(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
29 October 2009 (29.10.2009)

PCT

(10) International Publication Number
WO 2009/130658 A2

(51) International Patent Classification:
H04L 27/26 (2006.01) *H04B 1/69* (2006.01)
H04L 27/34 (2006.01)

(21) International Application Number:
PCT/IB2009/051621

(22) International Filing Date:
20 April 2009 (20.04.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/046,641 21 April 2008 (21.04.2008) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

[Continued on next page]

(54) Title: SYSTEMS AND METHODS FOR DECODING DUAL CARRIER MODULATED SIGNALS

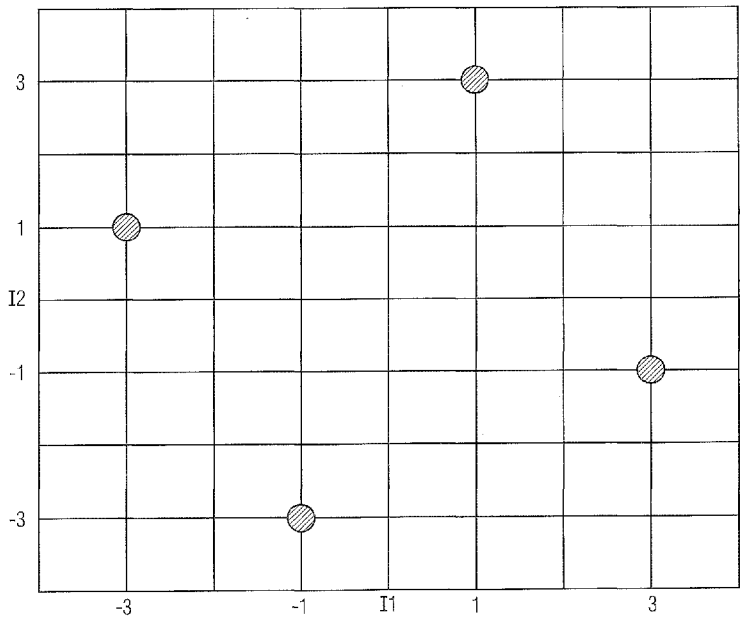


FIG. 1

(57) Abstract: Systems, methods and circuits are implemented in a various manners. Consistent with one such implementation, a method is employed for use in a system using a dual-carrier modulation (DCM) scheme that uses two quadrature-amplitude modulated (QAM) signals, the first QAM signal having an I1 and Q1 component and the second QAM signal having an I2 and a Q2 component. The method includes receiving the QAM signals (310) and transforming the received QAM signals into an I1-I2 domain or a Q1-Q2 domain (312). A data bit is decoded by calculating a Euclidean distance from constellation points in the I1 to I2 domain (314). The decoded data bit is then stored (316).

WO 2009/130658 A2

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

SYSTEMS AND METHODS FOR DECODING DUAL CARRIER MODULATED SIGNALS

The present invention relates generally to methods and system for decoding signals, and in particular to systems and methods for decoding wireless dual-carrier-modulated signals.

Wireless communications systems are used in a wide variety of applications. Important factors in many wireless communications systems include, but are not limited to, spectral bandwidth, power and processing complexity. Often these factors are at odds with the desire for increased bandwidth. Various techniques are used to implement wireless systems with high bandwidth. Examples of such techniques include quadrature-phase-shift keying (QPSK), quadrature amplitude modulation (QAM) and dual carrier modulation (DCM). These and other techniques are useful for implementing systems with both relatively high bandwidth communications and low error rates.

A specific type of communication system implements an ultra wideband (UWB) communications protocol. For high bandwidth applications (*e.g.*, those higher than 480Mbps), the UWB protocol implements a DCM scheme. Specifically, the DCM scheme is implemented using an encoder that applies a transform on each of two QPSK signals to produce two 16QAM signals. The receiver uses a decoder that determines the closest constellation point for each signal, and thus, the respective bit. This can be accomplished by calculating the 16 Euclidean distances for each signal, or calculating 32 such distances for each bit. For a four bit symbol, this can result in an exceedingly complex decoder algorithm totaling 124 total calculations. Thus, while such DCM schemes may provide high bandwidth for UWB transmissions, the processing requirements can be exceedingly high.

