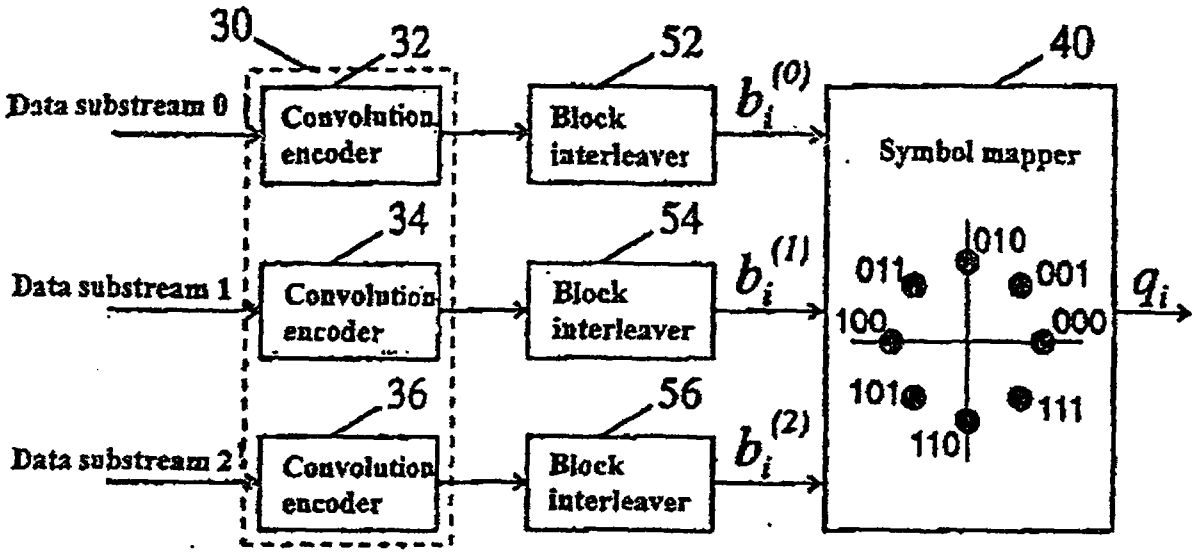

30
32
52
40
Data substream 0
Convolution encoder
Block interleaver
$b_i^{(0)}$
Symbol mapper
34
54
Data substream 1
Convolution encoder
Block interleaver
$b_i^{(1)}$
010
011
001
100
000
101
111
110
q_i
36
56
Data substream 2
Convolution encoder
Block interleaver
$b_i^{(2)}$

