**IEEE P802.15**

**Wireless Personal Area Networks**

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| Re: | TG8 Call for Contributions (CFC) (15-14-0087-00-0008) |
| Abstract | This is the text of the BPM/BPSK Impulse Radio Ultra-Wideband PHY proposal in response to Call for Contributions of IEEE 802.15.8 group for PAC. |
| Purpose | This document provides the details of the PHY proposal to IEEE 802.15.8 |
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# [This is draft text for BPM/BPSK UWB PHY for TG8]

# Overview

# Definitions

***burst:*** group of ultra wide band (UWB) pulses occurring at consecutive chip periods

***complex channel:*** combination of a channel [radio frequency (RF) center frequency] and a ternary code sequence

***frame:*** format of aggregated bits that are transmitted together in time

***mean pulse repetition frequency (PRF);*** total number of pulses within a symbol divided by the symbol duration

***payload data:*** contents of a data message that is being transmitted

***peak pulse repetition frequency (PRF):*** maximum rate at which an ultra wide band (UWB) physical layer (PHY) emits pulses

***ranging frame (RFRAME):*** ultra wide band (UWB) frame having the ranging bit set in the physical layer (PHY) header (PHR)

***ranging marker (RMARKER):*** first ultra wide band (UWB) pulse of the first bit of the physical layer (PHY) header (PHR) of a ranging frame (RFRAME).

***symbol:*** a period of time and a portion of the transmitted signal that is logically considered to be a unit signaling event conveying some defined number of data bits or repeated portion of the synchronization signal.

# Acronyms and abbreviations

BPM burst position modulation

BPSK binary phase-shift keying

CRC cyclic redundancy check

DPS dynamic preamble selection

FCS frame check sequence

FEC forward error correction

LFSR linear feedback shift register

LSB least significant bit

MAC medium access control

MSB most significant bit

PHR PHY header

PHY physical layer

PPDU PHY protocol data unit

PRBS pseudo-random binary sequence

PRF pulse repetition frequency

PSD power spectral density

PSDU PHY service data unit

RF radio frequency

RFRAME ranging frame

RMARKER ranging marker

SFD start-of-frame delimiter

SHR synchronization header

SYNC synchronization

UWB ultra wide band

# General descriptions

## Concepts and architecture

## Topology

## Reference model

# MAC Layer

## Synchronization

UWB PHY PLACEHOLDER: In general MAC layer procedures should be applicable on top of the UWB PHY, however this place holder is to note that there may be some PHY specific elements to the synchronization procedures that need to be considered and noted here – e.g. MAC provisions for ranging and localization.

## Discovery

UWB PHY PLACEHOLDER: In general MAC layer procedures should be applicable on top of the UWB PHY, however this place holder is to note that there may be some PHY specific elements to the discovery procedures that need to be considered and noted here – e.g. MAC provisions for ranging and localization.

## Peering

UWB PHY PLACEHOLDER: In general MAC layer procedures should be applicable on top of the UWB PHY, however this place holder is to note that there may be some PHY specific elements to the peering procedures that need to be considered and noted here – e.g. MAC provisions for ranging and localization.

## Communications

UWB PHY PLACEHOLDER: In general MAC layer procedures should be applicable on top of the UWB PHY, however this place holder is to note that there may be some PHY specific elements to the communications procedures that need to be considered and noted here – e.g. MAC provisions for ranging and localization.

## Frame Check Sequence (FCS)

*<Note to editor: the text below is the standard text for FCS; this should be placed as a sub-clause within the clauses that deal with the general MAC frame format>*

The FCS comes at the end of all frames. The FCS is 2 octets in length and contains a 16-bit ITU-T CRC. The FCS is calculated over the complete frame beginning with the Frame Control (FC) octet(s). The FCS shall be calculated using the following standard generator polynomial of degree 16:

*G16(x) = x16+x12+x5+1*

The FCS shall be calculated for transmission using the following algorithm:

* Let *M(x) = b0xk–1 + b1xk – 2 +…+ bk–2x + bk – 1* be the polynomial representing the sequence of bits for which the checksum is to be computed.
* Multiply *M*(*x*) by *x*16, giving the polynomial x16 × *M(x).*
* Divide x16 × *M(x)* modulo 2 by the generator polynomial, *G*16(*x*)*,* to obtain the remainder polynomial, *R(x) = r0x15 + r1x14 +…+ r14x + r15*.
* The FCS field is given by the coefficients of the remainder polynomial, *R(x)*.

Here, binary polynomials are represented as bit strings, in highest polynomial degree first order.

As an example, consider an acknowledgment frame with no payload and the following 3 byte header:

0100 0000 0000 0000 0101 0110 [leftmost bit (b0) transmitted first in time]

 b0................................................................b23

The FCS for this case would be the following:

0010 0111 1001 1110 [leftmost bit (r0) transmitted first in time]

r0.......................................r15

A typical implementation is depicted in Figure 14.



1. Initialize the remainder register (r0 through r15) to zero.

2. Shift header and payload into the divider in the order of transmission (LSB first).

3. After the last bit of the data field is shifted into the divider, the remainder register contains the FCS.

4. The FCS is appended to the data field so that r0 is transmitted first.

Figure 14 – typical FCS implementation

# UWB Physical (PHY) layer specifications

## Common Band Plan for UWB PHY:





Notes:

* Minimum 10 dB bandwidth shall be 400 MHz
* For interworking between units that occupy less than the full band width available within a channel, the receiving device needs to know which of the mandatory frequencies are occupied by the transmitting device
* It is expected that this will be specified by a channel index number and a single octet bitmap with a bit for each of the mandatory frequencies a to h.

# BPM/BPSK UWB Physical (PHY) layer specification

## General

The UWB PHY employs a mean PRF that is nominally 16 MHz or optionally nominally 64 MHz. The UWB PHY waveform is based upon an impulse radio signaling scheme using band-limited data pulses. The UWB PHY supports two independent bands of operation:

* The low band, which consists of four channels and occupies the spectrum from 3.1 GHz to 4.8 GHz
* The high band, which consists of eleven channels and occupies the spectrum from 6.0 GHz to 10.6 GHz

Within each channel, there is support for at least two complex channels that have unique length 31 SHR preamble codes. The combination of a channel and a preamble code is termed a *complex channel*.