Various aspects of the present invention are directed generally to methods and systems for decoding signals, and in particular to systems and methods for decoding wireless dual-carrier-modulated signals.

Consistent with a specific embodiment of the present invention a method is implemented for use in a system using a dual-carrier modulation (DCM) scheme that uses two quadrature-amplitude modulated (QAM) signals, the first QAM signal having an I1 and Q1 component and the second QAM signal having an I2 and a Q2 component. The method includes receiving the QAM signals and transforming the

received QAM signals into an I1 to I2 domain. A data bit is decoded by calculating a Euclidean distance from constellation points in the I1 to I2 domain. The decoded data bit is then stored.

Consistent with another embodiment of the present invention a receiver is implemented for use in a system using a dual-carrier modulation (DCM) scheme that uses two quadrature-amplitude modulated (QAM) signals, the first QAM signal having an I1 and Q1 component and the second QAM signal having an I2 and a Q2 component. The receiver includes a circuit that receives the QAM signals and a decoder. The decoder is arranged to transform the received QAM signals into an I1 to I2 domain, to decode a data bit by calculating a Euclidean distance from constellation points in the I1 to I2 domain, and to store the decoded data bit.

Consistent with another embodiment of the present invention a communication system is implemented. The system includes a circuit that receives quadrature-amplitude modulated (QAM) signals transmitted using a dual-carrier modulation (DCM) scheme that uses QAM signals, the first QAM signal having an I1 and Q1 component and the second QAM signal having an I2 and a Q2 component. The system also includes a decoder arranged to transform the received QAM signals into an I1 to I2 domain, to decode a data bit by calculating a Euclidean distance from constellation points in the I1 to I2 domain and to store the decoded data bit.

The above summary is not intended to describe each embodiment or every implementation of the present disclosure. The figures and detailed description that follow more particularly exemplify various embodiments.

The invention may be more completely understood in consideration of the following detailed description of various embodiments of the invention in connection with the accompanying drawings, in which:

FIG. 1 shows an example constellation map for an I1 – I2 domain, according to an example embodiment of the present invention;

FIG. 2 shows an example constellation map for a Q1 – Q2 domain, according to an example embodiment of the present invention; and

FIG. 3 shows an example wireless communication system, according to an example embodiment of the present invention.

While the invention is amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to

limit the invention to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the scope of the invention including aspects defined by the appended claims.

The present invention is believed to be applicable to a variety of circuits and approaches involving electronic communications, and in particular to those involving wireless communications using a dual carrier modulation-(DCM)-based system. While the present invention is not necessarily limited to such applications, an appreciation of various aspects of the invention is gained through a discussion of examples in such an environment.

The encoder of an example DCM-based communication system transmits data using two different signals. The first signal can be thought of as containing I1 and Q1 components, where I1 is the real portion and Q1 is the imaginary portion. Likewise, the second signal can be thought of as containing I2 and Q2 components. In Orthogonal frequency-division multiplexing (OFDM), these signals can be separated by a number of tones (*e.g.*, 50) to, for example, improve the error rate of the system. In a specific example, the signals are each transformed using 16 quadrature amplitude modulation (QAM).

A conventional decoder for DCM coded signals, such as those used with UWB, decodes a bit by calculating Euclidean distances for both I1-Q1 and I2-Q2 transforms. The present invention recognizes that the decoding can be optimized (*e.g.*, by reducing complexity) by instead calculating Euclidean in one (or both) of an I1-I2 domain or a Q1-Q2 domain. Such transformed domains have a reduced number of constellation points relative to the I1-Q1 and I2-Q2 domains. More specifically, for 16 QAM transformed DCM signals the I1-I2 domain has four constellation points, whereas the I1-Q1 has 16 constellation points. Moreover, due to the preservation of orthogonality of the two signals by OFDM, each bit can be determined entirely within one of the I1-I2 domain or the Q1-Q2 domain. Accordingly, the computation necessary to decode a particular bit can be reduced.

Table 1 shows an example dual-carrier modulation encoding table used with an ultra wideband (UWB) coding scheme.

