

BS ISO/IEC 24730-5:2010



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Information technology — Real-time locating systems (RTLS)

Part 5: Chirp spread spectrum (CSS) at 2,4 GHz
air interface

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The UK participation in its preparation was entrusted to Technical Committee IST/34, Automatic identification and data capture techniques.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Information technology — Real-time locating systems (RTLS) —

Part 5: Chirp spread spectrum (CSS) at 2,4 GHz air interface

*Technologies de l'information — Systèmes de localisation en temps réel
(RTLS) —*

*Partie 5: Spectre étalé de compression d'impulsions (CSS) à une
interface d'air de 2,4 GHz*



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Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work. In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of the joint technical committee is to prepare International Standards. Draft International Standards adopted by the joint technical committee are circulated to national bodies for voting. Publication as an International Standard requires approval by at least 75 % of the national bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO and IEC shall not be held responsible for identifying any or all such patent rights.

ISO/IEC 24730-5 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 31, *Automatic identification and data capture techniques*.

ISO/IEC 24730 consists of the following parts, under the general title *Information technology — Real-time locating systems (RTLS)*:

- *Part 1: Application program interface (API)*
- *Part 2: 2,4 GHz air interface protocol*
- *Part 5: Chirp spread spectrum at 2,4 GHz air interface*

Introduction

CSS is a technique for spreading the bandwidth of a digital signal by using chirp pulses. Chirp pulses are pulses with a monotonically increasing or decreasing instantaneous frequency. Chirp pulses were originally used for radar applications. Recently, systems and standards have been developed which use chirp pulses also for communication applications. This part of ISO/IEC 24730 includes ranging and bidirectional communication between tags and infrastructure. Bidirectional communication enables the infrastructure to control the behaviour of tags in a timely manner.

Information technology — Real-time locating systems (RTLS) —

Part 5: Chirp spread spectrum (CSS) at 2,4 GHz air interface

1 Scope

ISO/IEC 24730 defines air interface protocols and an application programming interface (API) for real-time locating systems (RTLS). This part of ISO/IEC 24730 defines an air interface protocol which utilizes chirp spread spectrum (CSS) at frequencies from 2,4 GHz to 2,483 GHz. This protocol supports bidirectional communication and two-way ranging between the readers and tags of an RTLS. The mandatory default mode ensures interoperability between tags and infrastructure from various manufacturers, while the availability of several options offers flexibility to the developer of the infrastructure to adapt the behaviour of the overall system to the specific needs of his application.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 15963, *Information technology — Radio frequency identification for item management — Unique identification for RF tags*

ISO/IEC 19762-1, *Information technology — Automatic identification and data capture (AIDC) techniques — Harmonized vocabulary — Part 1: General terms relating to AIDC*

ISO/IEC 19762-3, *Information technology — Automatic identification and data capture (AIDC) techniques — Harmonized vocabulary — Part 3: Radio frequency identification (RFID)*

ISO/IEC 19762-4, *Information technology — Automatic identification and data capture (AIDC) techniques — Harmonized vocabulary — Part 4: General terms relating to radio communications*

ISO/IEC 19762-5, *Information technology — Automatic identification and data capture (AIDC) techniques — Harmonized vocabulary — Part 5: Locating systems*

ISO/IEC 24730-1, *Information technology — Real-time locating systems (RTLS) — Part 1: Application program interface (API)*

Guidelines on Limiting Exposure to Non-Ionizing Radiation, International Commission on Non-Ionizing Radiation Protection (ICNIRP), Munich, 1999

IEC 62369-1 ed1.0, *Evaluation of human exposure to electromagnetic fields from short range devices (SRDs) in various applications over the frequency range 0 GHz to 300 GHz — Part 1: Fields produced by devices used for electronic article surveillance, radio frequency identification and similar systems*

IEEE Std C95.1-2005, *IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 19762-1, ISO/IEC 19762-3, ISO/IEC 19762-4, ISO/IEC 19762-5 and the following apply.

- 3.1**
chirp spread spectrum
technique for spreading the bandwidth of a digital signal using linear frequency sweep signals
- 3.2**
Class I
system that operates at a radiated power of up to 10 mW EIRP
- 3.3**
Class II
system that operates at a radiated power higher than 10 mW up to the maximum defined by local regulations
- 3.4**
ranging
process of determining the distance between two RTLS transceivers through the exchange of a specific set of messages
- 3.5**
ranging peer
RTLS transceiver with which to perform ranging
- 3.6**
RF channel
combination of a centre frequency value and bandwidth value
- 3.7**
RTLS tag
RTLS transceiver that accepts commands from RTLS readers and sends blinks and/or reports to the RTLS readers
- 3.8**
RTLS transmitter
part of an RTLS transceiver which is capable of sending messages
- 3.9**
demultiplexer
equipment for reversing the process of multiplexing
- 3.10**
medium
wireless channel
- 3.11**
trilateration
method of determining the relative positions of objects using the known locations of three reference points and the measured distance between the object to be located and each reference point
- 3.12**
interleaving
rearrangement or transposition of data to enhance the effectiveness of error control schemes
- 3.13**
interleaver
unit that performs interleaving (3.12)

3.14

baseband

frequency band occupied by the aggregate of the signals used to modulate a carrier before they combine with the carrier in the modulation process

