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Ultra-Wideband Design Library

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Contents

Chapter 1: Ultra-Wideband Design Library

Introduction

The Agilent EEsof Ultra-Wideband Design Library supports the UWB multi-band OFDM market. It follows IEEE P802.15-04/r0493r1, which is the latest version (September 2004) of the IEEE 802.15.3a proposal. Data rates 55 and 106.67 Mbps in the DataRate parameter in this design library are reserved for future use.

This design library focuses on the physical layer of UWB systems and is intended to be a baseline system for designers to get an idea of what nominal or ideal system performance would be. Evaluations can be made regarding degraded system performance due to system impairments that may include non-ideal component performance.

UWB Systems

In the high-data-rate wireless personal-area network (WPAN) space, two important solutions (one presented by the Multiband-OFDM Alliance and the other by the UWB Forum) provide similar data and range capabilities. Simply, these groups recognize that multiple UWB architectures are emerging to satisfy various price, data rate, and energy consumption requirements and that a means must be devised to enable their coexistence. This can be accomplished through a common physical-layer (PHY) standard that allows compliant UWB devices to use DS-UWB, MB-OFDM and/or some future UWB technology, while still inter-operating and coordinating in a shared UWB spectrum.

The direct-sequence UWB (DS-UWB) PHY protocol uses sub-nanosecond pulse sequences and occupies a lower-frequency band of 3.1 to 5 GHz and/or a higher-frequency band of 6 to 10.4 GHz. Different data rates are achieved through variable-length spreading sequences combined with 1/2- or 3/4-rate forward-error-correction codes. The data rates include 28, 55, 110, 220, 500, 660, 1,000 and 1,320 Mbps. The 660- and 1,320-Mbps modes operate without FEC for low energy consumption, specifically for handheld wireless devices.

MB-OFDM physical-layer protocol uses frequency hopping of 528-MHz-wide OFDM channels. The protocol uses 122 carriers or *tones*, of which 100 carry quadrature phase-shift keying modulated data. A basic 640-Mbps data rate combined with FEC rates of 11/32, 1/2, 5/8, or 3/4, and frequency-spreading ratios of 1, 2, or 4 on the carriers, results in data rates of 53.3, 80, 110, 160, 200, 320, and 480 Mbps. Multiple modes of operation include a mandatory 3-band mode (mode 1) operating between 3.1 and 5 GHz. Before any two MB-OFDM radios can communicate in their high-rate OFDM mode, they must first synchronize using a time-based sequence.

This UWB DL supports MB-OFDM proposal IEEE 802.15.3a.

The MB-OFDM (IEEE P802.15-04/0493r1) transmitter physical layer block diagram is shown in Figure 1-1; major specifications are listed in Table 1-1.

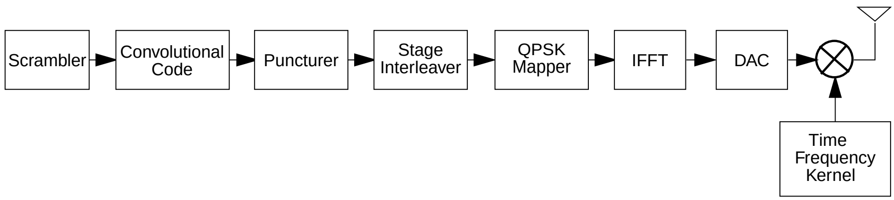


Figure 1-1. MB-OFDM Transmitter Physical Layer Block Diagram

Table 1-1. MB-OFDM Transmitter Physical Layer Major Specifications

Specification	Settings
Information data rate	53.3, 80, 110, 160, 200, 320, 400 and 480 Mbps (53.3, 110 and 200 Mbps are mandatory)
Modulation	QPSK OFDM
Error correcting code	K = 7 (64 states) convolutional code
Coding rate	1/3, 11/32, 1/2, 5/8, 3/4
Number of data subcarriers	100
Number of defined pilot subcarriers	10
Number of guard subcarriers	12
Number of total subcarriers used	122
Δ_F: Subcarrier frequency spacing	4.125 MHz (= 528 MHz/128)
T_{FFT}: IFFT/FFT period	242.42 ns ($1/\Delta_F$)
T_{ZP}: Zero pad duration	70.08 ns (= 37/528 MHz)

UWB Component Libraries

UWB component libraries are organized according to the type of behavioral models and subnetworks.

