802.15.4c™

IEEE Standard for
Information technology—
Telecommunications and information exchange between systems—
Local and metropolitan area networks—
Specific requirements

Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs)

Amendment 2: Alternative Physical Layer Extension to support one or more of the Chinese 314–316 MHz, 430–434 MHz, and 779–787 MHz bands

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

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17 April 2009

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(Amendment to
IEEE Std 802.15.4™-2006)

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IEEE-SA Standards Board

Abstract: This amendment defines alternate PHY and modifications to the MAC needed to support the PHY that complies with the applicable Chinese regulations, Radio Management of P. R. of China doc. # 6326360786867187500 or current document, for one or more of the 314–316 MHz, 430–434 MHz, and 779–787 MHz frequency bands.

Keywords: ad hoc network, low data rate, low power, LR-WPAN, mobility, PAN, personal area network, radio frequency, RF, short range, wireless, wireless personal area network, WPAN

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Introduction

This introduction is not part of IEEE Std 802.15.4c-2009, IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 15.4: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANS)—Amendment 2: Alternative Physical Layer Extension to support one or more of the Chinese 314–316 MHz, 430–434 MHz, and 779–787 MHz bands.

This amendment specifies alternate PHYs in addition to those of the IEEE Std 802.15.4-2006 and IEEE Std 802.15.4a™-2007. These alternate PHYs are specified for the Chinese 780 MHz band.

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EDITORIAL NOTE—The editing instructions contained in this amendment define how to merge the material contained therein into the existing base standard and its amendments to form the comprehensive standard.

The editing instructions are shown in ***bold italic***. Four editing instructions are used: change, delete, insert, and replace. ***Change*** is used to make corrections in existing text or tables. The editing instruction specifies the location of the change and describes what is being changed by using ~~strikethrough~~ (to remove old material) and <u>underscore </u>(to add new material). ***Delete*** removes existing material. ***Insert*** adds new material without disturbing the existing material. Insertions may require renumbering. If so, renumbering instructions are given in the editing instruction. ***Replace*** is used to make changes in figures or equations by removing the existing figure or equation and replacing it with a new one. Editorial notes will not be carried over into future editions because the changes will be incorporated into the base standard

2. Normative references

Insert the following new normative reference alphabetically into Clause 2:

NITS/CWPAN Part 15.4, Chinese standard for the Wireless Medium Access Control (MAC) and the Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (Task number: 20070007-T-469), version D2, Clause 6.5.2.

4. Acronyms and abbreviations

Insert the following abbreviations alphabetically into Clause 4:

CWPAN	Chinese Wireless Personal Area Network
MPSK	M-ary Phase Shift Keying

5. General description

5.1 Introduction

Change the following item in the dashed list of 5.1 as follows:

— 16 channels in the 2450 MHz band, 30 channels in the 915 MHz band, 3 channels in the 868 MHz band, 14 overlapping chirp spread spectrum (CSS) channels in the 2450 MHz band, ~~and~~ 16 channels in three UWB bands (500 MHz and 3.1 GHz to 10.6 GHz), and 8 channels in the 780 MHz band.

5.4 Architecture

5.4.1 Physical layer (PHY)

Insert a new dashed list item at the end of the third paragraph dashed list in 5.4.1 as follows:

— 779–787 MHz (People's Republic of China)

6. PHY specification

6.1 General requirements and definitions

Insert the following paragraph at the end of 6.1:

In further additions to the rates supported in IEEE Std 802.15.4-2006 and IEEE Std 802.15.4a-2007, two additional PHYs have been added. They are MPSK and O-QPSK PHYs operating in the Chinese 780 MHz band. The MPSK PHY is defined by NITS/CWPAN Part 15.4, Chinese standard for the Wireless Medium Access Control (MAC) and the Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (Task number: 20070007-T-469), which is included as a normative reference in Clause 2. An informative translation of the MPSK PHY specification as it relates to this standard is included in Annex J.

6.1.1 Operating frequency range

Change Table 1 (the entire table is not shown) as indicated:

Table 1—Frequency bands and data rates

PHY (MHz)	Frequency band (MHz)	Spreading parameters		Data parameters		
		Chip rate (kchip/s)	Modulation	Bit rate (kb/s)	Symbol rate (ksymbol/s)	Symbols
780	779–787	1000	O-QPSK	250	62.5	16-ary Orthogonal
780	779–787	1000	MPSK	250	62.5	16-ary Orthogonal
868/915	868–868.6	300	BPSK	20	20	Binary
	902–928	600	BPSK	40	40	Binary

Change the third paragraph in 6.1.1 as shown:

This standard is intended to conform with established regulations in Europe, Japan, Canada, China, and the United States. The regulatory documents listed below are for information only and are subject to change and revisions at any time. ~~IEEE 802.15.4 and IEEE 802.15.4a d~~Devices conforming to this standard shall also comply with specific regional legislation. Additional regulatory information is provided in Annex F.