**[Additional preamble codes and PRF options may be added to increase number of complex channels available, this affects a number of clauses below which will be updated when these additional options are included]**

A combination of burst position modulation (BPM) and binary phase-shift keying (BPSK) is used to support both coherent and non-coherent receivers using a common signaling scheme. The combined BPM-BPSK is used to modulate the symbols, with each symbol being composed of an active burst of UWB pulses. The various data rates are supported through the use of variable-length bursts.

Figure 1 shows the sequence of processing steps used to create and modulate a packet. The sequence of steps indicated here for the transmitter is used as a basis for explaining the creation of the UWB waveform. Note that the receiver portion of Figure 1 is informative and meant only as a guide to the essential steps that any compliant UWB receiver needs to implement in order to successfully decode the transmitted signal.



Figure 1 - signal flow

## PPDU format

Figure 2 shows the format for the UWB frame, which is composed of three major components: the SHR preamble, the PHR, and the PSDU. For convenience, the PPDU packet structure is presented so that the leftmost field as written in this standard shall be transmitted or received first. All multiple octet fields shall be transmitted or received least significant octet first, and each octet shall be transmitted or received LSB first. The same transmission order should apply to data fields.

The SHR preamble is first, followed by the PHR, and finally the PSDU. The SHR preamble is always sent at the base rate for the preamble code. The PHR is sent at a nominal rate of 850 kb/s for all data rates above 850 kb/s and at a nominal of 110 kb/s for the nominal data rate of 110 kb/s. The PSDU is sent at the desired information data rate as defined in Table 3 – rate-dependent and timing dependent parameters.

The PSDU contains MAC layer messages.

### PPDU encoding process

The encoding process is composed of many steps as illustrated in Figure 2. The details of these steps are fully described in later sub-clauses, as noted in the following list, which is intended to facilitate an understanding of those details:

* Perform Reed-Solomon encoding on PSDU as described in 2.3.3.1.
* Produce the PHR as described in 2.2.6.1.
* Add SECDED check bits to PHR as described in 2.2.6.2 and prepend to the PSDU.
* Perform further convolutional coding as described in 2.3.3.2. Note that in some instances at the 27 Mb/s data rate, the convolutional encoding of the data field is effectively bypassed and two data bits are encoded per BPM-BPSK symbol.
* Modulate and spread PSDU according to the method described in 2.3.1 and 2.3.2. The PHR is modulated using BPM-BPSK at 850 kb/s or at 110 kb/s (for the 110 kb/s data rate) and the data field is modulated at the rate specified in the PHR.
* Produce the SHR preamble field from the SYNC field (used for AGC convergence, diversity selection, timing acquisition, and coarse frequency acquisition) and the SFD field (used to indicate the start of frame). The SYNC and SFD fields are described in 2.2.5.1 and 2.2.5.2, respectively.



Figure 2 – PPDU encoding process

Table 1 and Table 2 show how the 19 header bits (H0‑H18), N data bits (D0‑DN-1), and two tail bits (T0‑T1) are mapped onto the symbols. In these tables, the polarity bit column operation is an XOR. The tables also show when the transition from the header bit rate to the data bit rate takes place. Note that the delay line of the convolutional code is initialized to zero. For this reason, the position bit of Symbol 0 shall always be zero. This means that Symbol 0 is always transmitted in the first half of the first header symbol.

Table 1 – mapping of header bits, data bits and tail bits onto symbols with Viterbi rate 0.5



### Symbol structure

In the BPM-BPSK modulation scheme, a symbol is capable of carrying two bits of information: one bit is used to determine the position of a burst of pulses while an additional bit is used to modulate the phase (polarity) of this same burst.

The structure and timing of a symbol is illustrated in Figure 3. Each symbol shall consist of an integer number of possible chip positions, *Nc*, each with duration *Tc*. The overall symbol duration denoted by *Tdsym* is given by *Tdsym*= *NcTc*. Furthermore, each symbol is divided into two BPM intervals each with duration *TBPM* =*Tdsym* /2, which enables binary position modulation.

A burst is formed by grouping *Ncpb* consecutive chips and has duration *Tburst* = *NcpbTc*. The location of the burst in either the first half or second half of the symbol indicates one bit of information. Additionally, the phase of the burst (either –1 or +1) is used to indicate a second bit of information.

In each symbol interval, a single burst event shall be transmitted. The fact that burst duration is typically much shorter than the BPM duration, i.e., *Tburst* << *TBPM*, provides for some multi-user access interference rejection in the form of time hopping. The total number of burst durations per symbol, *Nburst*, is given by *Nburst* = *Tdsym* /*Tburst*. In order to limit the amount of inter-symbol interference caused by multipath, only the first half of each *TBPM* period shall contain a burst. Therefore, only the first *Nhop*= *Nburst*/4 possible burst positions are candidate hopping burst positions within each BPM interval. Each burst position can be varied on a symbol-to-symbol basis according to a time hopping code as described in 2.3.

Table 2 –mapping of header bits, data bits and tail bits onto symbols with Viterbi rate 1



### PSDU timing parameters

The PSDU rate-dependent parameters and timing-related parameters are summarized in Table 3. Within each channel {0:15}, the peak PRF shall be 499.2 MHz. This rate corresponds to the highest frequency at which a compliant transmitter shall emit pulses. Additionally, the mean PRF is defined as the total number of pulses emitted during a symbol period divided by the length of the symbol duration. During the SHR preamble portion of a UWB frame, the peak and mean PRFs are essentially the same since pulses are emitted uniformly during each preamble symbol. During the data portion of a PPDU, however, the peak and mean PRFs differ due to the grouping of pulses into consecutive chip durations.

There are two possible preamble code lengths (31 or 127) and two mean PRFs (15.6 MHz or 62.4 MHz). A compliant device shall implement support for the preamble code length of 31 and the 15.6 MHz mean PRFs for the PSDU as depicted in Table 3. The use of the length 127 code is optional; when implemented, the mean PRF of the PSDU shall be 62.4 MHz.

UWB channels {4, 7, 11, and 15} are all optional channels and are differentiated from other UWB channels by the larger bandwidth (> 500 MHz) of the transmitted signals. These channels overlap the lower bandwidth channels. The larger bandwidth enables devices operating in these channels to transmit at a higher power (for fixed PSD constraints), and thus they may achieve longer communication range. The larger bandwidth pulses offer enhanced multipath resistance. Additionally, larger bandwidth leads to more accurate range estimates. The admissible data rates, preamble code lengths, PRFs, and modulation timing parameters are listed in Table 3. Each UWB channel allows for several data rates that are obtained by modifying the number of chips within a burst while the total number of possible burst positions remains constant. Therefore, the symbol duration, *Tdsym*, changes to obtain the stated symbol rate and bit rates.