Fig. 2

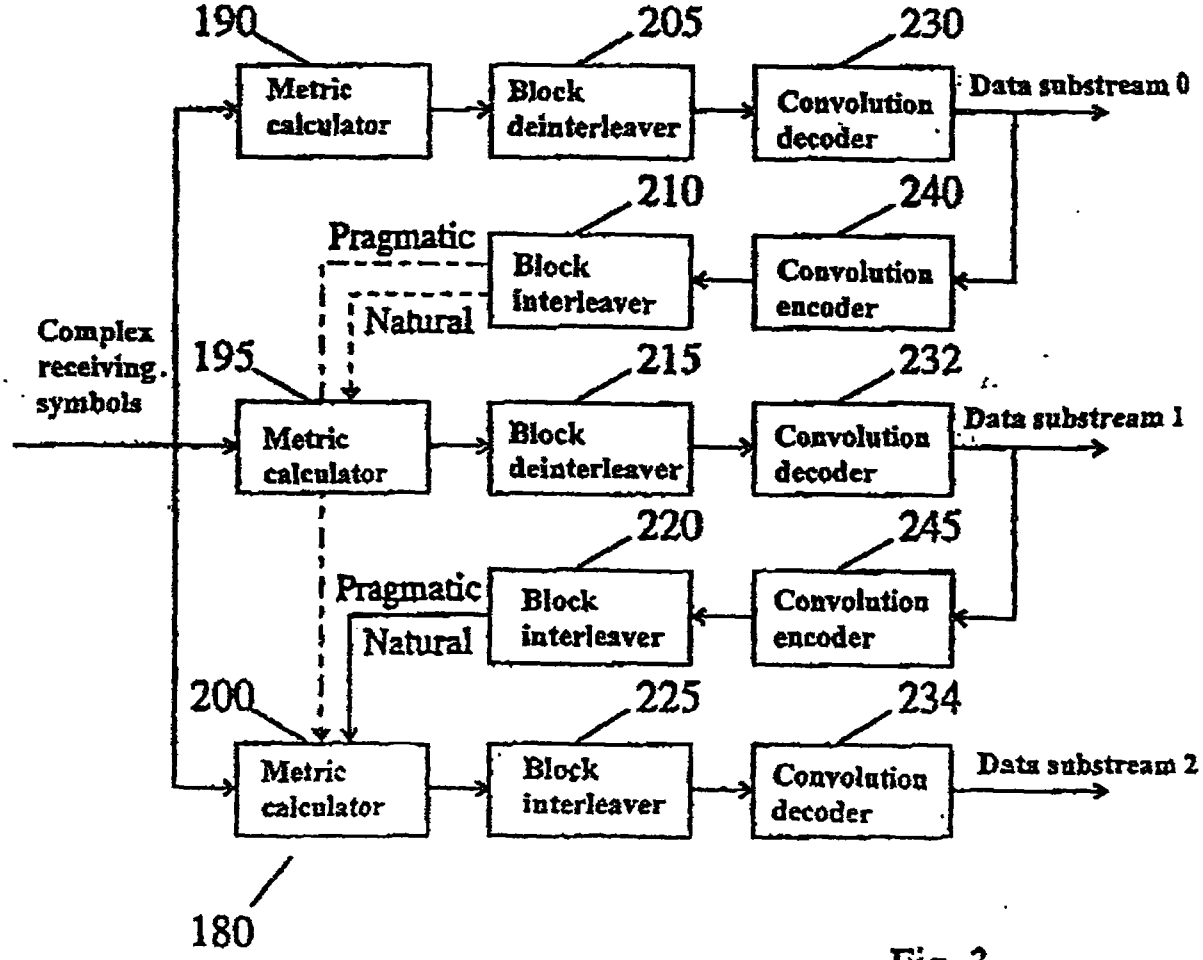

190
205
230
Metric calculator
Block deinterleaver
Convolution decoder
Data substream 0
210
240
Pragmatic
Block interleaver
Convolution encoder
Natural
Complex receiving symbols
195
215
232
Metric calculator
Block deinterleaver
Convolution decoder
Data substream 1
220
245
Pragmatic
Block interleaver
Convolution encoder
Natural
200
225
234
Metric calculator
Block interleaver
Convolution decoder
Data substream 2
180