Insert the following new list at the end of the current lists in 6.1.1:

China:

— Approval standards: The Radio Management Bureau of the Chinese Information Department, China-Document: Doc. # 6326360786867187500

6.1.2 Channel assignments

Insert the following new subclause after 6.1.2.1b:

6.1.2.1c Channel numbering for 779–787 MHz band

For channel page 5, eight channels numbered 0 to 7 are available across 780 MHz band. The center frequency of these channels is defined as follows:

$$F_c = 780 + 2\,k \text{ in megahertz, for } k = 0, \ldots, 3$$

$$F_c = 780 + 2\,(k - 4) \text{ in megahertz, for } k = 4, \ldots, 7$$

where k is the channel number.

6.1.2.2 Channel pages

Change the first sentence of 6.1.2.2 as indicated:

A total of 32 channel pages are available ~~with channel pages 3 to 31 being reserved for future use~~.

Change Table 2 (the entire table is not shown) as indicated:.

Table 2—Channel page and channel number

Channel page (decimal)	Channel page (binary) (b31,b30,b29,b28,b27)	Channel number(s) (decimal)	Channel number description
5	0 0 1 0 1	0–3	Channels 0 to 3 are in 780 MHz band using O-QPSK
		4–7	Channels 4 to 7 are in the 780 MHz band using MPSK
~~3~~6–31	0 0 1 1 0–1 1 1 1 1	Reserved	Reserved

6.1.3 Minimum LIFS and SIFS periods

Change Table 3 (the entire table is not shown) as indicated:

Table 3—Minimum LIFS and SIFS period

PHY	*macMinLIFSPeriod*	*macMinSIFSPeriod*	Units
779–787 MHz O-QPSK	40	12	Symbols
779–787 MHz MPSK	40	12	Symbols
868–868.6 MHz BPSK	40	12	Symbols

6.3 PPDU format

6.3.1 Preamble field

Change Table 19 (the entire table is not shown) as indicated:.

Table 19—Preamble field length

PHY	Length		Duration (uS)
<u>779–787 MHz O-QPSK</u>	<u>4 octets</u>	<u>8 symbols</u>	<u>128</u>
<u>779–787 MHz MPSK</u>	<u>4 octets</u>	<u>8 symbols</u>	<u>128</u>
868–868.6 MHz BPSK	4 octets	32 symbols	1600

6.3.2 SFD field

Change Table 20 (the entire table is not shown) as indicated:.

Table 20—SFD field length (except for ASK, CSS, and UWB PHYs)

PHY	Length	
<u>779–787 MHz O-QPSK</u>	<u>1 octet</u>	<u>2 symbols</u>
<u>779–787 MHz MPSK</u>	<u>1 octet</u>	<u>2 symbols</u>
868–868.6 MHz BPSK	1 octet	8 symbols

6.6 868/915 MHz band binary phase-shift keying (BPSK) PHY specifications

Insert after 6.6.3.5 the following new subclauses (6.6a through 6.6a.3.5):

6.6a 780 MHz band (optional) O-QPSK PHY specifications

6.6a.1 780 MHz band data rates

The data rate of the O-QPSK PHY shall be 250 kb/s when operating in the 780 MHz band.

6.6a.2 Modulation and spreading

The O-QPSK PHY employs a 16-ary quasi-orthogonal modulation technique. During each data symbol period, four information bits are used to select one of 16 nearly orthogonal PN sequences to be transmitted. The PN sequences for successive data symbols are concatenated, and the aggregate chip sequence is modulated onto the carrier using O-QPSK.

6.6a.2.1 Reference modulator diagram

The functional block diagram in Figure 21a is provided as a reference for specifying the 780 MHz band PHY modulation and spreading functions. The number in each block refers to the subclause that describes that function. Each bit in the PPDU shall be processed through the bit-to-symbol mapping, symbol-to-chip mapping, and modulation functions in octet-wise order, beginning with the Preamble field and ending with the last octet of the PSDU. Within each octet, the LSB, b_0, is processed first and the MSB, b_7, is processed last.

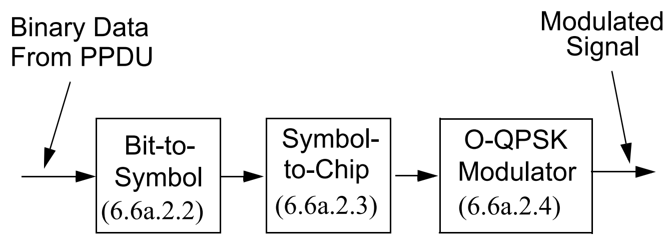

Figure 21a—Modulation and spreading functions

6.6a.2.2 Bit-to-symbol mapping

All binary data contained in the PPDU shall be encoded using the modulation and spreading functions shown in Figure 21a. This subclause describes how binary information is mapped into data symbols.