Figure 3 – symbol structure

Table 3 – rate-dependent and timing dependent parameters

|  |  |  |  |
| --- | --- | --- | --- |
| **Preamble****Code Length** | **Modulation & Coding** | **Data Symbol Structure** | **Data** |
| **Viterbi****Rate** | **RS****Rate** | **Overall****FEC Rate** | **#Burst****Positions per****Symbol Nburst** | **# Hop****Bursts****Nhop** | **# Chips****Per Burst****Ncpb** | **#Chips Per****Symbol** | **Burst****Duration****T burst (ns)** | **Symbol****Duration****Tdsym (ns)** | **Symbol****Rate****(MHz)** | **Bit Rate****Mb/s** | **Mean****PRF****(MHz)** |
| 31313131 | 0.50.50.51.0 | 0.870.870.870.87 | 0.440.440.440.87 | 32323232 | 8888 | 1281621 | 40965126432 | 256.4132.054.012.00 | 8205.131025.64128.2164.10 | 0.120.987.8015.60 | 0.110.856.8127.24 | 15.6015.6015.6015.60 |
| 127127127127 | 0.50.50.50.5 | 0.870.870.870.87 | 0.440.440.440.44 | 8888 | 2222 | 5126482 | 40965126416 | 1025.64128.2116.034.01 | 8205.131025.64128.2132.05 | 0.120.987.8031.20 | 0.110.856.8127.24 | 62.4062.4062.4062.40 |

The peak PRF is 499.2 MHz. This is the highest frequency in megahertz at which a compliant transmitter shall emit pulses. The peak PRF is also used to derive the chip duration *Tc* by the formula Tc = 1/peakPRF. The value of *Tc* is approximately 2 ns. The channel center frequencies and bandwidths are given in Table 11. Note that the bandwidth is not necessarily the inverse of the chip duration *Tc*. Pulse shape and bandwidth are further defined in 2.4.3.1.

The UWB PHY contains several optional data rates, preamble code lengths, and PRF. Table 3 describes the remaining timing parameters of Figure 3 for each permitted combination of preamble code length and PRF.

The preamble code length parameter denotes the length of the preamble code to be used during the SHR portion of a data frame. The code together with the channel number defines a complex channel. Individual codes to be used on each channel are given in Table 6 (length 31) and Table 7 (length 127).

The Viterbi rate parameter determines the rate of the convolutional code applied to the PSDU data bits. A value of 1 indicates that no convolutional coding is applied while a value of 0.5 indicates that a rate 1/2 code as described in 2.3.3.2 is applied to the PSDU data bits.

The RS rate parameters indicates the (63, 55) Reed-Solomon code rate, which is approximately 0.87. The Reed-Solomon code is applied to all the PSDU data bits that are transmitted by the UWB PHY. Reed-Solomon encoding is further described in 2.3.3.1.

The overall FEC rate is determine by the product of the Viterbi rate and the Reed-Solomon rate and has either a value of 0.44 or 0.87.

The burst-positions-per-symbol parameter is the total number of possible burst positions within the data symbol duration. *Nburst* has been chosen so that for each mean PRF a data symbol consists of a fixed number of burst durations.

The hop bursts parameter is the number of burst positions that may contain an active burst, that is, a burst containing UWB pulses. The value is computed as *Nhop = Nburst*/4.

The chips per burst parameter is the number of chip *Tc* durations within each burst period *Tburst*. Each burst consists of a multiple number of consecutive chips, as illustrated in Figure 3. Depending on the data rate to be used in the transmission of the PSDU, the number of chips in a burst varies, e.g., for low data rates, the burst consists of more chip periods than for high data rates. Particular, values of *Ncpb* have been selected so that the following is a valid data rate: (2 × Overall FEC rate)/(*Ncpb × Nburst × Tc*).

The burst duration is computed as *Tburst = Ncpb × Tc*.

The symbol duration is the duration of a modulated and coded PSDU symbol on the air and is computed as follows: *Tdsym = Nburst × Tburst*.

The symbol rate is the inverse of the PSDU symbol duration 1/*Tdsym*.

The bit rate is the user information rate considering FEC and is computed as follows:

*Bit Rate* = 2 × (*Overall FEC Rate*)/*Tdsym*

The mean PRF is the average PRF during the PSDU portion of a PHY frame and is computed as follows:

*Mean PRF = Ncpb/Tdsym*

### Preamble timing parameters

Due to the variability in the preamble code length and the PRF, there are several admissible values for the timing parameters of a preamble symbol. These values are summarized in Table 4. In this subclause, a preamble symbol is defined as the waveform consisting of one whole repetition of the modulated preamble code (either length 31 or 127). Details on the construction of the preamble symbol for various code lengths and PRFs are given in 2.2.5. For each target PRF, the preamble is constructed from a preamble code, *Ci*, by inserting a number of chip durations between code symbols. The number of chip durations to insert is denoted by *δL*, values for each code length and PRF are given in Table 4, and the chip insertion is detailed in 2.2.5.1.

Table 4 presents the timing parameters during the SHR portion of a UWB PHY frame while Table 3 presents the timing parameters for the PSDU portion of the frame. First, note that the preamble is sent at a slightly higher mean PRF than the data as defined in Table 3. This is due to the fact that length 31 or 127 ternary codes are being used within the SHR, and the number of chips within the SHR is no longer a power of 2. For example, for the 16 MHz PRF in channels {0:3, 5:6, 8:10, 12:14), the peak PRF during the preamble is 31.2 MHz, and the corresponding mean PRF during the preamble is 16.10 MHz. The mean PRF during the data (PSDU) is 15.60 MHz. The remaining peak and mean PRF values for other optional UWB channels and the optional length 127 code are listed in Table 4.

Table 4 – preamble parameters

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *Ci* Code Length | Peak PRF (MHz) | Mean PRF (MHz) | Delta Length δL | #Chips Per Symbol | Symbol Duration *Tpsym*(ns) | Base Rate Msymbol/s |
| 31 | 31.20 | 16.10 | 16 | 496 | 993.59 | 1.01 |
| 127 | 124.80 | 62.89 | 4 | 508 | 1017.63 | 0.98 |

The base symbol rate is defined as the rate at which the preamble symbols are sent. The base rate corresponding to the (default) mean PRF of 16.10 MHz is 1 Msymbol/s. This symbol rate corresponds to preamble symbol duration, *Tpsym*, of 993.59 ns.