TABLE 1

Input Bits	I1	Q1	I2	Q2
0000	-3	-3	1	1
0001	-3	-1	1	-3
0010	-3	1	1	3
0011	-3	3	1	-1
0100	-1	-3	-3	1
0101	-1	-1	-3	-3
0110	-1	1	-3	3
0111	-1	3	-3	-1
1000	1	-3	3	1
1001	1	-1	3	-3
1010	1	1	3	3
1011	1	3	3	-1
1100	3	-3	-1	1
1101	3	-1	-1	-3
1110	3	1	-1	3
1111	3	3	-1	-1

Aspects of the present invention recognize that the encoded I1 and I2 components uniquely identify the most significant input bits and further that the Q1 and Q2 components uniquely identify the least significant input bits. Accordingly, the transformed I1-I2 (or Q1-Q2) domain provides sufficient information for decoding a data bit. Moreover, such use of a component from each tone/signal can be particularly useful for maintaining the error performance of the system.

FIG. 1 shows an example constellation map for an I1-I2 domain, according to an example embodiment of the present invention. Consistent with the encoding scheme of Table 1, the I1-I2 {I1, I2} domain mapping can be used to decode the most significant bits of the input bits. For example, {-3, 1} decodes to 00, {-1, -3} decodes to 01, {1, 3} decodes to 10 and {3, -1} decodes to 11.

FIG. 2 shows an example constellation map for a Q1-Q2 domain, according to an example embodiment of the present invention. Consistent with the encoding

scheme of Table 1, the Q1-Q2 {Q1, Q2} domain mapping can be used to decode the most significant bits of the input bits. For example, {-3, 1} decodes to 00, {-1, -3} decodes to 01, {1, 3} decodes to 10 and {3, -1} decodes to 11.

FIG. 3 shows an example wireless communication system, according to an example embodiment of the present invention. Transmitter 300 receives a scrambled Phy Service Data Unit (PSDU) signal. The signal to noise ratio (SNR) can be improved through the use of error correcting circuitry such as a Viterbi decoder. Thus, a convolution encoder 302 produces an encoded bit-stream that can be decoded by a Viterbi decoder. In some instances, convolution encoder 302 can use punctured codes to reduce the amount of data transmitted by discarding or erasing symbols from the code.

Bit interleaver 304 interleaves the convolution encoded signal prior to modulation to provide robustness against burst errors. In a specific example, the bit interleaving operation is performed in three stages. A first stage involves symbol interleaving. This allows the bits to be permuted across consecutive OFDM symbols and can provide frequency diversity within a band group. A second stage involves intra-symbol tone interleaving. This allows the bits to permute across the data subcarriers within an OFDM symbol. It can also be useful to both exploit frequency diversity across subcarriers and to provide robustness against narrow-band interferers. A third stage involves intra-symbol cyclic shifts. Such shifts cyclically shift the bits in successive OFDM symbols by deterministic amounts. This can be useful to enable modes that employ time-domain spreading and the fixed frequency interleaving modes so as to better exploit frequency diversity.

DCM 306 divides the convolution coded and interleaved binary serial input data into groups of 200 bits that are converted into 100 complex numbers using DCM. This mapping is consistent with Table 1 and with FIGs. 1 and 2. In a specific instance, the two DCM signals are separated by 50 tones.

OFDM block 308 generates a discrete-time signal by taking the inverse discrete Fourier transform (IDFT) of the stream of complex values from DCM 306. The resulting signal is then transmitted using a wireless signal output from transmitter 300.

Remotely-located receiver 350 receives the signal output from transmitter 300, as is shown by block 310. As such, receiver 350 can be a device that is separate and distinct from the device of transmitter 300. For example, the transmitter may be a

UWB transmitter in a first device that is transmitting wireless signals to a second device that includes the receiver.

The received signal is transformed into one (or both) of the I1-I2 domain or the Q1-Q2 domain, as is shown by block 312. The Euclidean distances from the points in the transformed domain are then calculated, as is shown by block 314. This allows the bit to be determined and eventually stored, as is shown by block 314.

The transformation to the I1-I2 and Q1-Q2 domains results in a rotation of the constellation points. Thus, an additional step can be included to de-rotate the results of the transformation. Specifically, the rotation equals about 26.51 degrees. The domains can be de-rotated accordingly.