3.15

orthogonal

inner product being close to zero

3.16

peer X

x'th peer in a description of a situation with multiple peers

4 Symbols and abbreviated terms

ACK	acknowledge
ARQ	Automatic Repeat Query
BTS	Backoff Time Slot
CIFS	Carrier sense Inter Frame Space
CTS	Clear To Send
CRC	Cyclic Redundancy Check
CSMA/CA	Carrier Sense Multiple Access / Collision Avoidance
CSS	Chirp Spread Spectrum
dBr	decibel relative
DEMUX	demultiplexer
DQPSK	Differential Quadrature Phase Shift Keying
DQPSK-CSS	Differential Quadrature Phase Shift Keying over Chirp Spread Spectrum
Dst	Destination address
EIRP	Equivalent Isotropical Radiated Power
LFSR	Linear Feedback Shift Register
LSB	Least Significant Bit
MMSE	Minimum Mean Square Error
MAC	Medium Access Control
NAV	Network Allocation Vector
PHR	PHY header
PHY	physical layer
PPDU	PHY Protocol Data Unit

PSDU	PHY Service Data Unit
QPSK	Quadrature Phase Shift Keying
RTS	Request To Send
RTLS	Real Time Locating System
SFD	Start of Frame Delimiter
SHR	synchronization header
SIFS	Short Inter Frame Space
Src	source address
TWR	Two Way Ranging
SDS-TWR	Symmetric Double Sided Two Way Ranging
e	Euler constant
j	imaginary unit
$\tilde{s}^{M_0}(t)$	continuous time baseband representation of 2-ary orthogonal CSS signal
$\tilde{r}^{M_0}(t)$	implemented version of $\tilde{s}^{M_0}(t)$
$\tilde{s}_m^{M_1}(t)$	continuous time baseband representation of DQPSK-CSS signal
$\tilde{r}_m^{M_1}(t)$	implemented version of $\tilde{s}_m^{M_1}(t)$
m	configuration constant determining the type (one out of four possibilities) of sub-chirp sequence used
M_0	superscript indicating that 2-ary orthogonal CSS is described
M_1	superscript indicating that DQPSK-CSS is described
k	index variable
n	index variable
b_n	n'th symbol to be transmitted
$c_b(t)$	continuous time baseband representation of chirp pulse b for 2-ary orthogonal CSS
μ_0	configuration constant determining the chirp rate for 2-ary orthogonal CSS
μ_1	constant determining the chirp rate for DQPSK-CSS
T_{base}	timebase

T_{SBIFS}	time in between two sub blinks
T_{Blink}	average blink repetition time
T_{Rand}	random time
T_{Rxon}	duration of time interval for during which the receiver of a tag is activated
T_{Contact}	maximum expected duration between a tag receiving any packets from infrastructure if such is present
$T_{\text{TimeoutApplication}}$	duration of time interval during which a tag application shall respond to certain requests
$T_{\text{WaitAfterRange}}$	duration of time for which a tag shall go to Wait state after leaving Range state
T_0	configuration constant determining the duration of a chirp pulse for 2-ary orthogonal CSS
T_1	duration of sub-chirp sequence
T_{sub}	duration of sub-chirp
$T_{n,k,m}$	time position of k'th sub-chirp of n'th sub-chirp sequence of type m
$W_T(t)$	raised cosine window of duration T
α	roll off factor of the raised cosine window
A	amplitude variable which is minimized in minimum mean square error computation
τ_d	time delay variable that is minimized in minimum mean square error computation
φ	phase variable that is minimized in minimum mean square error computation
$d_{n,k}$	information sample of k'th sub-chirp in n'th sub-chirp sequence
$C_{k,m}^{\text{sub}}(t)$	continuous time baseband representation of k' sub-chirp of sub-chirp sequence type m
τ_m	timing constant that determines the time-gap between subsequent sub-chirp sequences for the sub-chirp sequence type m
$f_{k,m}$	offset centre frequency of k'th sub-chirp in sub-chirp sequence type m
$\zeta_{k,m}$	chirp direction of k'th sub-chirp in sub-chirp sequence type m
$S_m^{\text{sub}}(t)$	continuous time baseband representation of sub-chirp sequence of type m

5 Overview

5.1 Components

The major components of a real-time locating system (RTLS) and the relationship of those components are shown in Figure 1. As shown in this Figure the tags communicate with an infrastructure. The infrastructure provides an application program interface (API) through which an application can control the RTLS and retrieve information about location and state of tags.

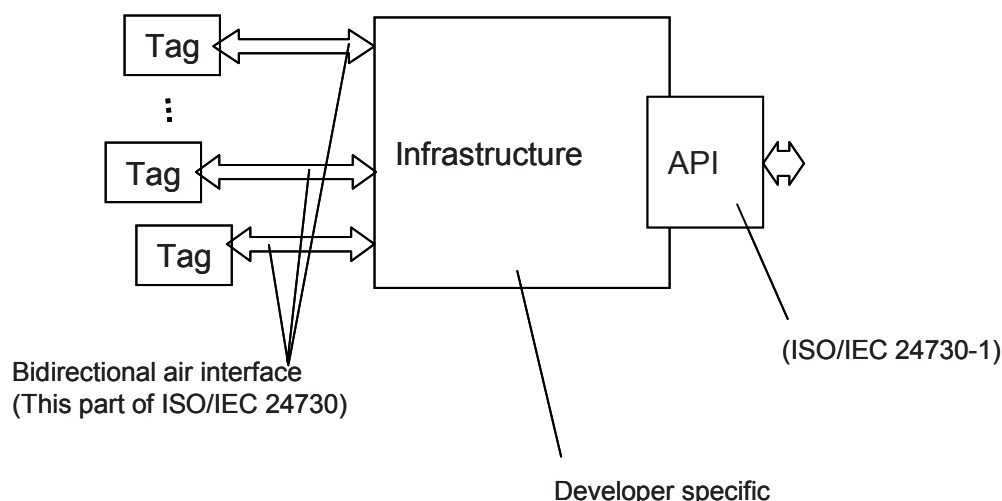


Figure 1 – RTLS components

As indicated in Figure 1 tags communicate with infrastructure over an air interface. Generally the air interface includes the definition of waveforms, formats of packets as well as commands and reports to be exchanged between tags and infrastructure. This can be depicted in a layered approach as shown in Figure 2. Similar interpretations can be found in other standards e.g. in ISO/IEC 18000-1^[1].