Table 5 – frame-dependent parameters

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Description** | **Value** |
| *Channel* | UWB PHY channel number | {1:15} |
| *PRFmean* | Mean PRF (MHz) | 16.10 | 62.89 |
| *Nc* | Number of chips per preamble symbol | 496 | 508 |
| *Tpsym* | Preamble symbol duration (ns) | 993.6 | 1017.6 |
| *Nsync* | Number of symbols in the packet sync sequence. | 64 to 4096 |
| *Tsync* | Duration of the packet sync sequence (μs) | 63.6 to 4069.7 | 65.1 to 4168.2 |
| *Nsfd* | Number of symbols in the SFD | 8 (or 64) |
| *Tsfd* | Duration of the SFD (μs) | 7.9 (or 63.6) | 8.1 (or 65.1) |
| *Npre* | Number of symbols in the SHR preamble | 72 to 4104 (or 128 to 4160) |
| *Tpre* | Duration of the SHR preamble (μs) | 71.5 to 4077.7(or 127.2 to 4133.3) | 73.3 to 4176.3 (or 319.5 to 4422.6) |
| *NCCA\_PHR* | Number of multiplexed preamble symbols in PHR | 4 or 32 |
| *NCCA\_data* | Number of multiplexed preamble symbols in the data field | *Tpre*/(4 × *Tdsym/M*) |

Note: the values in brackets apply to the 110 Kb/s data rate.

Finally, for each UWB frame consisting of the SHR, SFD, PHR, and a data field, there are four possible durations of the SHR. This is due to the four possible lengths of SYNC field in the SHR, as described in 2.2.5. The SYNC field consists of repetitions of the preamble symbol. The number of preamble symbol repetitions may be 64, 1024, or 4096, with additional optional values of 128, 256, 512, 1536 and 2048. These different SYNC field lengths yield different time durations of the UWB frame. The relationship between SYNC field length and frame duration is shown in Table 5. After the insertion of the SFD (the SFD may be either 8 or 64 preamble symbols long), the total length (in preamble symbols) of the SHR is *Npre* as shown in Table 5, and this in turn leads to the possible SHR durations denoted as *Tpre*. After creation of the SHR, the frame is appended with the PHR whose length, *Nhdr*, is 16 symbols and duration is denoted as *Thdr*. The values of the frame duration parameters are shown in Table 5.

### SHR preamble

A SHR preamble shall be added prior to the PHR to aid receiver algorithms related to AGC setting, antenna diversity selection, timing acquisition, coarse and fine frequency recovery, packet and frame synchronization, channel estimation, and leading edge signal tracking for ranging.

In this subclause, four different mandatory preambles are defined: a default preamble, a short preamble, a medium preamble, and a long preamble. The preamble to be used in the transmission of a frame is decided by the application layer.

Figure 4 shows the structure of the SHR preamble. The preamble can be subdivided into two distinct portions: SYNC (packet synchronization, channel estimation, and ranging sequence) and SFD (frame delimiter sequence). The duration of these portions are provided in Table 5. Subclauses 2.2.5.1 and 2.2.5.2 detail the different portions of the preamble.



Figure 4 – SHR preamble structure

#### SHR SYNC field

Each network operating on one of the UWB PHY channels {1–15} is also identified by a preamble code. The preamble code is used to construct symbols that constitute the SYNC portion of the SHR preamble as shown in Figure 4.

The UWB PHY supports two lengths of preamble code: a length 31 code and an optional length 127 code. Each preamble code is a sequence of code symbols drawn from a ternary alphabet {-1,0,1} and selected for use in the UWB PHY because of their perfect periodic autocorrelation properties. The length 31 code sequences are shown in Table 6 while the length 127 code sequences are shown in Table 7 where they are indexed from 1–24 (Ci i = 1,2,...24). The first 8 codes (index 1–8) are length 31 while the remaining 16 (index 9–24) are length 127. Which codes may be used in each of the channels is restricted, and the particular code assignments are made in Table 6 and Table 7. Specifically, the last column in each table indicates the set of channel numbers that permit use of the code. This restriction of codes is to ensure that codes with the lowest cross-correlation are used in the same channel. Additionally, 8 of the length 127 codes are reserved for use with the private ranging protocol only and are not used during normal operation. This restriction is indicated in the third column of Table 7 as well.

Table 6 – length 31 ternary codes

|  |  |  |
| --- | --- | --- |
| Code index | Code sequence | Channel numbera |
| 1 | -0000+0-0+++0+-000+-+++00-+0-00 | 1, 8, 12 |
| 2 | 0+0+-0+0+000-++0-+---00+00++000 | 1, 8, 12 |
| 3 | -+0++000-+-++00++0+00-0000-0+0- | 2, 5, 9, 13 |
| 4 | 0000+-00-00-++++0+-+000+0-0++0- | 2, 5, 9, 13 |
| 5 | -0+-00+++-+000-+0+++0-0+0000-00 | 3, 6, 10, 14 |
| 6 | ++00+00---+-0++-000+0+0-+0+0000 | 3, 6, 10, 14 |
| 7 | +0000+-0+0+00+000+0++---0-+00-+ | 4, 7, 11, 15 |
| 8 | 0+00-0-0++0000--+00-+0++-++0+00 | 4, 7, 11, 15 |
| **a-** Note code indices 1 through 6 may also be used for channels 4, 7, 11, and 15 (i.e., channels with bandwidth wider than 500 MHz) if interchannel communication is desired. |