For further details regarding specifics of such an example the encoding and decoding scheme reference can be made to "High Rate Ultra Wideband Phy and MAC Standard: ECMA-386" 2nd Edition, December 2007, which is fully incorporated herein by reference.

The skilled artisan would recognize that the various processing functions (*e.g.*, encoding, decoding, transforming or storage) can be implemented using a variety of different devices. A non-exclusive list includes programmable logic devices, general purposes processors configured with software, digital-signal processors, analog-to-digital converters, digital-to-analog converters or hardware circuits configured using discrete logic.

While the present invention has been described above and in the claims that follow, those skilled in the art will recognize that many changes may be made thereto without departing from the spirit and scope of the present invention. For example, the invention may be implemented for communication protocols including, but not limited to, Worldwide Interoperability for Microwave Access (WIMAX) and various wireless LANs.

What is claimed is:

1. For use in a system using a dual-carrier modulation (DCM) scheme that uses two quadrature-amplitude modulated (QAM) signals, the first QAM signal having an I1 and Q1 component and the second QAM signal having an I2 and a Q2 component, a method comprising:

receiving the QAM signals (310);

transforming the received QAM signals into an I1-I2 domain or a Q1-Q2 domain (312);

decoding a data bit by calculating a Euclidean distance from constellation points in the I1-I2 domain or the Q1-Q2 domain (314); and

storing the decoded data bit (316).

2. The method of claim 1, further including the steps of

transforming the received QAM signals into the other of the I1-I2 domain or the Q1-Q2 domain;

decoding another data bit by calculating a Euclidean distance from constellation points in the other of the I1-I2 domain or the Q1-Q2 domain; and

storing the decoded another data bit.

3. The method of claim 1, wherein the dual-carrier modulation (DCM) scheme is an ultrawide band (UWB) scheme.

4. The method of claim 1, wherein QAM signals are 16 QAM signals.

5. The method of claim 1, wherein QAM signals are 16 QAM signals that each contains data interleaved between the QAM signals and that are separated by about 50 tones.

6. The method of claim 1, wherein QAM signals are 16 QAM signals that each contains data interleaved between the QAM signals and that are separated by about 50 tones and each representing a same four bits of data.

7. For use in a system using a dual-carrier modulation (DCM) scheme that uses two quadrature-amplitude modulated (QAM) signals, the first QAM signal having an I1 and Q1 component and the second QAM signal having an I2 and a Q2 component, a receiver comprising:

circuit (350) that receives the QAM signals;

a decoder arranged to

transform the received QAM signals into an I1-I2 domain or a Q1-Q2 domain (312);

decode a data bit by calculating a Euclidean distance from constellation points in the I1-I2 domain or the Q1-Q2 domain (314); and

store the decoded data bit (316).

8. The receiver of claim 7, wherein the decoder is further arranged to

transform the received QAM signals into the other of the I1-I2 domain or the Q1-Q2 domain;

decode another data bit by calculating a Euclidean distance from constellation points in the other of the I1-I2 domain or the Q1-Q2 domain; and

store the decoded another data bit.

9. The receiver of claim 7, wherein the DCM scheme is an ultra wideband (UWB) scheme.

10. The receiver of claim 7, wherein QAM signals are 16 QAM signals.

11. The receiver of claim 7, wherein QAM signals are 16 QAM signals that each contains data interleaved between the QAM signals and that are separated by about 50 tones.

12. The receiver of claim 7, wherein QAM signals are 16 QAM signals that each contains data interleaved between the QAM signals and that are separated by about 50 tones and each representing a same four bits of data.

13. A communication system comprising:

circuit (350) that receives quadrature-amplitude modulated (QAM) signals transmitted using a dual-carrier modulation (DCM) scheme that uses QAM signals, the first QAM signal having an I1 and Q1 component and the second QAM signal having an I2 and a Q2 component; and

a decoder arranged to

transform the received QAM signals into an I1-I2 domain or a Q1-Q2 domain (312);

decode a data bit by calculating a Euclidean distance from constellation points in the II1-I2 domain or the Q1-Q2 domain (314); and

store the decoded data bit (316).

14. The system of claim 13, further including an encoder for generating the QAM signals.

15. The system of claim 14, further including a transmit circuit for transmitting the QAM signals.

16. The system of claim 14, wherein the encoder is consistent with the High Rate Ultra Wideband Phy and MAC Standard: ECMA-386" 2nd Edition, December 2007.