The 4 LSBs (b_0, b_1, b_2, b_3) of each octet shall map into one data symbol, and the 4 MSBs (b_4, b_5, b_6, b_7) of each octet shall map into the next data symbol. Each octet of the PPDU is processed through the modulation and spreading functions (see Figure 21a) sequentially, beginning with the Preamble field and ending with the last octet of the PSDU. Within each octet, the least significant symbol (b_0, b_1, b_2, b_3) is processed first, and the most significant symbol (b_4, b_5, b_6, b_7) is processed second.

6.6a.2.3 Symbol-to-chip mapping

Each data symbol shall be mapped into a 16-chip PN sequence as specified in Table 29a.

Table 29a—Symbol-to-chip mapping for O-QPSK

Data symbol (decimal)	Data symbol (binary) (b_0 b_1 b_2 b_3)	Chip values (c_0 c_1 … c_{14} c_{15})
0	0 0 0 0	0 0 1 1 1 1 1 0 0 0 1 0 0 1 0 1
1	1 0 0 0	0 1 0 0 1 1 1 1 1 0 0 0 1 0 0 1
2	0 1 0 0	0 1 0 1 0 0 1 1 1 1 1 0 0 0 1 0
3	1 1 0 0	1 0 0 1 0 1 0 0 1 1 1 1 1 0 0 0
4	0 0 1 0	0 0 1 0 0 1 0 1 0 0 1 1 1 1 1 0
5	1 0 1 0	1 0 0 0 1 0 0 1 0 1 0 0 1 1 1 1
6	0 1 1 0	1 1 1 0 0 0 1 0 0 1 0 1 0 0 1 1
7	1 1 1 0	1 1 1 1 1 0 0 0 1 0 0 1 0 1 0 0
8	0 0 0 1	0 1 1 0 1 0 1 1 0 1 1 1 0 0 0 0
9	1 0 0 1	0 0 0 1 1 0 1 0 1 1 0 1 1 1 0 0
10	0 1 0 1	0 0 0 0 0 1 1 0 1 0 1 1 0 1 1 1

Table 29a—Symbol-to-chip mapping for O-QPSK *(continued)*

Data symbol (decimal)	Data symbol (binary) (b_0 b_1 b_2 b_3)	Chip values (c_0 c_1 … c_{14} c_{15})
11	1 1 0 1	1 1 0 0 0 0 0 0 1 1 0 1 0 1 1 0 1
12	0 0 1 1	0 1 1 1 0 0 0 0 0 0 1 1 0 1 0 1 1
13	1 0 1 1	1 1 0 1 1 1 0 0 0 0 0 0 1 1 0 1 0
14	0 1 1 1	1 0 1 1 0 1 1 1 0 0 0 0 0 0 1 1 0
15	1 1 1 1	1 0 1 0 1 1 0 1 1 1 0 0 0 0 0 0 1

6.6a.2.4 O-QPSK modulation

The chip sequences representing each data symbol are modulated onto the carrier using O-QPSK with raised cosine pulse shaping. Even-indexed chips are modulated onto the in-phase (I) carrier and odd-indexed chips are modulated onto the quadrature-phase (Q) carrier. Because each data symbol is represented by a 16-chip sequence, the chip rate is 16 times the symbol rate. To form the offset between I-phase and Q-phase chip modulation, the Q-phase chips shall be delayed by T_c with respect to the I-phase chips (see Figure 21b), where T_c is the inverse of the chip rate.

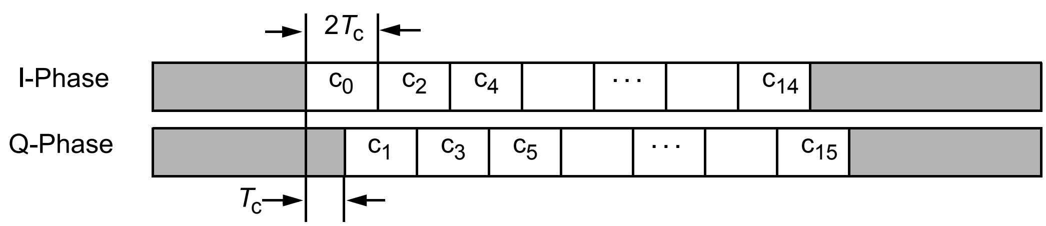

Figure 21b—O-QPSK chip offsets

6.6a.2.5 Pulse shape

The raised cosine pulse shape with roll-off factor of $r = 0.8$ is used to represent each baseband chip and is described by Equation (4a).

$$p(t) = \begin{cases} \dfrac{\sin(\pi t/T_c)}{\pi t/T_c} \times \dfrac{\cos(r\pi t/T_c)}{1 - 4r^2t^2/T_c^2}, & t \neq 0 \\ 1, & t = 0 \end{cases} \tag{4a}$$

Given the discrete-time sequence $\{c_k\}_{k=-\infty}^{\infty}$ of consecutive real-valued chip samples, the continuous-time pulse shaped complex baseband signal is given by Equation (4b).

$$y(t) = \sum_{k=-\infty}^{\infty} c_{2k}p(t - 2kT_c) + jc_{2k+1}p(t - 2kT_c - T_c) \tag{4b}$$

6.6a.2.6 Chip transmission order

During each symbol period, the least significant chip, c_0, is transmitted first, and the most significant chip, c_{15}, is transmitted last.