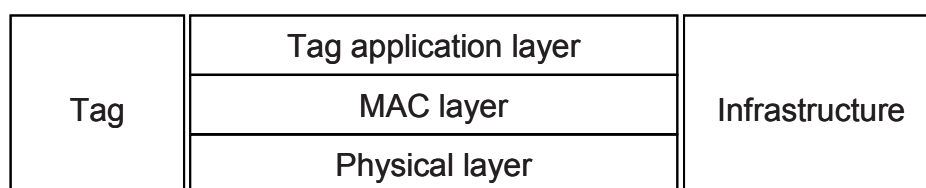


Figure 2 – Air interface layers

5.2 Purpose

This part of ISO/IEC 24730 defines an air interface protocol that optimizes small scale RTLS with an installation that enables simple, and also handheld, RTLS readers. Although the infrastructure itself is not defined in this part of ISO/IEC 24730, it is anticipated that the air interface protocol has a strong impact on the realization of the infrastructure and the related installation effort.

The key condition for simple installation is the possibility of 'autonomous' infrastructure nodes. In this part of ISO/IEC 24730, "autonomous" means there is not a requirement for these nodes to be synchronized with other infrastructure nodes. After being placed at a fixed location, an autonomous node simply responds to requests from RTLS tags.

This condition is achieved by specifying bidirectional communication and two-way ranging. As a consequence, the tag must also support bidirectional communication. Although this requirement increases the complexity of

the tag in one area, it also decreases the complexity in other areas, as additional interfaces for programming and conditioning the tag are not required. Thus bidirectional communication with the tag is seen as beneficial for many applications. Finally in order to utilize existing state of the art communication technology this part of ISO/IEC 24730 includes parts that correspond with IEEE 802.15.4a^[5], which is a PHY amendment of IEEE 802.15.4^[4], a successful standard for low power, low data rate wireless communication.

5.3 Not covered by the standard

The design of the infrastructure is left completely to the developer, e.g. the density of RTLS reader nodes, how the RTLS readers are controlled and communicate with each other, how the infrastructure is set up, etc. may be different in various scenarios and for systems from different vendors. For typical RTLS applications, at least three RTLS readers will communicate with each tag, measuring time of flight in order to locate the tag. For more details on this interaction, see Clause 9, Tag application layer specification.

5.4 System

After power on, a tag uses a default profile in which it blinks periodically. With each blink the tag signals its physical address, its capabilities and information about when it will be ready to receive commands from the infrastructure.

The infrastructure decides whether it needs to send commands to the tag while the tag is listening. By sending commands to the tag, the infrastructure controls which RTLS readers are part of the infrastructure the tag performs ranging with. Furthermore the infrastructure can adapt the behaviour of the tags to the actual conditions such as the number of tags in range, number of infrastructure nodes available, etc. For example, the infrastructure is able to instruct the tag to change to another mode (bandwidth, centre frequency, data rate) according to the actual environment or to perform ranging with a specific set of RTLS readers.

When the tag assumes that it has lost connection to the infrastructure e.g. because it doesn't receive any commands for a certain time, it reverts to the default profile. A more detailed description of complete system behaviour can be found in Annex D.

5.5 Document structure

The remainder of this part of ISO/IEC 24730 follows the "layered structure" mentioned above. This means that after the Requirements clause the three layers that form an air interface protocol (the Physical Layer [PHY], Media Access Control [MAC] and the Tag application layer) are addressed and specified separately. Additional information for the user of this part of ISO/IEC 24730 is provided in the informative annexes.

6 Requirements

6.1 Frequency range

This part of ISO/IEC 24730 addresses real-time locating systems (RTLS) operating in the 2,400 to 2,4835 GHz frequencies.

6.2 2,4 GHz spread spectrum air interface specifications

The minimum requirements shall include:

- RTLS transceivers shall autonomously generate a chirp spread spectrum frequency beacon indicating when the receiver will be activated.
- RTLS transceivers shall be able to perform two-way ranging when the receiver is activated.
- RTLS transmitters shall be fully compliant with local regulatory requirements.

- Class I RF transmissions shall not exceed 10 mW EIRP
- Class II RF transmissions shall not exceed 100 mW EIRP or the maximum EIRP according to the local radio regulations.

6.3 Compliance requirements

To be fully compliant with this part of ISO/IEC 24730, real-time locating systems (RTLS) shall also comply with ISO/IEC 24730-1.

Device manufacturers claiming conformance to this part of ISO/IEC 24730 shall self-certify RF emissions do not exceed the maximum permitted exposure limits recommended by either IEEE C95.1: 2005 or ICNIRP according to IEC 62369-1. If a device manufacturer is unsure as to which recommendation to be cited for compliance the manufacturer shall self-certify to ICNIRP limits.