Table 7 – length 127 ternary codes

| Code index | Code sequence | Channel numbera |
| --- | --- | --- |
| 9 | +00+000-0--00--+0+0+00-+-++0+0000++-000+00-00--0-+0+0--0-+++0++000+-0+00-0++-0+++00-+00+0+0-0++-+--+000000+00000-+0000-0-000--+ | 1–3, 5, 6, 8–10, 12–14 |
| 10 | ++00+0-+00+00+000000-000-00--000-0+-+0-0+-0-+00000+-00++0-0+00--+00++-+0+-0+0000-0-0-0-++-+0+00+0+000-+0+++000----+++0000+++0-- | 1–3, 5, 6, 8–10, 12–14 |
| 11 | -+-0000+00--00000-0+0+0+-0+00+00+0-00-+++00+000-+0+0-0000+++++-+0+--0+-0++--0-000+0-+00+0+----000-000000-+00+-0++000++-00++-0-0 | 1–3, 5, 6, 8–10, 12–14 |
| 12 | -+0++000000-0+0-+0---+-++00-+0++0+0+0+000-00-00-+00+-++000-+-0-++0-0++++0-00-0++00+0+00++-00+000+-000-0--+0000-0000--0+00000+-- | 1–3, 5, 6, 8–10, 12–14 |
| 13 | +000--0000--++0-++++0-0++0+0-00-+0++00++-0++0+-+0-00+00-0--000-+-00+0000-0++-00000+-0-000000-00-+-++-+000-0+0+0+++-00--00+0+000 | 1–15; DPS only |
| 14 | +000++0-0+0-00+-0-+0-00+0+0000+0+-0000++00+0+++++-+0-0+-0--+0++--000---0+000+0+0-+-000000+-+-0--00++000-00+00++-00--++-00-00000 | 1–15; DPS only |
| 15 | 0+-00+0-000-++0000---++000+0+-0-+00-+000--0-00--0--+++-+0-++00+-++0+00000+0-0+++-00+00+000-0000+00--+0++0+0+0-00-0-+-0+0++00000 | 1–15; DPS only |
| 16 | ++0000+000+00+--0+-++0-000--00+-0+00++000+++00+0+0-0-+-0-0+00+00+0++----+00++--+0+-0--+000000-0-0000-+0--00+00000+-++000-0-+0+0 | 1–15; DPS only |
| 17 | +--000-0-0000+-00000+000000+--+-++0-0+0+00+-00+++0-++0-00+0-+000++0+++-0--0+0+-0--00-00+000-++0000+0++-+-00+0+0+--00--0-000+00+ | 4, 7, 11, 15 |
| 18 | --0+++0000+++----000+++0+-000+0+00+0+-++-0-0-0-0000+0-+0+-++00+--00+0-0++00-+00000+-0-+0-0+-+0-000--00-000-000000+00+00+-0+00++ | 4, 7, 11, 15 |
| 19 | -0-++00-++000++0-+00+-000000-000----+0+00+-0+000-0--++0-+0--+0+-+++++0000-0+0+-000+00+++-00-0+00+00+0-+0+0+0-00000--00+0000-+-0 | 4, 7, 11, 15 |
| 20 | --+00000+0--0000-0000+--0-000-+000+00-++00+0+00++0-00-0++++0-0++-0-+-000++-+00+-00-00-000+0+0+0++0+-00++-+---0+-0+0-000000++0+- | 4, 7, 11, 15 |
| 21 | +0+00--00-+++0+0+0-000+-++-+-00-000000-0-+00000-++0-0000+00-+-000--0-00+00-0+-+0++0-++00++0+-00-0+0++0-0++++-0++--0000--000+000 | 1–15; DPS only |
| 22 | 0-00-++--00-++00+00-000++00--0-+-+000000-+-0+0+000+0---000--++0+--0-+0-0+-+++++0+00++0000-+0+0000+0+00-0+-0-+00-0+0-0++000+0000 | 1–15; DPS only |
| 23 | 000++0+0-+-0-00-0+0+0++0+--00+0000-000+00+00-+++0-0+00000+0++-+00++-0+-+++--0--00-0--000+-00+-0-+0+000++---0000++-000-0+00-+000 | 1–15; DPS only |
| 24 | +0+-0-000++-+00000+00--0+-0000-0-000000+--0-+0+--++00+----++0+00+00+0-0-+-0-0+0+00+++000++00+0-+00--000-0++-+0--+00+000+0000++0 | 1–15; DPS only |
| **a-** Note code indices 9 through 13 may also be used for UWB channels 4, 7, 11, and 15 (i.e., channels with bandwidth wider than 500 MHz) if interchannel communication is desired. |

Note that the assignment of preamble codes to channels has been done to enable interchannel communication. In other words, it is possible that a device operating on a wideband channel {4, 7, 11 or 15} may communicate with a device on a channel with which it overlaps.

When using the ternary code indexed by *i*, the SYNC field shall consist of *Nsync* repetitions of the symbol ***Si***,where ***Si*** is the code ***Ci***spread by the delta function δ*L* of length *L* as shown in Table 4. The spreading operation, where code ***Ci*** is extended to the preamble symbol duration indicated in Table 4, is described mathematically by



where the operator  indicates a Kronecker product. After the Kronecker operation, a preamble symbol is formed as depicted in Figure 5, where *L* – 1 zeros have been inserted between each ternary element of ***Ci****.*

The spreading factor *L*, number of chips per symbol, preamble symbol duration *Tpsym*, and base symbol rate for different channels are given in Table 4.



Figure 5 – construction of symbol *Si* from code *Ci*

#### SHR SFD

**[TEXT TO BE UPDATED WITH ADDITIONAL SFD OPTIONS]**

Length 8 SFD (15.4a compatable): 0+0−+00−

New length 8 SFD for optional use at 6.8Mbps: −−−−+−00

New length 16 SFD for optional use at 850kbps: −−−−+−+−−++−−+00

Length 64 SFD (15.4a compatable):

0+0−+00−0+0−+00−−00+0−0+0+000−0−0−00+0−−0−+0000++00−−−+−++0000++

New length 64 SFD for optional use at 110kbps:

 −−−−−−−+−+−−−−−−+−−+−+−−+−−+−−+−−−++−−−+++−+−+−+−−−+−−+−−−−+++00

**[Original text TO BE UPDATED WITH ADDITIONAL SFD OPTIONS defined above]**

An SFD shall be added to establish frame timing. The UWB PHY uses a short SFD for default and medium data rates and a long SFD for the optional low data rate of 110 kb/s as shown in Figure 4. The short SFD shall be [0 +1 0 -1 +1 0 0 -1] spread by the preamble symbol *Si*, where the leftmost bit shall be transmitted first in time. The optional long SFD shall be obtained by spreading the sequence [0 +1 0 -1 +1 0 0 -1 0 +1 0 -1 +1 0 0 -1 -1 0 0 +1 0 -1 0 +1 0 +1 0 0 0 -1 0 -1 0 -1 0 0 +1 0 -1 -1 0 -1 +1 0 0 0 0 +1 +1 0 0 -1 -1 -1 +1 -1 +1 +1 0 0 0 0 +1 +1] by the preamble sequence *Si.* Note that the long SFD is eight times longer than the short SFD and consists of 64 preamble symbols, only 32 of which are active, and the other 32 are zeros. The structure of the SHR preamble and SFD are shown in Figure 4.

