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Method and apparatus for modulating UWB signals

Field of the invention

The present invention relates to method and apparatus for modulating ultra-wideband (UWB) signals, for example in a optical fibre or wireless UWB
5 communication system.

Background of Invention

It is well known to transmit data in pulses including a wide range of frequency components, known as UWB pulses. In such current communication systems
10 a plurality of users can share a signal channel (e.g. a wireless channel or optical fibre).

Conventionally, data is encoded in the signals in one of four ways. Fig. 1 illustrates four of these techniques, all of which transmit bits as respective
15 pulses. The pulses transmitted by a given user have a pulse duration of T_w , and in each of the techniques each user transmits one bit within each period of T_P , referred to as the pulse repetition period.

A first known modulation technique, known as pulse position modulation (PPM), is illustrated in Fig. 1(a). When a "1" is to be transmitted, the pulse 3 is
20 located within a period of duration τ at the beginning of the period T_P , and when a "0" is to be transmitted the pulse 3 is transmitted only after the period of duration τ has finished. The duration τ is the accuracy with which the system is able to resolve the time of the pulse, and is hence referred to as the
25 "resolution". It can be written as $\tau = \alpha T_w$, where α is referred to as the "relative factor".

A second known modulation technique, known as "bi-phase" modulation, is illustrated in Fig. 1(b). In this technique, when a "1" is to be transmitted, the pulse 3 is transmitted with a first polarity, and when a "0" is to be transmitted the pulse 3 is transmitted with the opposite polarity.

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A third known modulation technique, known as pulse amplitude modulation (PAM), is illustrated in Fig. 1(c). In this technique, when a "1" is to be transmitted, the pulse 3 is transmitted with a high amplitude, and when a "0" is to be transmitted the pulse 3 is transmitted with a low amplitude.

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A fourth known modulation technique, known as on-off keying modulation, is illustrated in Fig. 1(d). In this technique, when a "1" is to be transmitted, the pulse 3 is transmitted at the beginning of the period T_P , and when a "0" is to be transmitted no pulse is transmitted during the period T_P .

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The value of the pulse repetition rate limits the data transmission rate, even though the pulse width is very short. The data transmission rate of current single band UWB systems is up to a few hundred Mb/s, but it would be desirable to increase this value. One possibility would be to increase the pulse repetition rate, but this would degrade the capability of the transmission channel to support multi-user applications. Furthermore, a pulse generator with a fast pulse repetition rate (i.e. a low value of T_P) is expensive,

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Summary of the Invention

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The present invention aims to provide new and useful methods for UWB modulation, and in particular techniques which provide a higher data transmission rate, without sacrificing multi-user capability.

In general terms, the present invention proposes that the data modulation technique should provide a number of possible states in each pulse repetition period which is greater than two.

- 5 A first way in which this may be achieved is for more than one of the four known modulation techniques be used to modulate the pulses. Preferably all four of the known modulation techniques are used to modulate the pulses, but the invention is not limited in this respect.

According to one aspect of this invention, there is provided a method as defined in claim 1 of the appended claims.

- 10 A second way of providing a number of possible states in each pulse repetition period which is greater than two is for the data transmission to include pulse repetition periods in which a plurality of basic pulses are transmitted (i.e. that multiple copies of pulse are transmitted at different respective time positions within a single pulse repetition period).

- 15 According to a second aspect of this invention, there is provided a method as defined in claim 2.

These two ways of providing a number of possible states in each pulse repetition period which is greater than two may in principle be used separately, but more preferably are combined.

- 20 According to a third aspect of this invention, there is provided a UWB transmitter as defined in claim 4.

According to a fourth aspect of this invention, there is provided a UWB transmitter as defined in claim 5.

- 25 According to a fifth aspect of this invention, there is provided a receiver as defined in claim 7.

According to a sixth aspect of this invention, there is provided a receiver as defined in claim 8.

According to a seventh aspect of this invention, there is provided a method as defined in claim 11.

5 Brief Description of The Figures

Preferred features of the invention will now be described, for the sake of illustration only, with reference to the following figures in which:

Fig. 1, which is composed of Figs. 1(a) to 1(d), illustrates four known UWB pulse modulation techniques;

10 Fig. 2, which is composed of Figs. 2(a) to 2(c), illustrates modulation in a first embodiment of the invention, and systems for respectively generating and decoding this modulation;

Fig. 3, which is composed of Figs. 3(a) and 3(b), illustrates the channel capacity of the first embodiment of the invention, compared to two known techniques; and

Fig. 4, which is composed of Figs. 4(a) to 4(c), illustrates modulation in
 5 a second embodiment of the invention, and systems for respectively generating and decoding this modulation

Detailed Description of the embodiments

10 Referring firstly to Fig. 2, a modulation system which is an embodiment of the invention is shown. As in the known technique, pulses are transmitted with a basic period of T_P , which is the reciprocal of the pulse repetition rate. However, in contrast to the known technique, the pulse may be transmitted with any of a greater number of possible pulse states.