Fig. 3

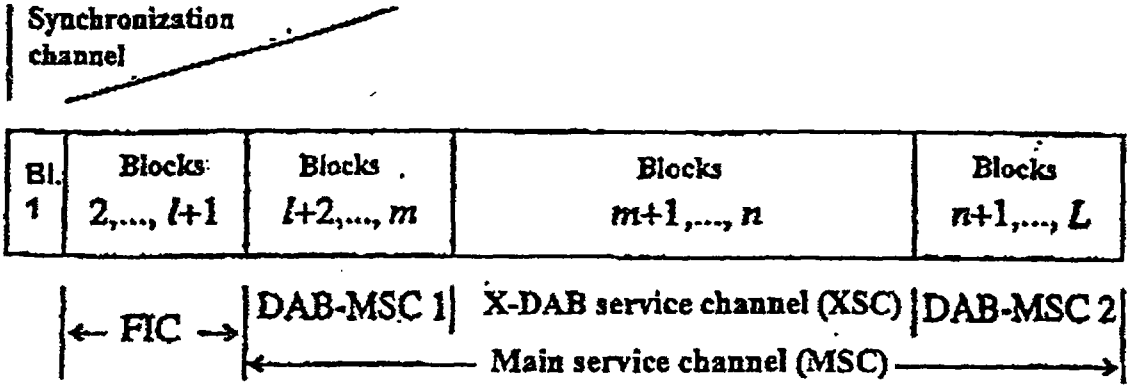


Fig. 4

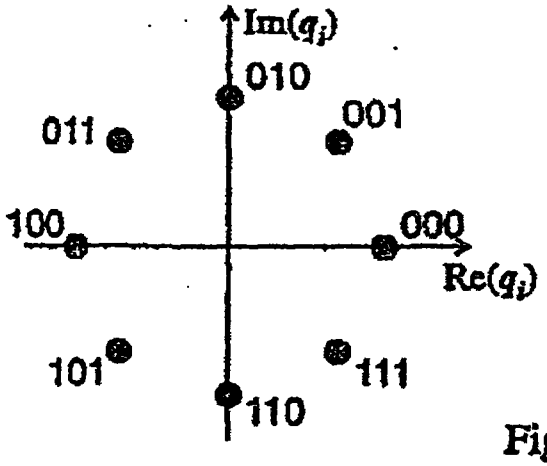


Fig. 5

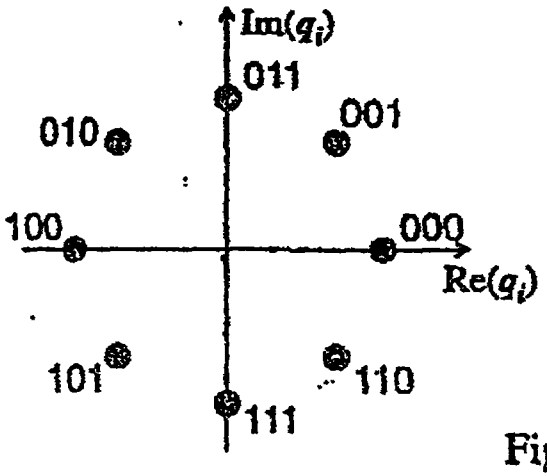


Fig. 6

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State of New York)
: SS:
County of New York)

AFFIDAVIT

On this day, Suzanne Gagliardi, personally appeared before me and after being duly sworn, deposes and states:

1. That she is accredited by the American Translators Association as a translator for the language combination German to English and is employed as such by Kenyon & Kenyon (One Broadway, New York, New York 10004);

2. That she has carefully reviewed the attached English language translation from the original German document, revised claims 1-20 for PCT Application no. PCT/EP97/01090, entitled

"Method and System for the OFDM Multicarrier Transmission of Digital Broadcasting Signals",

which were part of the International Examination Report dated 2/24/1998; and

3. That the attached translation is an accurate English version of such original to the best of her knowledge and belief.

Suzanne F. Gagliardi
SUZANNE F. GAGLIARDI

Subscribed and Sworn to before me
this 20th day of November, 1998.

Barbara A. Inserra
Notary Public

BARBARA A. INSERRA
Notary Public, State of New York
No. 01IN4853232
Qualified in New York County
Commission Expires December 22, 2000

* C L M S *

(on the basis of the Office Action of 02/24/1998)

Revised Patent Claims

1. Method for the OFDM multicarrier transmission of digital broadcasting signals, in particular for digital added-value services, with the following steps:

(a) generate at least one source data stream which is divided into a plurality of frames of a predetermined length;

(b) break down the source data stream into N parallel data substreams;

(c) supply each of the N data substreams to a separate channel encoder (32, 34, 36) having a predetermined code rate, with each channel encoder supplying an encoded sequence of M bits;

(d) combine the bits of the N data substreams encoded in step c) into an N tuple and map them to a complex symbol of a 2^N-PSK symbol alphabet (40);

(e) combine the complex symbols into blocks of a predefined size;

(f) frequency-interleave the complex symbols combined block-wise in step e);

(g) assign the complex symbols in each block to different subcarriers;

(h) generate an analog OFDM signal from the complex symbols in each block and broadcast the OFDM signals to receiving equipment.

2. Method for the OFDM multicarrier transmission of digital broadcasting signals according to Claim 1, characterized in that each data substream is convolution-encoded in step c).

3. Method for the OFDM multicarrier transmission of digital broadcasting signals according to Claim 1 or 2, characterized in that the complex signals generated in step d) are time-interleaved.