6.6a.3 780 MHz band radio specification

6.6a.3.1 Operating frequency range

The 780 MHz O-QPSK PHY operates in the 779–787 MHz frequency band.

6.6a.3.2 Transmit PSD mask

When operating in the 780 MHz band, the transmitted spectral products shall be less than the limits specified in Table 29b. For both relative and absolute limits, average spectral power shall be measured using a 100 kHz resolution bandwidth. For the relative limit, the reference level shall be the highest average spectral power measured within ± 600 kHz of the carrier frequency f_c.

Table 29b—780 MHz band O-QPSK PHY transmit PSD limits

Frequency	Relative limit	Absolute limit
$\|f - f_c\| > 1.2$ MHz	–20 dB	–20 dBm

6.6a.3.3 Symbol rate

The O-QPSK PHY symbol rate shall be 62.5 ksymbol/s when operating in the 780 MHz band with an accuracy of ± 40 ppm.

6.6a.3.4 Receiver sensitivity

Under the conditions specified in 6.1.7, a compliant device shall be capable of achieving a sensitivity of –85 dBm or better.

6.6a.3.5 Receiver jamming resistance

The minimum jamming resistance levels are given in Table 29c. The adjacent channel is one on either side of the desired channel that is closest in frequency to the desired channel, and the alternate channel is one more removed from the adjacent channel. For example, when channel 2 is the desired channel, channel 1 and channel 3 are the adjacent channels, and channel 0 is the alternate channel.

Table 29c—Minimum receiver jamming resistance requirements for 780 MHz O-QPSK PHY

Adjacent channel rejection	Alternate channel rejection
0 dB	30 dB

The adjacent channel rejection shall be measured as follows: the desired signal shall be a compliant 780 MHz IEEE 802.15.4 O-QPSK PHY signal, as defined by 6.6a.2, of pseudo-random data. The desired signal is input to the receiver at a level 3 dB above the maximum allowed receiver sensitivity given in 6.6a.3.4.

In either the adjacent or the alternate channel, a compliant signal, as defined by 6.6a.2, is input at the relative level specified in Table 29c. The test shall be performed for only one interfering signal at a time. The receiver shall meet the error rate criteria defined in 6.1.7 under these conditions.

Change the text in 6.9 as shown (based on IEEE Std 802.15.4a text):

6.9 General radio specifications

The specifications in 6.9.1 through 6.9.9 apply to the 2450 MHz DS PHY described in 6.5.1 through 6.5.3, the CSS PHY described in 6.5a, the UWB PHY described in 6.8a, ~~and~~ the 868/915 MHz PHYs described in 6.6 through 6.8, and the 780 MHz PHYs described in 6.6a and Clause 2 and, with the exception of 6.9.3 and 6.9.5, apply to all PHY implementations including the alternate PHYs. The specification of 6.9.3 does not apply to the CSS PHY nor the UWB PHY. The specification of 6.9.5 does not apply to the UWB PHY.

Annex D

(normative)

Protocol implementation conformance statement (PICS) proforma[1]

D.1 Introduction

D.1.2 Scope

Change the text of D.1.1 as shown:

This annex provides the PICS proforma for IEEE Std 802.15.4~~-2006 and IEEE Std 802.15.4a amendment~~ in compliance with the relevant requirements, and in accordance with the relevant guidance, given in ISO/IEC 9646-7:1995.

D.1.2 Purpose

Change the first paragraph of D.1.2 as shown:

The supplier of a protocol implementation claiming to conform to IEEE Std 802.15.4~~-2006 and IEEE Std 802.15.4a amendment~~ shall complete the following PICS proforma and accompany it with the information necessary to identify fully both the supplier and the implementation.

D.5 Identification of the protocol

Change the text of D.5 as shown:

This PICS proforma applies to IEEE Std 802.15.4~~-2006 and IEEE Std 802.15.4a amendment~~.

D.7 PICS proforma tables

Change the third sentence in D.7 as shown:

The first subclause contains the major roles for a device compliant with IEEE 802.15.4~~-2006 and IEEE 802.15.4a amendment~~.

[1]*Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this annex so that it can be used for its intended purpose and may further publish the completed PICS.