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Specifically, the pulse may be transmitted with: (i) any of b possible amplitudes, (ii) either of 2 possible polarities, (iii) at any of 2^n possible positions within the period T_P . The 2^n positions are spaced apart by time intervals τ . Furthermore, as in the on-off keying technique, it is possible for
 20 no pulse at all to be transmitted during the T_P period. Thus, the total number of possible pulse states is $b \cdot 2^{n+1} + 1$. Thus, the number of information bits which can be transmitted per pulse is $\log_2(b \cdot 2^{n+1} + 1)$.

This is illustrated in Fig. 2(a) which shows (in superposition) a number of the
 25 possible states. The first 2^n of these states are shown as having the amplitude b and being displaced from each other pairwise by the period τ . There are indeed 2^n of these states for each of the b possible amplitude values.

Furthermore, for each of these $b \cdot 2^n$ possible pulse states, there is another pulse state having opposite polarity. Thus, there are a total of $b \cdot 2^{n+1}$ possible

pulse states. This is in addition to the possibility that no pulse at all is transmitted during the period T_P .

The system for modulating the pulse is as shown in Fig. 2(b). A data stream input from the left of Fig. 2(b), and passes to a serial-to-parallel converter 11 (SPC). The SPC 11 is arranged to process its input in blocks, so that it receives $\log_2(b \cdot 2^{n+1} + 1)$ bits successively and uses them to simultaneously output respective bits on $\log_2(b \cdot 2^{n+1} + 1)$ lines. A mapping unit 13 receives the signals on these $\log_2(b \cdot 2^{n+1} + 1)$ lines, and uses them to select one of the $\log_2(b \cdot 2^{n+1} + 1)$ possible pulse states according to a predefined (but arbitrary) mapping between input strings and possible states. Depending on the selected state, the mapping unit 13 sends corresponding control signals to an inversion unit 15, a variable attenuator 17 and a variable delay unit 19. The system further includes a pulse clock 21, which provides a timing signal to a pulse generator unit 17. The output of the pulse generator unit 17 is transmitted successively to the inversion unit 15, the variable attenuator 17 and the variable delay unit 19, to produce a pulse which has the pulse state selected by the mapping unit.

The system for demodulating the signal is shown in Fig. 2(c). The received signal, which is input from the left of Fig. 2(c), is input to a synchronisation unit 31, to determine the clock timing. This is input to a pulse clock 33 which thereby becomes synchronised with the timing of the received signal. The output of the pulse clock 33 is transmitted to a pulse generation unit 35. The output of the pulse generation unit 35 is transmitted to a first line 37 which does not introduce a delay to it, and to each of $2^n - 1$ delay units 39, which respectively produce regularly spaced respective delays from τ up to $\tau \cdot (2^n - 1)$. The outputs from the line 37 and delay units 39 are transmitted to 2^n respective correlation units 41, which measure their correlation with the

received signal. The outputs of the correlation units 41 are transmitted to 2^n polarity detection units 42 which measure whether the correlation is positive or negative. The correlation is then transmitted to 2^n respective amplitude measurement units 43 which measure the amplitude of the correlation, and

5 classify it into one of the $b+1$ possible values (i.e. 0 or 1 to b). The results obtained by the polarity detection units 41 and amplitude measurement units 43 are transmitted to a demapping unit 45, which is able to use them to determine which of the $b \cdot 2^{n+1} + 1$ pulse types has been received, and which

10 decodes this result into the corresponding one of the $b \cdot 2^{n+1} + 1$ strings by the inverse of the mapping performed by the mapping unit 13. The result is transmitted to a parallel to serial signal converter unit 47, which converts this one result into $b \cdot 2^{n+1} + 1$ bit values and transmits those binary values successively towards the right of Fig. 2(c).

15 Fig. 3(a) is a comparison of the normalised channel capacity of the first embodiment of the invention for $b=1$ and over an ideal channel, against the value of α . The capacity of conventional PPM and bi-phase modulation are shown by the lines with corresponding labels, and the channel capacity of the first embodiment in the two cases $n=2$ and $n=4$ is shown as the lines 2 and 4

20 respectively. Note that the larger the value of n , the longer the time duration of the pulse modulation, so if n becomes large for a given value of α the pulse repetition rate may be reduced, and the channel capacity falls.