6.4 Manufacturer tag ID

The manufacturer's tag identification number identifies a particular manufacturer and consists of 16 bits. A manufacturer may have more than one ID number. The frame format used in this part of ISO/IEC 24730 mandates a MAC address of at least 48 bits for each device. The first 16 bits of the MAC address are designated for the manufacturer's identification number and shall be assigned according to ISO/IEC 15963 Annex D, under Allocation Class 0000 0000.

6.5 Physical layer parameters

For the purposes of this part of ISO/IEC 24730, the following parameter definitions apply in Table 1. These parameters are referenced by parameter name. These operating parameters are to be defined for the temperature range of minus 30 degrees Celsius to 50 degrees Celsius.

Table 1 – 2,4 GHz CSS link parameters

Parameter name	Description
Operating frequency range	As permitted by local radio regulations in the band from 2400 to 2483,5 MHz.
Operating frequency accuracy	± 70 ppm (2-ary orthogonal CSS) ± 40 ppm (DQPSK –CSS)
Maximum phase noise	-85 dBc/Hz @ 1 MHz
Occupied 20 dB channel bandwidth	80 MHz (Default value) 22 MHz (Configuration option)
Centre frequency, bandwidth combination	According to Table 2 and Table 6
Time base, T_{base}	31,25 ns
Time base accuracy	± 40 ppm
Transmit power	Class 1: 10 dBm EIRP. max. Class 2: Maximum in accordance to local regulations.
Transmitter spectrum mask	According to Table 3 and Figure 13
Spurious emission, out of band	The device shall transmit in conformance with spurious emissions requirements defined by the country's regulatory authority within which the system is operated.
Modulation	2-ary orthogonal CSS DQPSK-CSS (optional)

Parameter name	Description
Data bit rates	1 Mbit/s 250 kbit/s
Symbol rates	10^6 symbols/s, 250000 symbols/s 166667 symbols/s (with DQPSK-CSS)

7 Physical (PHY) layer specification

7.1 Modulations

The PHY layer specification shall contain two modulations (2-ary orthogonal CSS and DQPSK-CSS). The support of 2-ary orthogonal shall be mandatory while the support of DQPSK-CSS is optional.

7.2 Data rates

2-ary orthogonal CSS shall support data rates of 1 Mbits/s and 250 kbit/s.

DQPSK-CSS, when implemented, shall support data rates of 1 Mbits/s and 250 kbit/s.

7.2.1 General PHY packet format

A PHY packet shall consist of a synchronization header and a PHY protocol data unit as shown in Figure 3.

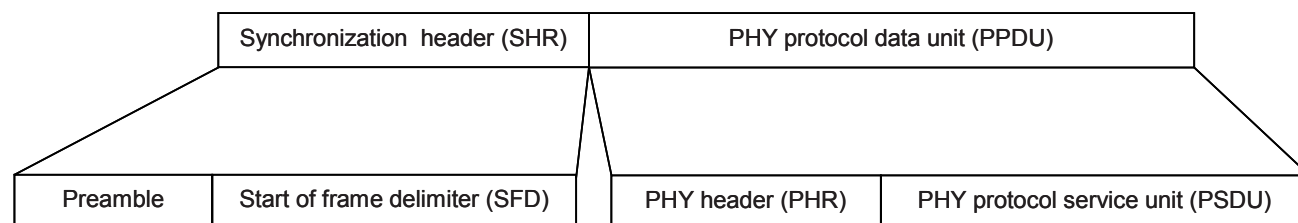


Figure 3 – General PHY packet structure

The definitions of preamble, SFD and PHY are given in 7.3.7, 7.3.8, 7.3.10 and 7.4.14, 7.4.15, 7.4.16.

The PSDU shall contain the MAC a frame defined Clause 8.

7.3 2-ary orthogonal CSS

2-ary orthogonal CSS shall be the mandatory PHY mode. A combination of centre frequency and bandwidth shall called "RF channel". The possible RF channels are defined in Table 2.

Table 2 – Possible combinations of centre frequency and bandwidth for 2-ary orthogonal CSS

RF channel number	Centre frequency	Bandwidth
0	2441,75 MHz	80 MHz
1	2441,75 MHz	22 MHz
2	2412 MHz	22 MHz
3	2417 MHz	22 MHz
4	2422 MHz	22 MHz
5	2427 MHz	22 MHz
6	2432 MHz	22 MHz
7	2437 MHz	22 MHz
8	2442 MHz	22 MHz
9	2447 MHz	22 MHz
10	2452 MHz	22 MHz
11	2457 MHz	22 MHz
12	2462 MHz	22 MHz
13	2467 MHz	22 MHz
14	2472 MHz	22 MHz
15	2484 MHz	22 MHz

7.3.1 Reference modulator diagram

The functional block diagram in Figure 4 is provided as a reference for specifying 2-ary orthogonal CSS for both data rates 1 Mbits/s and 250 kbit/s. The functionality of the Bit scrambler block is specified in 7.3.9. The functionality of the Bit to symbol mapping block is specified in 7.3.5. The functionality of the chirp generator block is specified in 7.3.6.