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4. Method for the OFDM multicarrier transmission of digital broadcasting signals according to one of Claims 1 through 3, characterized in that N is set to a value greater than or equal to 3.

5. Method for the OFDM multicarrier transmission of digital broadcasting signals according to one of Claims 1 through 4, characterized in that the complex symbols in step f) undergo a differential modulation on each subcarrier.

6. Method for the OFDM multicarrier transmission of digital broadcasting signals according to Claim 5, characterized in that the complex symbols modulated in step f) undergo an inverse discrete Fourier transform in step g).

7. Method for the OFDM multicarrier transmission of digital broadcasting signals according to one of Claims 1 through 6, characterized in that multiple source data streams are generated, processed according to steps b) through d), and then time-division multiplexed.

8. Digital OFDM multicarrier transmission system for carrying out the method according to one of Claims 1 through 7, including:

a) a transmitter (10) with the following features: at least one set (30) of at least N parallel-connected channel encoders (32, 34, 36) having a predetermined code rate for encoding one data substream each;
a symbol mapper (40), connected to the outputs of the N parallel-connected channel encoders (32, 34, 36), for mapping an N-bit tuple to a complex symbol of a 2^N-PSK symbol alphabet;
a block generator (80) for combining a predetermined number of complex symbols into a block;
a multicarrier modulator (100) for modulating the complex symbols combined into a block;

a frequency interleaver (90), connected between the block generator (80) and the multicarrier modulator (100), for frequency-interleaving the complex symbols in each block; and
a device (110) for generating analog OFDM signals from the complex symbols in each block and for broadcasting the analog OFDM signals.

9. Digital OFDM multicarrier transmission system according to Claim 8, characterized by a time interleaver (60), connected downstream from the symbol mapper (40) for time-interleaving the complex symbols.

10. Digital OFDM multicarrier transmission system according to Claim 8 or 9, characterized in that the multicarrier modulator (100) performs a differential modulation on each subcarrier, and in that each channel encoder (32, 34, 36) is a convolution encoder.

11. Digital OFDM multicarrier transmission system according to one of Claims 8 through 10, characterized by a frame multiplexer (70) for multiplexing complex symbols from different source data streams.

12. Digital OFDM multicarrier transmission system according to one of Claims 8 through 11, characterized in that a block interleaver (52, 54, 56) is connected downstream from each channel encoder (32, 34, 36).

13. Digital OFDM multicarrier transmission system according to one of Claims 8 through 11, characterized by
b) a transmitting part (130), positioned parallel to the transmitter (10), which supplies a blocked 4-PSK symbol stream, like the one produced by a symbol mapper (160) of a known DAB transmitter, and is connected to the frequency interleaver (90) via a block multiplexer (170), to which the block generator (80) of the transmitter (10)

is also attached.

14. Digital OFDM multicarrier transmission system according to one of Claims 8 through 13, characterized in that N is greater than or equal to 3.

15. Digital OFDM multicarrier transmission system according to one of Claims 8 through 14, characterized by

c) a receiver with the following features:
an OFDM demodulator;
a differential demodulator;
a frequency deinterleaver;
a device for removing the block structure;
a demultiplexer for time-division demultiplexing the complex symbols from different source data streams;
a time deinterleaver;
N parallel-connected metric calculators (190, 195, 200) downstream from each of which is connected a separate convolution decoder (230, 232, 234), with the outputs of the convolution decoders (230, 232, 234) being fed back to the respective metric calculators (195, 200) via assigned complementary convolution encoders (240, 245) according to a selected symbol mapping rule.

16. Digital OFDM multicarrier transmission system according to Claim 15, characterized in that a block deinterleaver (205, 215, 225) is connected between each metric calculator (190, 195, 200) and each convolution decoder (230, 232, 234), and a block interleaver (210, 220) is connected between each convolution encoder (240, 245) for re-encoding each data bit stream detected and the respective, downstream metric calculator (195, 200).