Fig. 3(b) is a comparison of the normalised channel capacity of the first

25 embodiment of the invention for $n=4$ and over an ideal channel, against the value of α . The capacity of conventional PPM and bi-phase modulation are shown by the lines with corresponding labels, and the channel capacity of the first embodiment in the two cases $b=2$ and $b=4$ is shown as the lines 6 and 8 respectively.

Note that in both Figs. 3(a) and 3(b) the channel capacity is higher than in the known techniques.

A second embodiment of the invention will now be discussed with reference to Fig. 4. In this embodiment the waveform transmitted in each time period T_P is more complex: a "mixed pulse", which is a superposition of one or more of the pulses transmitted in the first embodiment. These latter pulses referred to here as "basic pulses". All have the same fundamental shape, barring translations in time, and transformations of polarity and amplitude. As discussed below all of these basic pulses are formed from the same generated pulse, which is then modified, and in this sense the basic pulses are all "copies" of the generated pulse.

Thus, the information which is encoded in the mixed pulse is determined by:

- (1) the number of basic pulses of which the mixed pulse is a superposition;
- (2) the polarity of each of the basic pulses;
- (3) the position (in time) of each of the basic pulses; and
- (4) the amplitude of each of the basic pulses.

Fig. 4(a) illustrates the mixed pulse modulation. The state shown as "state 1" is a superposition of two basic pulses, as is the state shown as "state i". Comparing Fig. 4(a) with Fig. 2(a) it is clear that there are many more possible states in the second embodiment, which means that we can modulate much more information into each pulse repetition period.

Fig. 4(b) is a block diagram of a modulator which is capable of generating these pulses. As in Fig. 2(b), the system receives an input signal as a bit-stream from the left of the figure, and a serial-to-parallel converter 51 converts it to a parallel signal. The parallel signal is input to a mapping unit 53, which determines how many basic pulses should be generated, the positions of the

basic pulses, the polarities of the basic pulses and the amplitude values of the basic pulses.

The system includes a pulse clock 61, which provides a timing signal to a pulse generator unit 57. The output of the pulse generator unit is transmitted to a chain of $n - 1$ delay units 59 which each introduce a delay of τ . Having determined how many basic pulses there should be, and their positions, the mapping unit 53 closes corresponding ones of a set of switches 52, to thereby select these pulses for survival into the final mixed signal.

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The outputs of the switches 52 are transmitted to respective inversion units 55. Each inversion unit 55 includes an inverter 54 and a switch 56, which outputs (in the direction to the right of the figure) either the output of the respective switches 52 or the output of the inverter 54. The switch 56 is controlled by the mapping unit 53, which thereby controls whether the output of the switch 56 is the signal input from the corresponding switch 52, or an inverted version of it, i.e. the mapping unit 53 controls the polarity of the basic pulse.

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The outputs of the switches 56 are transmitted to respective amplifier units 57, which amplify the respective basic pulses to an amount determined by the mapping unit 53.

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The results are then combined by a combination unit 58, to generate a modulation output.

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There are many ways in which the mapping unit 53 could be selected to determine the relationship between sets of bits input to it and corresponding mixed signals generated.

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Suppose for example, that the system is limited to generating mixed pulses including only up to two basic pulses. Suppose also that there are two possible amplitude levels for each basic pulse, a_1 and a_2 . In this case, there are 25 possible mixed pulses (states), as shown in Table 1.

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Table 1: mixed pulse states and example mapping

States	Pulse copies (yes: 1; no:0)		Pulse polarities		Pulse amplitudes ($a_1:1; a_2:2$)		Example mapping (modulation)
	Pulse 1	Pulse 2	Pulse 1	Pulse 2	Pulse 1	Pulse 2	
0	0	0	*	*	*	*	0000
1	0	1	*	+	*	1	0001
2	0	1	*	+	*	2	0010
3	0	1	*	-	*	1	0011
4	0	1	*	-	*	2	0100
5	1	0	+	*	1	*	0101
6	1	0	+	*	2	*	0110
7	1	0	-	*	1	*	0111
8	1	0	-	*	2	*	B
9	1	1	+	+	1	1	B
10	1	1	+	+	1	2	B
11	1	1	+	+	2	1	B
12	1	1	+	+	2	2	B
13	1	1	+	-	1	1	1000
14	1	1	+	-	1	2	1001
15	1	1	+	-	2	1	1010
16	1	1	+	-	2	2	1011
17	1	1	-	+	1	1	1100
18	1	1	-	+	1	2	1101
19	1	1	-	+	2	1	1110
20	1	1	-	+	2	2	1111
21	1	1	-	-	1	1	B
22	1	1	-	-	1	2	B
23	1	1	-	-	2	1	B
24	1	1	-	-	2	2	B