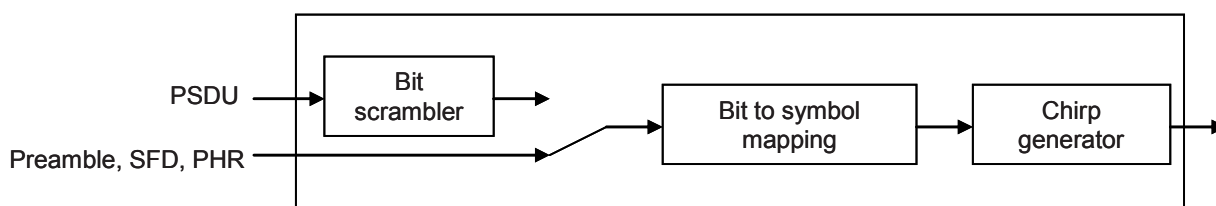


Figure 4 – Reference modulator for 2-ary orthogonal CSS

7.3.2 Bandwidths and Transmit power spectral density (PSD) mask

The supported bandwidth values shall be 80 MHz and 22 MHz. The transmitted spectral products shall be less than the limits specified in Table 3, Figure 5 and Figure 6. 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 $\pm$ Bandwidth/2 of the centre frequency, f_c . For testing the transmitted spectral power density a pseudo-random binary sequence shall be used as input data.

Table 3 – Transmit PSD limits for 2-ary CSS

Frequency	Relative limit	Absolute limit
$ f-f_c > \text{Bandwidth}/2$	-20 dBr	-30 dBm