D.7.2 Major capabilities for the PHY

D.7.2.3 Radio frequency (RF)

Insert after the RF4.3 row the following new rows in Table D.4 and add a new note entry to the final row (the entire table is not shown):

Table D.4—Radio frequency (RF)

Item number	Item description	Reference	Status	Support		
				N/A	Yes	No
RF5	780 MHz band PHYs	5.4.1, Clause 6, Table 1	O.3			
RF5.1	Offset quadrature phase-shift keying (O-QPSK) PHY	6.6a	O.6			
RF5.2	M-ary phase-shift keying (MPSK) PHY	Clause 2	O.6			
O.3 At least one of these features shall be supported. O.5 At least one of these features shall be supported. O.6 At least one of these features shall be supported.						

Annex E

(informative)

Coexistence with other IEEE standards and proposed standards

E.1 Introduction

Insert the following new paragraph at the end of E.1:

This is the first IEEE 802® standard defining use of the 780 MHz band (779 MHz to 787 MHz) in China and as such coexistence is not a practical issue at this time. However, the two PHYs specified for use in the 780 MHz band use the exact same channel plan; hence they can potentially cause interference to each other. Due to the short duration (burst nature) of IEEE 802.15.4 packets and use of CSMA-CA, coexistence is not considered to be a problem for the two PHYs when they share a common channel. Similar examples of this are shown in E.5.

Annex F

(informative)

Regulatory requirements

F.2 IEEE 802.15.4a UWB

F.2.4.3 Technical requirements on radio equipment

Insert the following new subclause after F.2.4.3:

F.3 Applicable Chinese rules

Operation in the 779–787 MHz band in China is defined by the Radio Management of P. R. of China in the Technical Requirements for Micropower (Short Distance) Radio Equipment (Doc. # 6326360786867187500). The original document and any version superseding it should be used for a final disposition on the rules. An English translation of the applicable sections are covered in this clause in order to give the reader a familiarity with the regulations governing the use of the 779–787 MHz band in China.

F.3.1 Category F equipment

Category F equipment refers to other short distance radio equipment rather than digital cordless telephone, Bluetooth®[2] equipment and wireless LAN equipment, working at the range of 2400–2483.5 MHz.

a) Working frequency: 2400–2483.50 MHz
b) Transmitting power limit: 10 mW (EIRP)
c) Frequency tolerance: 75 kHz

F.3.2 Radio control devices for all kinds of civil equipment

Radio controlled devices are prohibited for use for toys and models, but can be used for civilian equipment for the following working frequencies:

a) Working frequency: 314–316 MHz, 430–432 MHz, and 433.00–434.79 MHz
   Transmitting power limit: 10 mW (EIRP)
   Occupied bandwidth: no greater than 400 kHz

b) Working frequency: 779–787 MHz
   Transmitting power limit: 10 mW (EIRP)
   No occupied bandwidth requirement

[2]The *Bluetooth* word mark, figure mark, and combination mark are all trademarks that are owned by the Bluetooth SIG.

F.3.3 General requirements

This subclause outlines spurious radiation emission limits (the demarcation between spurious radiation and out of band radiation is the carrier frequency ±2.5 multiples of carrier frequency). (See Table F.17.)

Table F.17—Spurious radiation emission measurement frequency range

Working frequency range	Spurious radiation emission measurement frequency range:	
	Lower limit	Upper limit
600 MHz–2.5 GHz	30 MHz	12.75 GHz

Table F.18—Transmitter in transmission state at the maximum power

Frequency range	Test bandwidth	Limit	Detection method
30 MHz–1 GHz	100 kHz (3 dB)	–36 dBm	Effective value
1 GHz–40 GHz	1 MHz (3 dB)	–30 dBm	Effective value

Table F.19—Transmitter in standby or idle state

Frequency range	Test bandwidth	Limit	Detection method
30 MHz–1 GHz	100 kHz (3 dB)	–47 dBm	Effective value
>1 GHz	1 MHz (3 dB)		

NOTE—Magnetic field test is performed at open area and radiation power test is performed at full anechoic chamber. For the equipment the working frequency of which is below 30 MHz, the emission state can be set to single frequency (SF) emission.[3]

For the frequency bands above 30 MHz, the radiation power at the upper/lower limits of the specified working frequency is no more than –80 dBm/Hz (EIRP).

[3]Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

Annex J

(informative)

MPSK PHY requirements

The following is an informative translation of the MPSK PHY, which is one of the co-alternative PHYs in the CWPAN specification. Another co-alternative PHY in the CWPAN specification is the O-QPSK PHY specified in 6.6a. The CWPAN specification is NITS/CWPAN Part 15.4, Chinese standard for the Wireless Medium Access Control (MAC) and the Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (Task number: 20070007-T-469).

J.1 780 MHz band data rates

The data rate of the MPSK PHY is 250 kb/s when operating in the 780 MHz band.

J.2 Modulation and spreading

The MPSK PHY employs a 16-ary orthogonal modulation technique. During each data symbol period, four information bits are used to select one of 16 orthogonal PN sequences to be transmitted. The PN sequences for successive data symbols are concatenated, and the aggregate chip phase is modulated onto the carrier using PSK.