*: not available

10 The left column labels these 25 states (by the values 0 to 24), and the next six columns indicate which state this corresponds to. Specifically, the second and third columns respectively indicate, by a 0 or a 1, whether the corresponding state includes a corresponding one of the two basic pulses. The fourth and fifth columns indicate the respective polarities of the two basic pulses. The

sixth and seventh columns indicate the respective amplitudes of the two basic pulses. In this table, the symbol * indicates a meaningless possibility (e.g. for state 0, for which neither of the basic pulses is transmitted, it is meaningless to talk about the polarities or amplitudes of those pulses).

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The eighth column of the table (i.e. the column on the right) indicates the mapping applied to the mapping unit 53 between these states and the possible bit patterns input to it from the serial-to-parallel converter 51. In other words, for each of the states, the eighth column of the table indicates which
 10 bit pattern would cause that state to be generated. The association of these states with bit patterns is determined by the mapping unit 53, but is completely arbitrary. As shown in Table 1, the mapping unit may not associate some states with any bit patterns, and these states are shown by the symbol "o". This means that, irrespective of what bit patterns are input the mapping
 15 unit 53, these states will never be generated. This reduces the efficiency of the unit, but as shown in Table 1 the mixed signal is still capable of generating different states for each respective different sets of 4 input bits. Thus, a single mixed pulse carries 4 bits during one pulse-repetition period.

20 By contrast, if the system is a "single pulse" system which is only allowed to generate at most one basic pulse (i.e. it is as in Fig. 2(b)), but this one pulse may take either of two positions, two amplitudes and two polarities, then this corresponds to states 0 to 7 shown in Table 1. Therefore, the system is only able to transmit 3 bits during one pulse repetition period.

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Note that the coding system of Fig. 4(b) could be made even more efficient if respective bit strings were associated with all of the possible states, so that it would be possible for the system to transmit more than 4 bits of information in each mixed pulse. However, since the number of states is not as high as the
 30 number of possible values taken by 5 bits (i.e. 32) this would mean that the

system would have to be modified so that a given pulse repetition period would no longer be associated with a part of the input bit string always having the same number of bits.

5 Turning to Fig. 4(c), a system for demodulating this signal is shown. It is very similar to the system of Fig. 2(c), and accordingly corresponding units are labelled by reference numerals higher by 40. The received signal, which is input from the left of Fig. 4(c), is input to a synchronisation unit 71, to determine the clock timing. This is input to a pulse clock 73 which thereby
 10 becomes synchronised with the timing of the received signal. The output of the pulse clock 73 is transmitted to a pulse generation unit 75. The output of the pulse generation unit 75 is transmitted to a first line 77 which does not introduce a delay to it, and to each of $2^n - 1$ delay units 79, which produce regularly spaced respective delays from τ up to $\tau \cdot (2^n - 1)$. The output from
 15 the line 77 and delay units 79 are transmitted to 2^n respective correlation units 81, which measure their correlation with the received signal.

In principle, it would be possible for the outputs of the correlation units 81 to be decoded exactly by polarity and amplitude detection units corresponding
 20 exactly to those of Fig. 2(c). However, in the system of Fig. 4(c), since the number of possible states is much higher, it is preferred that the decoding is performed by a standard "maximum likelihood" or "Viterbi" decoder unit 72, which directly determines which of the possible input signals to the system of Fig. 4(b) is most likely to have produced the mixed pulse input to the left of
 25 Fig. 4(c).

The result is transmitted to a parallel to serial signal converter unit 77, which converts this one result into a serial bit stream and transmits that bit stream successively towards the right of Fig. 4(c).

Thus, each of the embodiments provides a new coding scheme which can be used in wired or wireless UWB transmitters/receivers to improve the data transmission rate, without requiring a correspondingly increased pulse repetition rate. Thus, the embodiments provide a higher channel capacity than
 5 in known techniques.

References

The disclosure of the following references is incorporated herein in its entirety:

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14. App. No US 2003/0036374A1: Wireless local area network using impulse radio technology to improve communications between mobile nodes
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15. App. No US 2002/0018514A1: Method and system for fast acquisition of pulsed signals.
16. App. No US 2002/006080A1: Method and system for reducing potential interference in an impulse radio.
- 15 17. App. No US 2002/0176511A1: High pulse-rate radio-frequency apparatus and associated methods.
18. App. No US 20020168003A1: System and method of communicating high rate pulse signals in a multipath environment.
19. App. No US 20020143666A1: Package data tracking system and
20 method utilizing impulse radio communications.
20. US patent 5,802,104: Method and apparatus for vector modulation in a communication system.
21. US patent 4,843,351: Vector modulation signal generator.