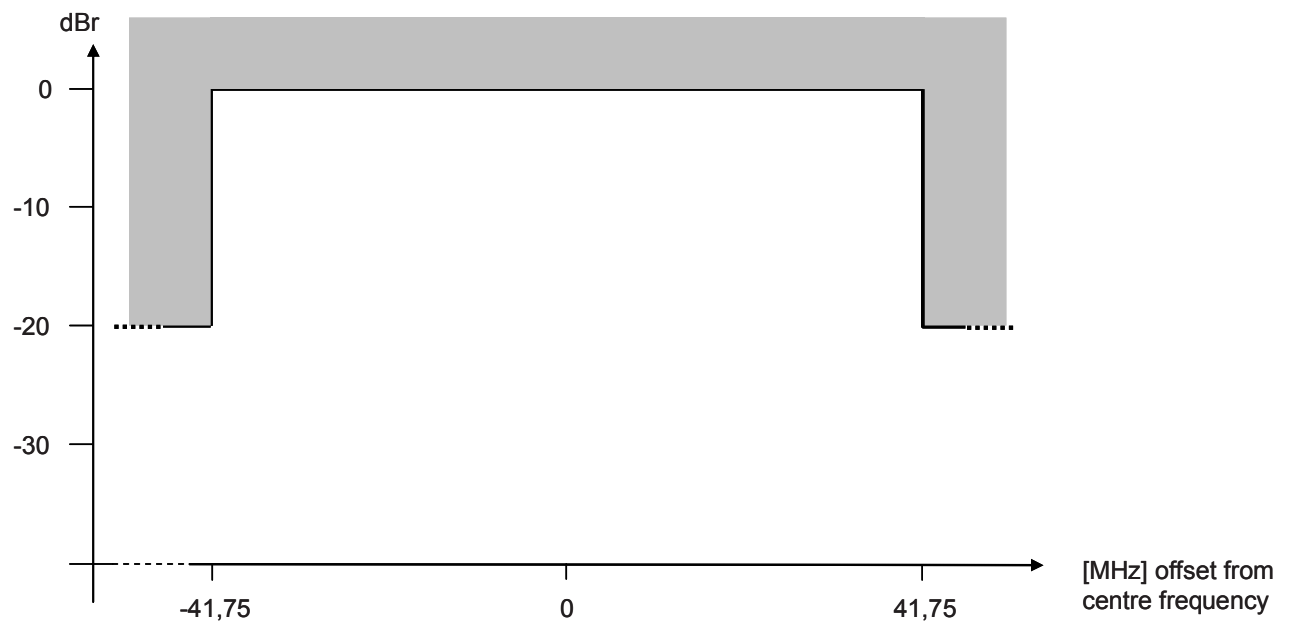


Figure 5 – Transmit PSD limits for 2-ary orthogonal CSS at 80 MHz bandwidth

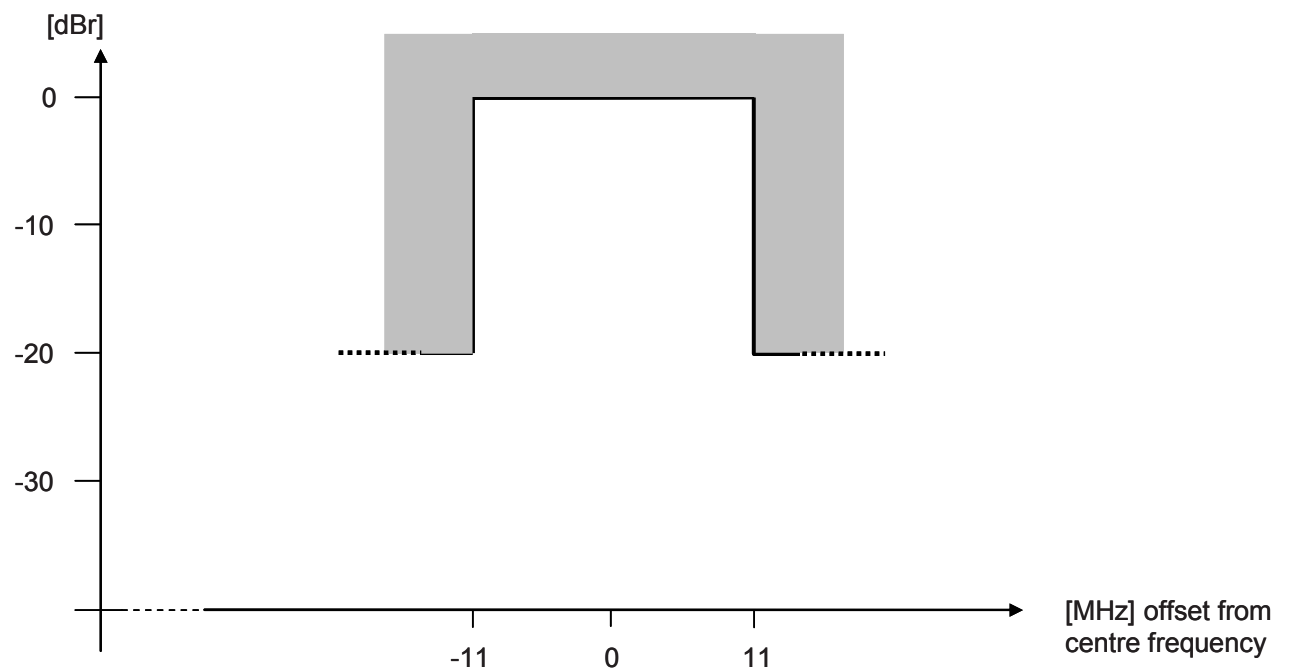


Figure 6 – Transmit PSD limits for 2-ary orthogonal CSS at 22 MHz bandwidth

7.3.3 Equivalent baseband representation of the continuous time 2-ary orthogonal CSS signal

The mathematical representation of the continuous time-domain baseband signal $\tilde{s}^{M_0}(t)$ for 2-ary orthogonal CSS shall be given by Equation (1).

$$\tilde{s}^{M_0}(t) = \sum_{n=0}^{\infty} c_{b_n} \left(t - nT_0 - \frac{T_0}{2} \right) \quad (1)$$

Where

M_0 is indicating that 2-ary orthogonal CSS is described,

n is the index of the symbol,

b_n are symbols to be transmitted, which can take the values from [1, -1] and determine which of the two possible pulses is actually realized.

$c_b(t)$ are the continuous time-domain baseband versions of the two possible pulses, which are required for 2-ary orthogonal modulation and which shall be chirp pulses as described by Equation (2).

$$c_b(t) = \begin{cases} \exp \left[j \cdot b \cdot \frac{\mu_0}{2} \cdot t^2 \right] \cdot W_{T_0}(t) & \text{for } |t| \leq \frac{T_0}{2} \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

Where

μ_0 is a constant which either takes the value $2\pi \cdot \frac{80\text{MHz}}{T_0}$ or $2\pi \cdot \frac{22\text{MHz}}{T_0}$ depending on the bandwidth selected.

T_0 is the duration of the chirp pulse which can take a value of 1 μs or 4 μs , depending on the data rate,

$$j = \sqrt{-1}$$

and

$W_T(t)$ is the raised cosine window as described in Equation (3).

$$W_T(t) = \begin{cases} 1 & \text{for } |t| \leq \frac{(1-\alpha)T}{(1+\alpha)2} \\ \frac{1}{2} \left[1 + \cos \left(\frac{(1+\alpha)\pi}{\alpha T} \left(|t| - \frac{(1-\alpha)T}{(1+\alpha)2} \right) \right) \right] & \text{for } \frac{(1-\alpha)T}{(1+\alpha)2} < |t| \leq \frac{T}{2} \\ 0 & \text{for } |t| > \frac{T}{2} \end{cases} \quad (3)$$

with $\alpha = 0.25$

Where

T is the duration of the raised cosine window.

α is the roll off factor of the raised cosine window.

7.3.4 Signal tolerance

In addition to the limits specified in Table 3, the Minimum Mean Square Error, MMSE, shall be used as criterion for the compliance of the signal. Let $\tilde{s}^{M_0}(t)$ be the signal that is defined by (1). Then $\tilde{r}^{M_0}(t)$, the implemented version of $\tilde{s}^{M_0}(t)$, shall satisfy (4) for $b_0=+1$ and $b_0=-1$.

$$MMSE = \min_{A, \tau_d, \varphi} \left[\frac{\int_0^{T_0} |\tilde{s}^{M_0}(t) - A \cdot \tilde{r}^{M_0}(t - \tau_d) \cdot e^{j\varphi}|^2 dt}{\int_0^{T_0} |\tilde{s}^{M_0}(t)|^2 dt} \right] \leq 0.005 \quad (4)$$

where the variables A , τ_d , and φ are used to minimize the mean squared error.

7.3.5 Bit to symbol mapping

A bit value of 0 shall be mapped to $b=-1$.

A bit value of 1 shall be mapped to $b=1$.

7.3.6 Chirp generator

The chirp generator shall generate subsequent pulses as defined in Equation (2).

7.3.7 Preamble

The preamble for 2-ary orthogonal CSS shall consist of 30 alternating bits starting with bit 0 as shown in Table 4.

Table 4 – Preamble bit sequence for 2-ary orthogonal CSS

Bit 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0

7.3.8 Start of frame delimiter

The start of frame delimiter (SFD) for 2-ary orthogonal CSS shall consist of 64 bits that correspond to 8 octets as specified in Table 5. The SFD shall start with the least significant bit of octet 0 and end with the most significant bit of octet 7.

Table 5 – Start of frame delimiter for 2-ary orthogonal CSS

Octet 0	Octet 1	Octet 2	Octet 3	Octet 4	Octet 5	Octet 6	Octet 7
64h	52h	52h	9Ah	5Ah	4Bh	DBh	54h

7.3.9 Bit scrambler

Before transmission, the bit sequence shall be scrambled with a pseudo-random noise (PRN) sequence. The PRN-sequence shall be generated with the polynomial $g(D) = D^7 + D^4 + D^0$ (221 in octal representation) and is subsequently EXORed with the bit stream. The 127-bit-length PRN-sequence shall be generated with the linear feedback shift register, as illustrated in Figure 7.