17. The system of claim 13, wherein the decoder is further configured to

transform the received QAM signals into the other of the I1-I2 domain or the Q1-Q2 domain;

decode a another data bit by calculating a Euclidean distance from constellation points in the other of the I1-I2 domain or the Q1-Q2 domain; and

store the decoded another data bit.

FIG. 1

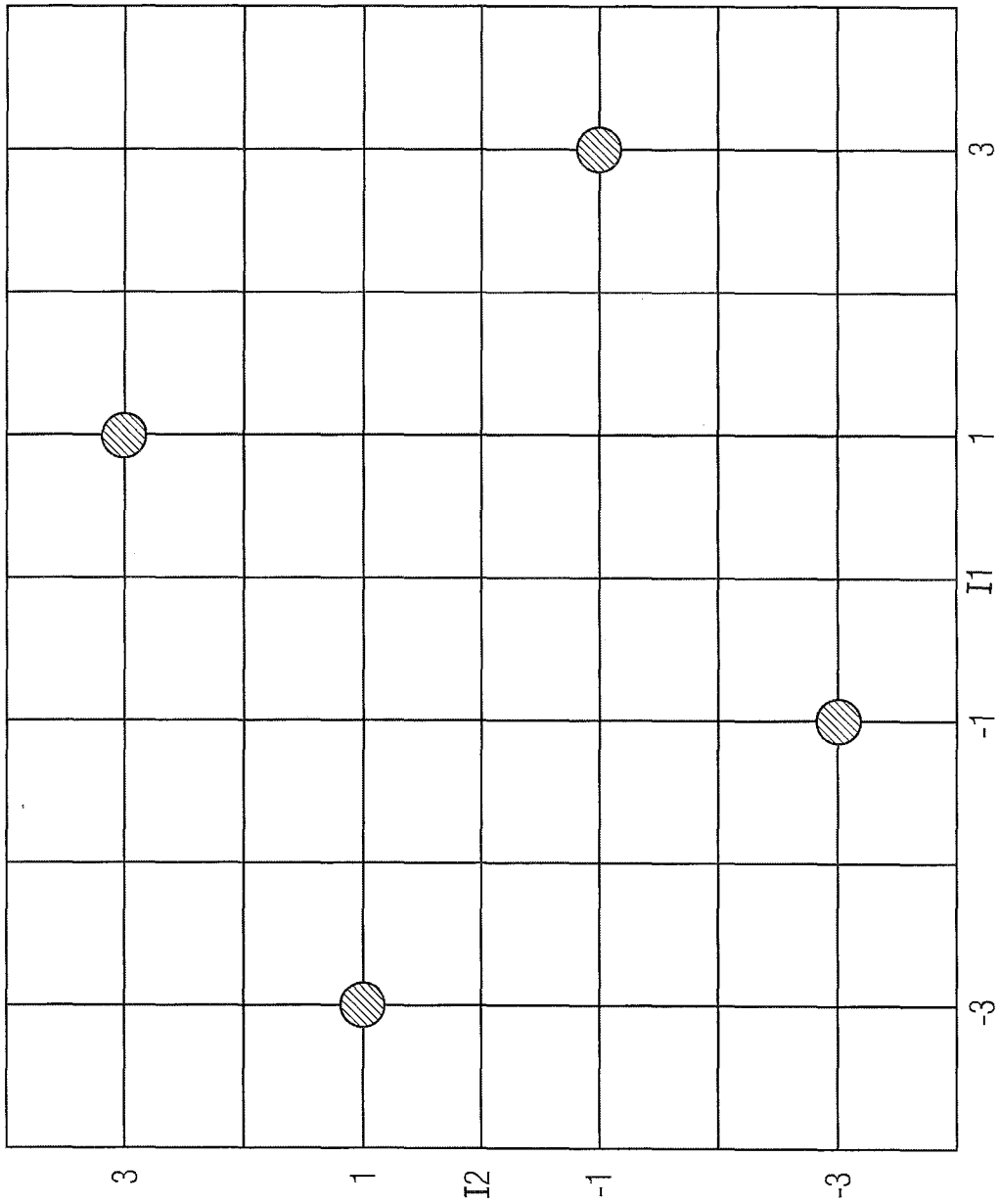
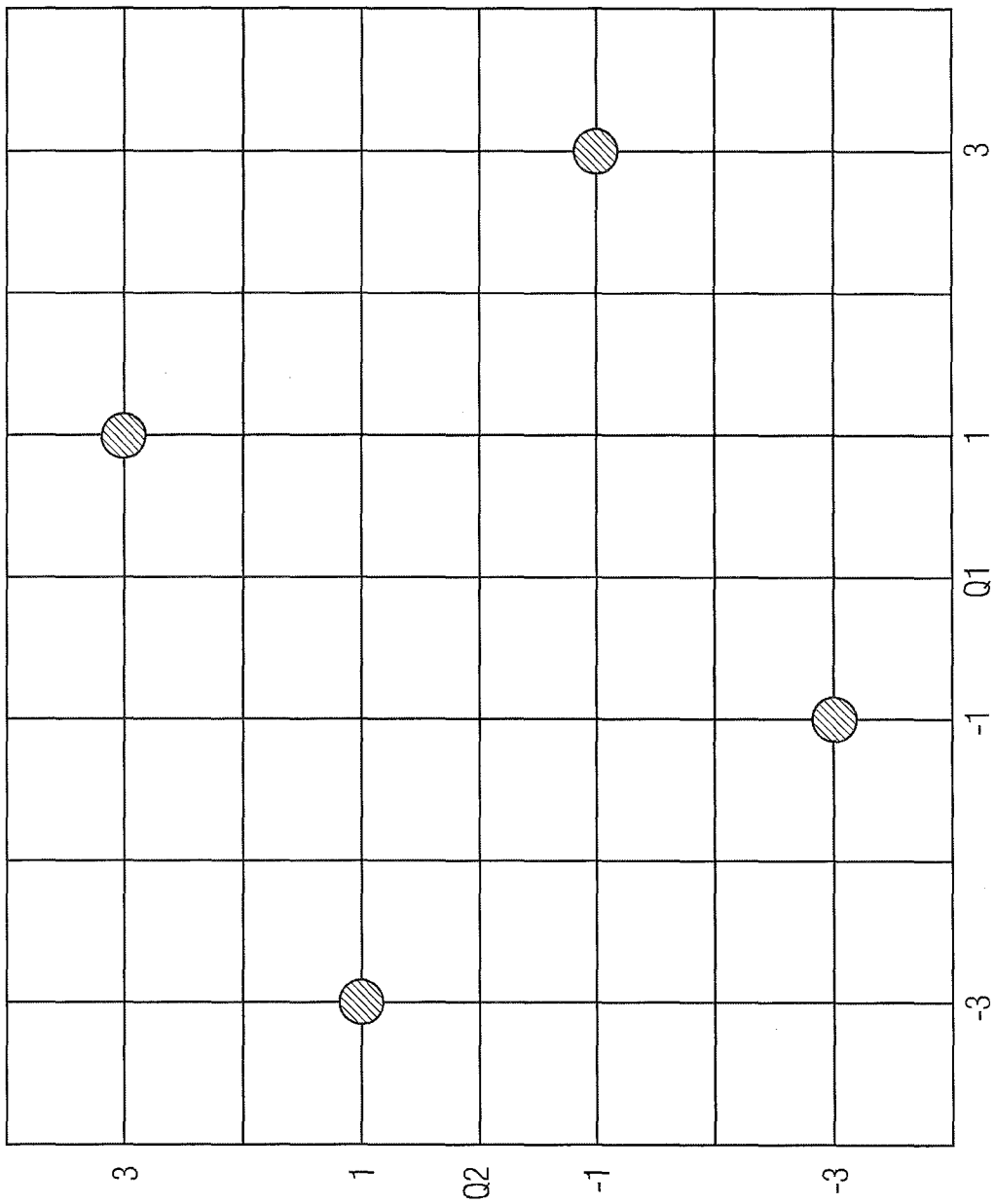