J.2.1 Reference modulator diagram

The functional block diagram in Figure J.1 is provided as a reference for specifying the 780 MHz band MPSK PHY modulation and spreading functions. The number in each block refers to the subclause that describes that function. Each bit in the PPDU is processed through the bit-to-symbol mapping, symbol-to-chip mapping, pre-processing, and modulation functions in octet-wise order, beginning with the Preamble field and ending with the last octet of the PSDU. Within each octet, the LSB, b_0, is processed first and the MSB, b_7, is processed last.

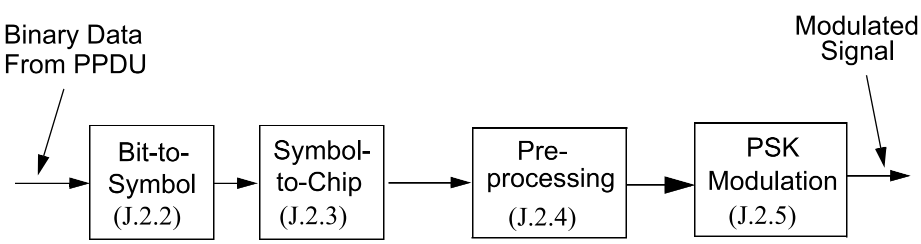

Figure J.1—Modulation and spreading functions

J.2.2 Bit-to-symbol mapping

All binary data contained in the PPDU is encoded using the modulation and spreading functions shown in Figure J.1. This subclause describes how binary information is mapped into data symbols.

The 4 LSBs (b_0, b_1, b_2, b_3) of each octet is mapped into one data symbol, and the 4 MSBs (b_4, b_5, b_6, b_7) of each octet is mapped into the next data symbol. Each octet of the PPDU is processed through the modulation and spreading functions (see Figure J.1) sequentially, beginning with the Preamble field and ending with the last octet of the PSDU. Within each octet, the least significant symbol (b_0, b_1, b_2, b_3) is processed first, and the most significant symbol (b_4, b_5, b_6, b_7) is processed second.

J.2.3 Symbol-to-chip mapping

Each data symbol is mapped into a 16-chip PN sequence as specified in Table J.1.