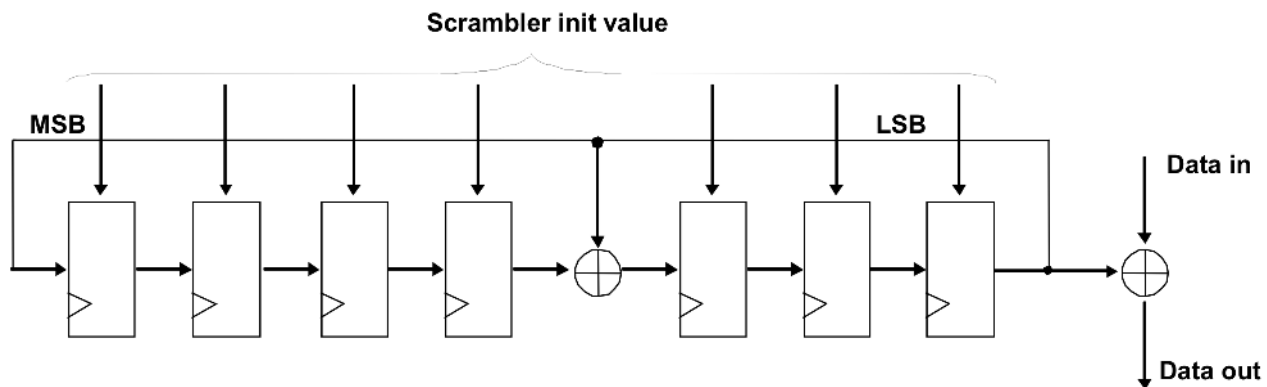


Figure 7 – Bit scrambler

7.3.10 PHY Header

The PHY Header for 2-ary orthogonal CSS shall consist of 8 bits. The first bit shall be reserved. The subsequent 7 bits shall contain the Scrambler init value as depicted in Figure 7 starting with the MSB.

7.3.11 Overview (informative)

For illustrative purposes Figure 8 shows an up chirp pulse and a down chirp pulse in passband domain, while Figure 9 shows the same pulses in time frequency domain. A bit sequence modulated with 2-ary orthogonal CSS is depicted in Figure 10 and Figure 11.