22. US patent 6,529,568: Method and system for canceling interference in an impulse radio.

Claims

1. A method of transmitting data comprising, during each of number of
5 pulse repetition periods, transmitting a respective UWB pulse waveform which
is selected from a number of possible UWB pulse waveforms, the set of
possible UWB pulse waveforms including pairs of pulse waveforms which differ
from each other in the polarity of the pulse waveforms and one or more of the
following respects:
- 10 (i) the amplitude of the pulse waveforms;
(ii) the position in time of the pulse waveforms within the pulse repetition
period; and
(iii) the absence or presence of the pulse waveforms.
- 15 2. A method of transmitting data comprising, during each of number of
pulse repetition periods, generating and transmitting a respective UWB pulse
waveform which is selected from a number of possible UWB pulse waveforms,
the possible UWB pulse waveforms including waveforms which are a
superposition of two or more basic UWB pulses at different respective positions
20 in time within the pulse repetition period.
3. A method according to claim 2 in which the set of possible UWB pulse
waveforms includes pairs of pulse waveforms which differ from each other in
two or more of the following respects:
- 25 (1) the number of basic pulses;
(2) the polarity of the basic pulses;
(3) the position in time of each of the basic pulses; and
(4) the amplitude of each of the basic pulses.
- 30 4. A UWB transmitter comprising:

means for generating a UWB pulse during each of a number of pulse repetition periods,

a pulse modification unit arranged to receive the UWB pulse and to modify it; and

- 5 mapping means for controlling the pulse modification unit according to data to be transmitted, the mapping means controlling the pulse modification units according to a predefined mapping between data and the respective possible modifications;

10 the pulse modification unit being arranged to modify the UWB pulse in two or more of the following respects:

- (i) the amplitude of the pulse;
- (ii) the position in time of the pulse within the pulse repetition period;
- (iii) the polarity of the pulse; and
- (iv) the absence or presence of the pulse.

- 15 5. A UWB transmitter comprising:

means for generating a UWB pulse during each of a number of pulse repetition periods,

a pulse modification unit arranged to receive the UWB pulse and to modify it;

- 20 mapping means for controlling the pulse modification unit according to data to be transmitted, the mapping means controlling the pulse modification units according to a predefined mapping between data and the respective possible modifications;

the pulse modification unit being arranged to modify the UWB pulse to include two or more copies of the received UWB pulse.

6. A transmitter according to claim 5 in which the pulse modification unit is further arranged to modify the UWB pulse in two or more of the following
5 respects:

- (1) the number of copies;
- (2) the polarity of the copies;
- (3) the position in time of each of the copies; and
- (4) the amplitude of each of the basic copies.

10 7. A receiver for receiving and decoding a UWB signal, the receiving comprising a receiving unit for receiving during each of number of pulse repetition periods one of a set of possible UWB pulse waveforms, and decoding means for determining which of set of UWB pulse waveforms was received during each pulse repetition period,

15 the set of possible UWB pulse waveforms including pairs of pulse waveforms which differ from each other in two or more of the following respects:

- (i) the amplitude of the pulse waveforms;
- (ii) the position in time of the pulse waveforms within the pulse
20 repetition period;
- (iii) the polarity of the pulse waveforms; and
- (iv) the absence or presence of the pulse waveforms.

8. A receiver for receiving and decoding a UWB signal, the receiving comprising a receiving unit for receiving during each of number of pulse
25 repetition periods one of a set of possible UWB pulse waveforms, and

decoding means for determining which of set of UWB pulse waveforms was received during each pulse repetition period,

the set of possible UWB pulse waveforms including waveforms which are a superposition of two or more basic UWB pulses at different respective
5 positions in time within the pulse repetition period.

9. A receiver according to claim 8 in which the set of possible UWB pulse waveforms including pairs of pulse waveforms which differ from each other in two or more of the following respects:

- (1) the number of basic pulses;
- 10 (2) the polarity of the basic pulses;
- (3) the position in time of each of the basic pulses; and
- (4) the amplitude of each of the basic pulses.

10. A receiver according to any of claims 7 to 9 in which the decoder means includes a maximum likelihood estimation unit for determining which of
15 the set of possible UWB pulse waveforms was most likely to have generated the received UWB signal.

11. A method of transmitting data comprising, during each of number of pulse repetition periods, generating and transmitting a respective UWB pulse which is selected from a number of possible UWB pulses which is greater
20 than two.