Table J.1—Symbol-to-chip mapping for MPSK

Data symbol (decimal)	Data symbol (binary) (b_0 b_1 b_2 b_3)	Chip phases (c_0 c_1 … c_{14} c_{15})
0	0 0 0 0	$0\ \frac{\pi}{4}\ \frac{\pi}{16}\ \frac{9\pi}{16}\ \pi\ -\frac{7\pi}{16}\ \frac{\pi}{4}\ -\frac{15\pi}{16}\ 0\ -\frac{15\pi}{16}\ \frac{\pi}{4}\ -\frac{7\pi}{16}\ \pi\ \frac{9\pi}{16}\ \frac{\pi}{4}\ \frac{\pi}{16}$
1	1 0 0 0	$\frac{\pi}{16}\ 0\ \frac{\pi}{4}\ \frac{\pi}{16}\ \frac{9\pi}{16}\ \pi\ -\frac{7\pi}{16}\ \frac{\pi}{4}\ -\frac{15\pi}{16}\ 0\ -\frac{15\pi}{16}\ \frac{\pi}{4}\ -\frac{7\pi}{16}\ \pi\ \frac{9\pi}{16}\ \frac{\pi}{4}$
2	0 1 0 0	$\frac{\pi}{4}\ \frac{\pi}{16}\ 0\ \frac{\pi}{4}\ \frac{\pi}{16}\ \frac{9\pi}{16}\ \pi\ -\frac{7\pi}{16}\ \frac{\pi}{4}\ -\frac{15\pi}{16}\ 0\ -\frac{15\pi}{16}\ \frac{\pi}{4}\ -\frac{7\pi}{16}\ \pi\ \frac{9\pi}{16}$
3	1 1 0 0	$\frac{9\pi}{16}\ \frac{\pi}{4}\ \frac{\pi}{16}\ 0\ \frac{\pi}{4}\ \frac{\pi}{16}\ \frac{9\pi}{16}\ \pi\ -\frac{7\pi}{16}\ \frac{\pi}{4}\ -\frac{15\pi}{16}\ 0\ -\frac{15\pi}{16}\ \frac{\pi}{4}\ -\frac{7\pi}{16}\ \pi$
4	0 0 1 0	$\pi\ \frac{9\pi}{16}\ \frac{\pi}{4}\ \frac{\pi}{16}\ 0\ \frac{\pi}{4}\ \frac{\pi}{16}\ \frac{9\pi}{16}\ \pi\ -\frac{7\pi}{16}\ \frac{\pi}{4}\ -\frac{15\pi}{16}\ 0\ -\frac{15\pi}{16}\ \frac{\pi}{4}\ -\frac{7\pi}{16}$
5	1 0 1 0	$-\frac{7\pi}{16}\ \pi\ \frac{9\pi}{16}\ \frac{\pi}{4}\ \frac{\pi}{16}\ 0\ \frac{\pi}{4}\ \frac{\pi}{16}\ \frac{9\pi}{16}\ \pi\ -\frac{7\pi}{16}\ \frac{\pi}{4}\ -\frac{15\pi}{16}\ 0\ -\frac{15\pi}{16}\ \frac{\pi}{4}$
6	0 1 1 0	$\frac{\pi}{4}\ -\frac{7\pi}{16}\ \pi\ \frac{9\pi}{16}\ \frac{\pi}{4}\ \frac{\pi}{16}\ 0\ \frac{\pi}{4}\ \frac{\pi}{16}\ \frac{9\pi}{16}\ \pi\ -\frac{7\pi}{16}\ \frac{\pi}{4}\ -\frac{15\pi}{16}\ 0\ -\frac{15\pi}{16}$
7	1 1 1 0	$-\frac{15\pi}{16}\ \frac{\pi}{4}\ -\frac{7\pi}{16}\ \pi\ \frac{9\pi}{16}\ \frac{\pi}{4}\ \frac{\pi}{16}\ 0\ \frac{\pi}{4}\ \frac{\pi}{16}\ \frac{9\pi}{16}\ \pi\ -\frac{7\pi}{16}\ \frac{\pi}{4}\ -\frac{15\pi}{16}\ 0$
8	0 0 0 1	$0\ -\frac{15\pi}{16}\ \frac{\pi}{4}\ -\frac{7\pi}{16}\ \pi\ \frac{9\pi}{16}\ \frac{\pi}{4}\ \frac{\pi}{16}\ 0\ \frac{\pi}{4}\ \frac{\pi}{16}\ \frac{9\pi}{16}\ \pi\ -\frac{7\pi}{16}\ \frac{\pi}{4}\ -\frac{15\pi}{16}$
9	1 0 0 1	$-\frac{15\pi}{16}\ 0\ -\frac{15\pi}{16}\ \frac{\pi}{4}\ -\frac{7\pi}{16}\ \pi\ \frac{9\pi}{16}\ \frac{\pi}{4}\ \frac{\pi}{16}\ 0\ \frac{\pi}{4}\ \frac{\pi}{16}\ \frac{9\pi}{16}\ \pi\ -\frac{7\pi}{16}\ \frac{\pi}{4}$
10	0 1 0 1	$\frac{\pi}{4}\ -\frac{15\pi}{16}\ 0\ -\frac{15\pi}{16}\ \frac{\pi}{4}\ -\frac{7\pi}{16}\ \pi\ \frac{9\pi}{16}\ \frac{\pi}{4}\ \frac{\pi}{16}\ 0\ \frac{\pi}{4}\ \frac{\pi}{16}\ \frac{9\pi}{16}\ \pi\ -\frac{7\pi}{16}$
11	1 1 0 1	$-\frac{7\pi}{16}\ \frac{\pi}{4}\ -\frac{15\pi}{16}\ 0\ -\frac{15\pi}{16}\ \frac{\pi}{4}\ -\frac{7\pi}{16}\ \pi\ \frac{9\pi}{16}\ \frac{\pi}{4}\ \frac{\pi}{16}\ 0\ \frac{\pi}{4}\ \frac{\pi}{16}\ \frac{9\pi}{16}\ \pi$
12	0 0 1 1	$\pi\ -\frac{7\pi}{16}\ \frac{\pi}{4}\ -\frac{15\pi}{16}\ 0\ -\frac{15\pi}{16}\ \frac{\pi}{4}\ -\frac{7\pi}{16}\ \pi\ \frac{9\pi}{16}\ \frac{\pi}{4}\ \frac{\pi}{16}\ 0\ \frac{\pi}{4}\ \frac{\pi}{16}\ \frac{9\pi}{16}$
13	1 0 1 1	$\frac{9\pi}{16}\ \pi\ -\frac{7\pi}{16}\ \frac{\pi}{4}\ -\frac{15\pi}{16}\ 0\ -\frac{15\pi}{16}\ \frac{\pi}{4}\ -\frac{7\pi}{16}\ \pi\ \frac{9\pi}{16}\ \frac{\pi}{4}\ \frac{\pi}{16}\ 0\ \frac{\pi}{4}\ \frac{\pi}{16}$