FIG. 2



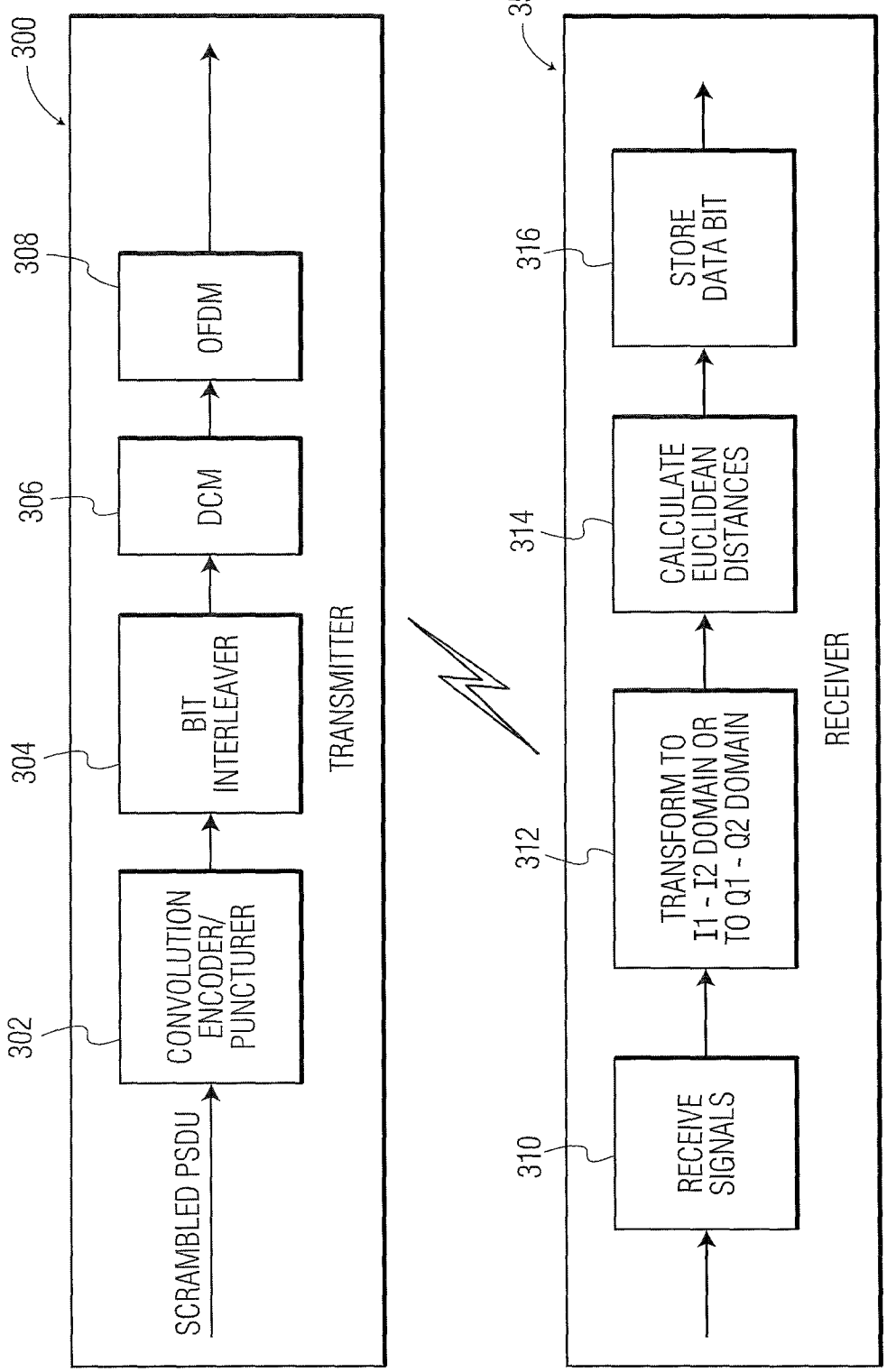

300
302
CONVOLUTION ENCODER/ PUNCTURER
304
BIT INTERLEAVER
306
DCM
308
OFDM
SCRAMBLED PSDU
TRANSMITTER
350
310
RECEIVE SIGNALS
312
TRANSFORM TO I1 - I2 DOMAIN OR TO Q1 - Q2 DOMAIN
314
CALCULATE EUCLIDEAN DISTANCES
316
STORE DATA BIT
RECEIVER

FIG. 3