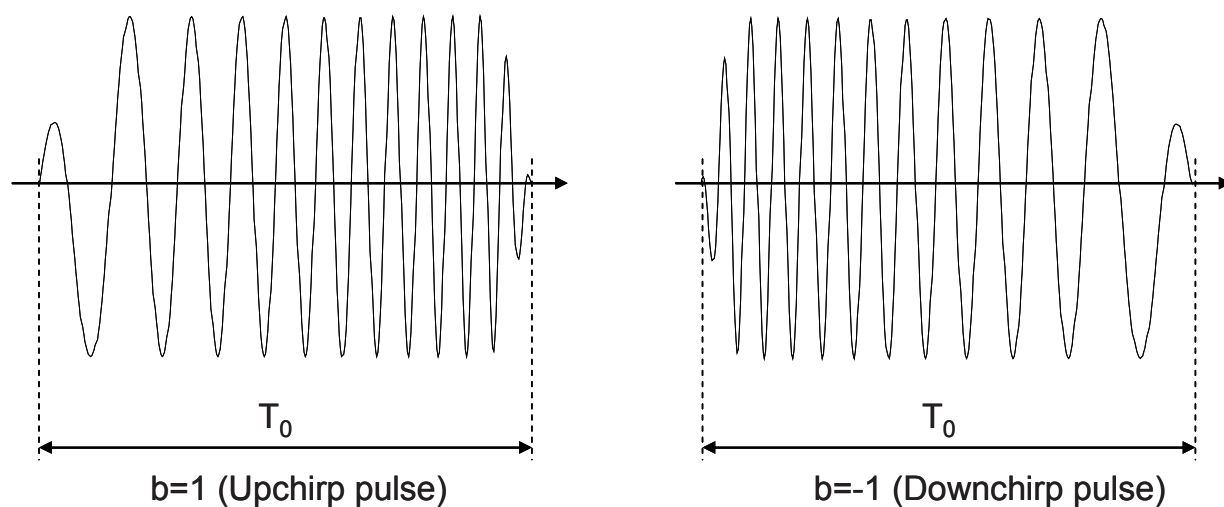


Figure 8 – Chirp pulses in passband domain

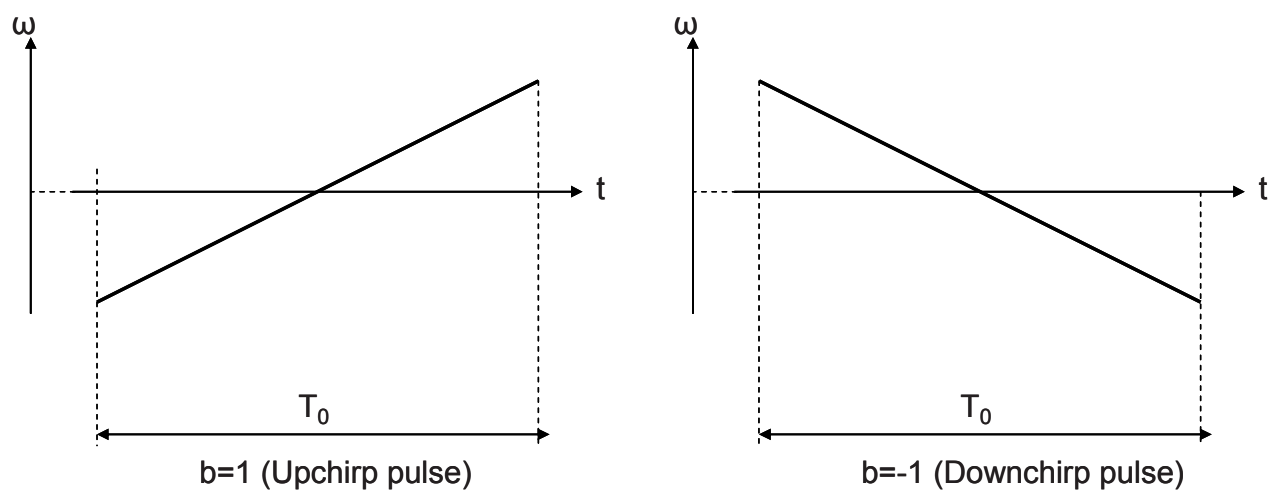


Figure 9 – Chirp pulses in time frequency domain

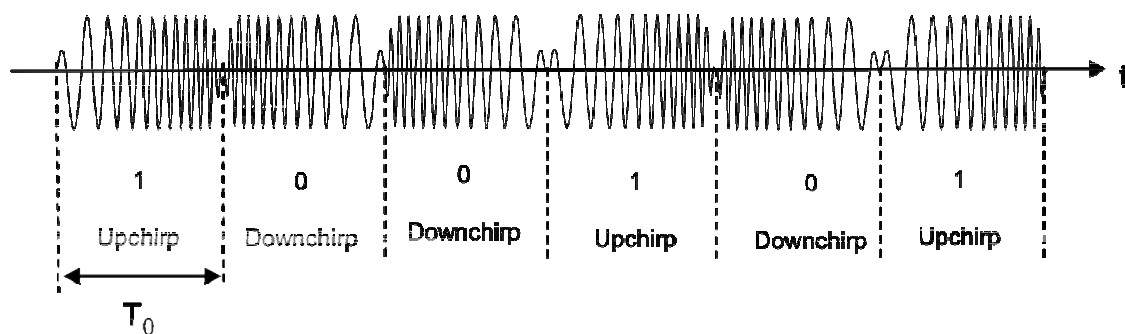


Figure 10 – 2-ary orthogonal CSS modulated bit sequence in passband domain

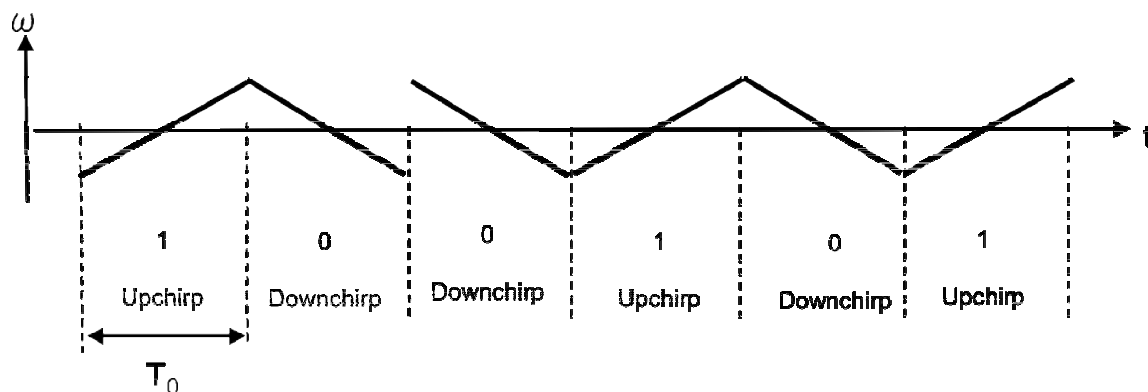


Figure 11 – 2-ary orthogonal CSS modulated bit sequence in time frequency domain

7.4 DQPSK-CSS

Differential Quadrature Phase Shift Keying, in combination with chirp spread spectrum, is an optional PHY mode. The possible combinations of centre frequencies and bandwidths are defined in Table 6.

Table 6 – Possible combinations of centre frequency and bandwidth for DQPSK-CSS

Centre frequency	Bandwidth
2412 MHz	22 MHz
2417 MHz	22 MHz
2422 MHz	22 MHz
2427 MHz	22 MHz
2432 MHz	22 MHz
2437 MHz	22 MHz
2442 MHz	22 MHz
2447 MHz	22 MHz
2452 MHz	22 MHz
2457 MHz	22 MHz
2462 MHz	22 MHz
2467 MHz	22 MHz
2472 MHz	22 MHz
2484 MHz	22 MHz

7.4.1 Reference modulator diagram

The functional block diagram in Figure 12 is provided as a reference for specifying the DQPSK CSS mode for both data rates 1 Mbit/s and 250 kbit/s. The functionality of the 1:2 DEMUX block is specified in 7.4.6. The functionality of the S/P block is specified in 7.4.7. The functionality of the Symbol Mapper block is specified in 7.4.8. The functionality of the Interleaver block is specified in 7.4.13. The functionality of the P/S block is specified in 7.4.9. The functionality of the QPSK mapper is specified in 7.4.9. The functionality of the chirp generator block mapper is specified in 7.4.12.