Table J.1—Symbol-to-chip mapping for MPSK *(continued)*

Data symbol (decimal)	Data symbol (binary) (b_0 b_1 b_2 b_3)	Chip phases (c_0 c_1 … c_{14} c_{15})
14	0 1 1 1	$\frac{\pi}{16}$ $\frac{9\pi}{16}$ π $-\frac{7\pi}{16}$ $\frac{\pi}{4}$ $-\frac{15\pi}{16}$ 0 $-\frac{15\pi}{16}$ $\frac{\pi}{4}$ $-\frac{7\pi}{16}$ π $\frac{9\pi}{16}$ $\frac{\pi}{4}$ $\frac{\pi}{16}$ 0 $\frac{\pi}{4}$
15	1 1 1 1	$\frac{\pi}{4}$ $\frac{\pi}{16}$ $\frac{9\pi}{16}$ π $-\frac{7\pi}{16}$ $\frac{\pi}{4}$ $-\frac{15\pi}{16}$ 0 $-\frac{15\pi}{16}$ $\frac{\pi}{4}$ $-\frac{7\pi}{16}$ π $\frac{9\pi}{16}$ $\frac{\pi}{4}$ $\frac{\pi}{16}$ 0

J.2.4 Pre-processing

The chip sequence that the chip phase is mapped to consists of some DC value. To mitigate the DC effect, this pre-processing block subtracts each chip by the following value in Equation (J.1).

$$A_{\mathrm{DC}} = \left(\frac{1}{4}\right)\exp\left(j\frac{\pi}{4}\right) \tag{J.1}$$

J.2.5 PSK modulation

The chip phases representing each data symbol are modulated onto the carrier using PSK with raised cosine pulse shaping. Because each data symbol is represented by a 16-chip sequence, the chip rate is 16 times the symbol rate.

J.2.6 Pulse shape

The raised cosine pulse shape with roll-off factor of $r = 0.5$ is used to represent each baseband chip and is described by Equation (J.2).

$$p(t) = \begin{cases} \dfrac{\sin(\pi t/T_c)}{\pi t/T_c} \times \dfrac{\cos(r\pi t/T_c)}{1 - 4r^2t^2/T_c^2}, & t \neq 0 \\ 1, & t = 0 \end{cases} \tag{J.2}$$

Given the discrete-time sequence $\{\exp(jc_k)\}_{k=-\infty}^{\infty}$ of consecutive complex-vlaued chip samples, the continuous-time pulse shaped complex baseband signal is given by Equation (J.3).

$$y(t) = \sum_{k=-\infty}^{\infty} \exp(jc_k)p(t - kT_c) \tag{J.3}$$

where T_c is the inverse of the chip rate.

J.2.7 Chip transmission order

During each symbol period, the least significant chip phase, c_0, is transmitted first, and the most significant chip phase, c_{15}, is transmitted last.

J.3 780 MHz band radio specification

The transmit power (EIRP) is limited to 10 mW.

J.3.1 Operating frequency range

The 780 MHz MPSK PHY operates in the 779–787 MHz frequency band.

J.3.2 Transmit PSD mask

When operating in the 780 MHz band, the transmitted spectral products are less than the limits specified in Table J.2. For both relative and absolute limits, average spectral power is measured using a 100 kHz resolution bandwidth. For the relative limit, the reference level is the highest average spectral power measured within ± 600 kHz of the carrier frequency f_c.

Table J.2—780 MHz band MPSK PHY transmit PSD limits

Frequency	Relative limit	Absolute limit
$\|f – f_c\| > 1.2$ MHz	–20 dB	–20 dBm

J.3.3 Symbol rate

The MPSK PHY symbol rate is 62.5 ksymbol/s when operating in the 780 MHz band with an accuracy of ± 40 ppm.

J.3.4 Receiver sensitivity

A compliant device is capable of achieving a sensitivity of –85 dBm or better for the definitions in Table J.3.

Table J.3—Receiver sensitivity definitions

Term	Definition of term	Conditions
Packet error rate (PER)	Average fraction of transmitted packets that are not correctly received.	– Average measured over random PSDU data.
Receiver sensitivity	Threshold input signal power that yields a specified PER.	– PSDU length = 20 octets. – PER < 1%. – Power measured at antenna terminals. – Interference not present.

J.3.5 Receiver jamming resistance

The minimum jamming resistance levels are given in Table J.4. The adjacent channel is one on either side of the desired channel that is closest in frequency to the desired channel, and the alternate channel is one more removed from the adjacent channel. For example, when channel 2 is the desired channel, channel 1 and channel 3 are the adjacent channels, and channel 0 is the alternate channels.

Table J.4—Minimum receiver jamming resistance requirements for 780 MHz MPSK PHY

Adjacent channel rejection	Alternate channel rejection
0 dB	30 dB

The adjacent channel rejection is measured as follows: the desired signal is a compliant 780 MHz IEEE 802.15.4 MPSK PHY signal, as defined by J.2, of pseudo-random data. The desired signal is input to the receiver at a level 3 dB above the maximum allowed receiver sensitivity given in J.3.4.

In either the adjacent or the alternate channel, a compliant signal, as defined by J.2, is input at the relative level specified in Table J.4. The test is performed for only one interfering signal at a time. The receiver will meet the error rate criteria defined in J.3.4 under these conditions.