17. Digital OFDM multicarrier transmitter for use in a digital OFDM multicarrier transmission system according to one of Claims 8 through 16 with the following

features:
at least one set (30) of at least N parallel-connected channel encoders (32, 34, 36) having a predetermined code rate for encoding one data substream;
a symbol mapper (40), connected to the outputs of the N parallel-connected channel encoders (32, 34, 36), for mapping an N-bit tuple to a complex symbol of a 2^N-PSK symbol alphabet;
a block generator (80) for combining a predetermined number of complex symbols into a block;
a multicarrier modulator (100) for modulating the complex symbols combined into a block;
a device (110) for generating analog OFDM signals from the complex symbols in each block and for broadcasting the analog OFDM signals; and
a frequency interleaver (90), connected between the block generator (80) and the multicarrier modulator (100), for frequency-interleaving the complex symbols in each block.

18. Digital OFDM multicarrier transmitter according to Claim 17, characterized by a time interleaver (60), connected downstream from the symbol mapper (40), for time-interleaving the complex symbols.

19. Digital OFDM multicarrier transmitter according to Claim 17 or 18, characterized in that the multicarrier modulator (100) performs a differential modulation on each subcarrier, and in that each channel encoder (32, 34, 36) is a convolution encoder.

20. Digital OFDM multicarrier receiver for use in a digital OFDM multicarrier transmission system according to one of Claims 8 through 16, characterized by
an OFDM demodulator;
a differential demodulator;
a frequency deinterleaver;
a device for removing the block structure;

* C L M S *

a demultiplexer for time-division demultiplexing the complex symbols from different source data streams;
a time deinterleaver;
N parallel-connected metric calculators (190, 195, 200) downstream from each of which is connected a separate convolution decoder (230, 232, 234), with the outputs of the convolution decoders (230, 232, 234) being fed back to the respective metric calculators (190, 195, 200) via assigned complementary convolution encoders (240, 245) according to a selected symbol mapping rule.

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transmitted at higher data rates without impairing the transmission quality.

The present invention achieves this object with the steps described in Claim 1 and with the features of Claims 8, 17, and 20.

In accordance with the present invention, there is provided a method for the OFDM multicarrier transmission of digital broadcasting signals, in particular for digital added-value services, with the following steps:

(a) generate at least one source data stream which is divided into a plurality of frames of a predetermined length;

(b) break down the source data stream into N parallel data substreams;

(c) supply each of the N data substreams to a separate channel encoder (32, 34, 36) having a predetermined code rate, with each channel encoder supplying an encoded sequence of M bits;

(d) combine the bits of the N data substreams encoded in step c) into an N tuple and map them to a complex symbol of a 2^N-PSK symbol alphabet (40);

(e) combine the complex symbols into blocks of a predefined size;

(f) frequency-interleave the complex symbols combined block-wise in step e);

(g) assign the complex symbols in each block to different subcarriers;

(h) generate an analog OFDM signal from the complex symbols in each block and broadcast the OFDM signals to receiving equipment.

The subclaims describe advantageous embodiments and improvements.

The main idea behind the present invention is to provide a digital OFDM multicarrier transmission system that is based on the existing DAB transmission system with improved system performance. At the same time, attention was paid to the ability to use known hardware components from the existing DAB transmission system when designing the digital OFDM multicarrier transmission system, making it possible to easily incorporate the present invention into an existing DAB transmission system.

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To keep things simple, the transmission system according to the present invention is called the X-DAB transmission system. "X-DAB" stands for extended (or enhanced) digital audio broadcasting system. To prevent misunderstandings at the outset, note that the X-DAB transmission system can be used to advantageously transmit high-speed data signals, such as video signals, to mobile receivers along with audio programs, even though this cannot be done with a conventional DAB transmission system at a sufficient level of quality.

With the method according to the present invention for the OFDM multicarrier transmission of digital broadcasting signals, at least one source data stream, which is split into several frames of a predetermined length, is generated, just like with the known DAB system. In order to considerably improve system performance compared to the DAB transmission system, the source data stream is broken down into N parallel data substreams, each of which is supplied to a separate channel encoder having a predetermined code rate. Each channel encoder supplies an encoded, preferably convolution-encoded, sequence of M bits at its output. The bits of the N encoded parallel data substreams are each combined into an N-tuple, i.e., a group or a

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