### PHY header (PHR)

**[Original text below to be updated to allow:**

1. **Option to send PHR at 6.8Mbps, (and possibly 27Mbps), to shorten frame and save power and air-time.**
2. **Modifications to allow longer frames (i.e. up to 1023 octets)**

**]**

A PHR, as shown in Figure 6, shall be added after the SHR preamble. The PHR consists of 19 bits and conveys information necessary for a successful decoding of the packet to the receiver. The PHR contains information about the data rate used to transmit the PSDU, the duration of the current frame’s preamble, and the length of the frame payload. Additionally, six parity check bits are used to further protect the PHR against channel errors.



Figure 6 – PHR bit assignment

The PHR shall be transmitted using the BPM-BPSK modulation outlined in 2.3. The PHR shall be transmitted at the nominal rate of 850 kb/s for all data rates above 850 kb/s and at the nominal rate of 110 kb/s for the nominal low data rates of 110 kb/s.

#### PHR rate, length, ranging, extension, preamble duration fields

The Data Rate field shall consist of two bits (R1, R0) that indicate the data rate of the received PSDU. The bits R1–R0 shall be set according to Table 9. The default value of the bits R1–R0 shall be set to 01 as this is the only mandatory data rate that is supported by a UWB-compliant PHY implementation. Support for other data rates listed in Table 9 is optional.

The Frame Length field, L6–L0, shall be an unsigned 7-bit integer number that indicates the number of octets in the PSDU that the MAC sublayer is currently requesting the PHY to transmit.

The Ranging Packet bit, RNG, indicates that the current frame is an RFRAME if it is set to 1; otherwise, it is set to 0.

The Header Extension bit, EXT, is reserved for future extension of the PHR. This bit shall be set to 0.

The Preamble Duration field, P1–P0, represents the length (in preamble symbols) of the SYNC portion of the SHR. P1–P0 shall be set according to Table 8. The default Preamble Duration setting is 01, which corresponds to a SYNC field of length 64 preamble symbols.

Table 8 – Preamble Duration field values

|  |  |
| --- | --- |
| P1–P0 | SYNC length(symbols) (Si) |
| 01 | 64 |
| 10 | 1024 |
| 11 | 4096 |

The Preamble Duration field is intended for use during ranging operations and is used by a receiver of the PHY frame to help determine at which preamble symbol the UWB PHY acquired and began tracking the preamble. A receiver may use the Preamble Duration field to set the value of its own preamble duration based upon the received value when communicating a ranging ACK packet. The optional values of 128, 256, 512, 1536 and 2048 cannot be encoded within the PHY header (PHR), but may be ascertained in the receiver by counting the number of preamble symbols received. Where one of these optional values is used the PHR encoding shall be the nearest smaller length value.

Table 9 – nominal data rates

|  |  |
| --- | --- |
| R1–R0 | Data rate Mb/s |
| 00 | 0.11 |
| 01 | 0.85 |
| 10 | 6.81 |
| 11 | 27.24 |

#### PHR SECDED check bits

The SECDED (single error correct, double error detect) field, C5–C0, is a set of six parity check bits that are used to protect the PHR from errors caused by noise and channel impairments. The SECDED bits are a simple Hamming block code that enables the correction of a single error and the detection of two errors at the receiver. The SECDED bit values depend on PHR bits 0–12 and are computed as follows:

C0 = *XOR* (R0, R1, L0, L2, L4, L5, EXT, P1)

C1 = *XOR* (R1, L2, L3, L5, L6, RNG, EXT, P0)

C2 = *XOR* (R0, L0, L1, L5, L6, RNG, EXT)

C3 = *XOR* (L0, L1, L2, L3, L4, RNG, EXT)

C4 = *XOR* (P0, P1)

C5 = *XOR* (R1, R0, L6, L5, L4, L3, L2, L1, L0, RNG, EXT, P1, P0, C4, C3, C2, C1, C0)

### Data field

The Data field is the last component of the PPDU and is encoded as shown in Figure 7.



Figure 7 – data field encoding process

The data field shall be formed as follows:

* Encode the PSDU using systematic Reed-Solomon block code, which adds 48 parity bits as described in 2.3.3.1.
* Encode the output of the Reed-Solomon block code using a systematic convolutional encoder as described in 2.3.3.2, except in the cases where the Viterbi rate for the modulation is 1.0 in Table 3. In these cases the convolutional encoder is bypassed.
* Spread and modulate the encoded block using BPM-BPSK modulation as described in 2.3.

## UWB PHY modulation

### Modulation mathematical framework

The transmit waveform during the *kth* symbol interval may be expressed as



This equation describes the time hopping with polarity scrambling, which improves interference rejection capabilities of the UWB PHY. The *kth* symbol interval carries two information bits  and . Bit  is encoded into the burst position whereas bit  is encoded into the burst polarity. The sequence  is the scrambling code used during the *kth* symbol interval,  is the *kth* burst hopping position, and *p*(*t*) is the transmitted pulse shape at the antenna input. The burst hopping sequence  provides for multiuser interference rejection. The chip scrambling sequence  provides additional interference suppression among coherent receivers as well as spectral smoothing of the transmitted waveform. Note that equation defines the transmitted signal during the valid burst interval; at all other possible burst positions, no signal shall be transmitted. A reference modulator illustrating the BPM-BPSK modulation is shown in Figure 8.



Figure 8 – reference symbol modulator

Note here that the FEC Encoder is not included if the modulation Viterbi rate is 1.0, as described in 2.2.7. In this case, the FEC encoder is replaced by a multiplexer which shall apply even bits to the position input and odd bits to the polarity input.

### Spreading

The time-varying spreader sequence  and the time-varying burst hopping sequence  shall be generated from a common PRBS scrambler.

The polynomial for the scrambler generator shall be 

where *D* is a single chip delay, *Tc*, element. This polynomial forms not only a maximal length sequence, but also is a primitive polynomial. By the given generator polynomial, the corresponding scrambler output is generated as

 where  denotes modulo-2 addition.

A linear feedback shift register (LFSR) realization of the scrambler is shown in Figure 9. The LFSR shall be initialized upon the transmission of bit 0 of the PHR. Note that *Ncpb* may change depending on the data rate and PRF in use during the PSDU. The LFSR shall not be reset after transmission of the PHR.



Figure 9 – LFSR implementation of the scrambler

The initial state of the LFSR shall be determined from the preamble code by first removing all the 0s in the ternary code and then replacing all the –1s with a zero. The first 15 bits of the resulting binary state shall be loaded into the LFSR. Table 10 shows an example of the above procedure for preamble code, *C*6 (length 31, preamble code index 6, see Table 6). Table 10 shows the initial state as well as the first 16 output bits from the scrambler.

Table 10 – Example LFSR initial state for preamble code 6

|  |  |
| --- | --- |
| Initial state(*s-15, s-14, …, s-1*) | LFSR output: First 16 bits *s0, s1, …, s15* (*s0* first in time) |
| 111000101101101 | 0010011101101110 |

Note that even though each device within a network use the same initial LFSR setting, the communication is asynchronous so that the hopping and scrambling provides interference rejection.

The LFSR shall be clocked at the peak PRF of 499.2 MHz as specified in Table 3. During the *kth* symbol interval, the LFSR shall be clocked *Ncpb* times, and the scrambler output shall be the *kth* scrambling code . Furthermore, the *kth* burst hopping position, shall be computed as follows:



where



As shown in Table 3, the number of hopping burst *Nhop* is always a power of two, and consequently *m* is always an integer. Note that for *Ncpb < m*,the LFSR is clocked *Ncpb* times, not *m* times.

For the mandatory mode with mean data PRF of 15.60 MHz, the numbers of hopping bursts is 8, as indicated in Table 3, and consequently *m* takes on the values 3 and the corresponding hopping sequence is as follows:

*h*

*k*





*s*

*k*

*N*

*c*

*p*

*b*

2

*s*

1

*k*

*N*

*c*

*p*

*b*

+

4

*s*

2

*k*

*N*

*c*

*p*

*b*

+

+

+

=

### Forward error correction (FEC)

The FEC used by the UWB PHY is a concatenated code consisting of an outer Reed-Solomon systematic block code and an inner half-rate systematic convolutional code. The inner convolutional code is not necessarily enabled at all data rates; the rows of Table 3 that have a Viterbi rate of 1 indicate that the inner convolutional code is disabled for the PSDU part of the PHY frame.

The FEC encoding of a block of *M* PSDU bits, *b0, b1, …, bM-1*, is shown in Figure 10. The Reed-Solomon encoder shall append 48 parity bits, *p0, p1, …, p47*, to the original block. This results in a Reed-Solomon encoded block of length *M* + 48. Where the Viterbi rate is 0.5, a half-rate systematic convolutional encoder shall encode the Reed-Solomon encoded block into a systematic coded block of length 2*M* + 96 bits. The convolutional systematic bits shall be used to encode the position of the burst whereas the convolutional parity bits shall be used to encode the polarity of the pulses within a burst. Where the Viterbi rate is 1.0, even outputs of the Reed-Solomon encoder *(b0, b2,..., bM–2, p0, p2,…, p46)* shall be used to encode the position of the burst, and odd outputs *(b1, b3,..., bM–1, p1, p3,…, p47)* shall be used to encode the polarity of the pulses. Note here that *M* is always an even number.

A noncoherent receiver cannot see the convolutional parity bits (parity bits), and consequently a noncoherent receiver may use only a Reed-Solomon decoder to improve its performance. A coherent receiver may use either or both Reed-Solomon and convolutional decoding algorithms. Note here that since both the Reed-Solomon and the convolutional codes are both systematic, a receiver (either coherent or noncoherent) may be implemented without an FEC decoder. In this case, the information bits are simply recovered by demodulating the position of the burst. There will be additional parity check bits as a result of the Reed-Solomon encoding, but these may be simply ignored.



Figure 10 – FEC encoding process

#### Reed-Solomon encoding

The systematic Reed-Solomon code is over Galois field, GF(26), which is built as an extension of GF(2). The systematic Reed-Solomon code shall use the generator polynomial



where α = 010000 is a root of the binary primitive polynomial  in GF(26).

In Reed-Solomon encoding RS6(*K* + 8, *K*), a block of *I* bits (with ) is encoded into a codeword of *I* + 48 bits. The Reed-Solomon encoding procedure is performed in the following five steps:

* *Addition of dummy bits*. The  block  of  *I* information  bits  is  expanded  to  330 bits by adding 330 – *I*dummy (zero) bits to the beginning of the block. The expanded block is denoted as {*d*0*, d*1*, ..., d*329} where *d*0 is the first in time.
* *Bit-to-symbol conversion*. The 330 bits {*d*0*, d*1*, ..., d*329} are converted into 55 Reed-Solomon symbols {*D*0*, D*1*, ..., D*54} having the following polynomial representation:



Resulting 6-bit symbols are presented as , where *d*6k+5 is the MSB and *d*6k is the LSB.

* *Encoding*. The information symbols {*D*0*, D*1*, ..., D*54} are encoded by systematic RS6(63,55) code with output symbols {*U*0*, U*1*, ..., U*62} ordered as follows:



where *Pk* are parity check symbols added by RS6(63,55) encoder.

The information polynomial associated with the information symbols {*D*0*, D*1*, ..., D*54} is denoted as . The parity check polynomial associated with the parity check symbols is denoted as . The parity check symbols are calculated as:



* *Symbol-to-bit conversion*. The output symbols {*U*0*, U*1*, ..., U*62} are converted into binary form with LSB coming out first, resulting in a block of 378 bits {*u*0*, u*1*, ..., u*377}.
* *Removal of dummy bits*. The 330 – *I* dummy bits added in the first step are removed. Only the last *I*+ 48 bits are transmitted, i.e., {*u*330-*I, u*331-*I, ..., u*377} with *u*330-*I* being first in time.

#### Systematic convolutional encoding

The inner convolutional encoder shall use the rate *R* = ½ code with generator polynomials *g*0 = [010]2 and *g*1= [101]2 as shown in Figure 11. Upon transmission of each PPDU, the encoder shall be initialized to the all zero state. Additionally, the encoder shall be returned to the all zero state by appending two zero bits to the PPDU. Note that since the generator polynomials are systematic, they are also noncatastrophic.



Figure 11 – systematic convolutional encoder

## UWB PHY RF requirements

### Operating frequency bands

The set of operating frequency bands are as defined in Table 11. Default channel is channel 5.

### Channel assignments

For each of the 15 operating frequency bands defined in Table 11, at the nominal 16 MHz PRF, two preamble codes are assigned, as per Table 6, giving a total of 30 complex channels. At the optional nominal 64 MHz PRF, an additional 60 complex channels are available by employing the four preamble codes assigned for each channel as per Table 7.

**[This table from 15.4a may be removed/merged with common band plan agreed for 15.8 UWB PHY]**

Table 11 – band allocation

| Channel number (decimal) | Center frequency, *fc* (MHz) | Band width (MHz) |
| --- | --- | --- |
| 1 | 3494.4 | 499.2 |
| 2 | 3993.6 | 499.2 |
| 3 | 4492.8 | 499.2 |
| 4 | 3993.6 | 1331.2 |
| 5 | 6489.6 | 499.2 |
| 6 | 6988.8 | 499.2 |
| 7 | 6489.6 | 1081.6 |
| 8 | 7488.0 | 499.2 |
| 9 | 7987.2 | 499.2 |
| 10 | 8486.4 | 499.2 |
| 11 | 7987.2 | 1331.2 |
| 12 | 8985.6 | 499.2 |
| 13 | 9484.8 | 499.2 |
| 14 | 9984.0 | 499.2 |
| 15 | 9484.8 | 1354.97 |

### Transmitter specification

#### Baseband impulse response

The transmitted pulse shape *p*(*t*) of the UWB PHY shall be constrained by the shape of its cross-correlation function with a standard reference pulse, *r*(*t*). The normalized cross-correlation between two waveforms is defined as



In the above, *Er* and *Ep* are the energies of *r*(*t*) and *p*(*t*), respectively. The reference *r*(*t*) pulse used in the calculation of is a root raised cosine pulse with roll-off factor of β = 0.5. Mathematically this is



In the above equation, *Tp* is the reciprocal of the chip frequency. Table 12 shows the required pulse duration for each channel.

Table 12 – required reference pulse durations in each channel

| Channel number | Pulse duration, *Tp* (ns) | Main lobe width, *Tw* (ns) |
| --- | --- | --- |
| {1:3, 5:6, 8:10, 12:14} | 2.00 | 0.5 |
| 7 | 0.92 | 0.2 |
| {4, 11} | 0.75 | 0.2 |
| 15 | 0.74 | 0.2 |

In order for a UWB PHY transmitter to be compliant with this standard, the transmitted pulse *p*(*t*) shall have a magnitude of the cross-correlation function  whose main lobe is greater or equal to 0.8 for a duration of at least *Tw* (see Table 12), and any sidelobe shall be no greater than 0.3. For the purposes of testing a pulse for compliance, the following are defined: Let  be the magnitude of the cross-correlation of *p*(*t*) and *r*(*t*), and let  *i =* 1,2,... be a set of critical points, i.e. points at which . The maximum of the function occurs at one of these critical points,  where  for all values of . The requirement above thus states that for some continuous set of values that contain the point  the function  is greater than 0.8. In addition, the second constraint on the value of sidelobes may be stated mathematically as  for all .

Figure 12 shows an example UWB-compliant pulse, *p*(*t*) (left plot), along with the root raised cosine reference pulse *r*(*t*) (middle plot) with *Tp =* 2.0 nsand the magnitude of the cross-correlation  (right plot). The pulse *p*(*t*) is an 8 order butterworth pulse with a 3 dB bandwidth of 500 MHz. The figure is intended to show that this example pulse meets the requirements for compliance. Specifically, the main lobe is above 0.8 for nearly 1 ns, and no sidelobe is greater than 0.3 (in this case, the largest sidelobe peak is 0.2). The pulse *p*(*t*) is a compliant pulse for channels {1:3, 5:6, 8:10, 12:14}.



Figure 12 – compliant pulse example

Note that it is not the intention of this standard to imply that pulse shaping shall occur at baseband, only that the measurements described here occur on the pulse envelope if shaping is done at passband.

#### Transmit PSD mask

The transmitted spectrum shall be less than –10 dBr (dB relative to the maximum spectral density of the signal) for  and –18 dBr for . For example, the transmit spectrum mask for channel 4 is shown in Figure 13. The measurements shall be made using 1 MHz resolution bandwidth and a 1 kHz video bandwidth.



Figure 13 – transmit spectrum mask for band 4

#### Chip rate clock and chip carrier alignment

A UWB transmitter shall be capable of chipping at the peak PRF given in Table 3 with an accuracy of ± 20 parts per million. In addition, for each UWB PHY channel, the center of transmitted energy shall be at the values listed in Table 11 also with an accuracy of ± 20 parts per million. The measurements shall be made using 1 MHz resolution bandwidth and a 1 kHz video bandwidth.

## Timestamps and time units

The UWB PHY supports precision ranging and localization through the capability of time stamping, using a *ranging counter,* the precise instant that RMARKERS are received (and transmitted) at the device antenna.

#### Time units

The time units used for ranging timestamps is defined by the least significant bit (LSB) of the time values which represents 1/128 of a chip time at the mandatory chipping rate of 499.2 MHz.

Note: The LSB of the ranging counter represents a time interval so small that an actual physical counter would have to run at a nominal 64 GHz to produce values with this resolution. An actual physical realization is not expected. Instead it is assumed that computational techniques will be used to generate sufficient of the less significant bits to yield the desired operational precision.

#### Antenna delays

The time of arrival and time of sending events relate to the RMARKER being at the antenna.

The receive timestamp will naturally occur in the digital domain of the receiver some period of time after the RMARKER arrives at the antenna. To calculate when the RMARKER was at the antenna, and generate an accurate time of arrival, all the system delays between the antenna and the internal digital receive timestamp need to be accounted for. This receive antenna delay then needs to be subtracted from the internal digital receive timestamp to give the time of arrival value.

Similarly in the transmitter all the system delays between the internal digital transmit timestamp and the antenna need to be accounted. This transmit antenna delay then needs to be added to the internal digital transmit timestamp to give the time of sending value, when the transmit RMARKER is at the antenna.

The mechanisms for determining these antenna delays are beyond the scope of this standard.