The Channel Coding library provides channel coding, scrambling and interleaving in the transmitter end, and channel decoding and de-interleaving in the receiving end (details in Chapter 2, Channel Coding Components) .

- UWB_FCS: UWB frame check sequence
- UWB_Interleaver: UWB interleaver or de-interleaver
- UWB_Puncturer: UWB puncturer or de-puncturer
- UWB_Scrambler: UWB scrambler

The Measurement library provides basic measurements (details in Chapter 3, Measurement Components) .

- UWB_EVM: UWB EVM measurement without frequency hopping
- UWB_FH_EVM: UWB EVM measurement with frequency hopping
- UWB_RF_CCDF: UWB CCDF measurement

The Multiplex library provides models for use with MB-OFDM systems (details in Chapter 4, Multiplex Components) .

- UWB_Conjugate: UWB conjugator
- UWB_DemuxDataPLCP: UWB PLCP and PSDU demultiplexer
- UWB_DemuxOFDMSym: UWB OFDM symbol demultiplexer
- UWB_GuardGain: UWB guard subcarriers gain
- UWB_MuxFrame: UWB frame multiplexer
- UWB_MuxHeadPSDU: UWB PLCP header and PSDU multiplexer
- UWB_MuxOFDMSym: UWB OFDM symbol multiplexer
- UWB_TimeSpreading: UWB time-domain spreader or despreader

The Receiver library provides models for use with UWB MB-OFDM receivers (details in Chapter 5, Receiver Components) .

- UWB_ChEstimator: UWB channel estimator

- UWB_DemuxFrame: frame de-multiplexer with frequency offset compensation, cyclic prefix and guard interval removed
- UWB_FrameSync: UWB coarse timing synchronizer
- UWB_FreqSync: UWB frequency synchronizer
- UWB_PhaseTracker: UWB phase tracker
- UWB_Receiver: UWB receiver
- UWB_Receiver_FH_RF: UWB RF frequency hopping receiver
- UWB_Receiver_RF: UWB RF receiver

The Signal Source library provides models for use with UWB MB-OFDM signal sources (details in Chapter 6, Signal Source Components).

- UWB_Freq_Hopping: UWB frequency hopping synthesizer
- UWB_PHY_Header: UWB physical header generator
- UWB_SignalSource: UWB signal source
- UWB_SignalSource_RF: UWB RF signal source
- UWB_Source_FH_RF: UWB RF frequency hopping signal source
- UWB_TimeDomainSeq: UWB time domain synchronization sequence generator

Design Examples

Design examples for UWB receiver and transmitter projects are available in ADS at *File > Example Project > UWB*.

UWB_OFDM_Rx_prj provides UWB receiver test and measurement design examples based on IEEE P802.15-04/0493r1 (details in Chapter 7, Receiver Design Examples).

- UWB_OFDM_RxSensitivity.dsn: minimum receiver sensitivity measurement
- UWB_OFDM_PER_vs_Range_AWGN.dsn: PER performance under an AWGN channel
- UWB_OFDM_PER_vs_Range_Fading.dsn: PER performance under multipath channel

UWB_OFDM_Tx_prj provides UWB transmitter test and measurement design examples based on IEEE P802.15-04/0493r1 (details in Chapter 8, Transmitter Design Examples).

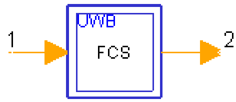
- UWB_OFDM_Demo.dsn: encodes a multi-band OFDM PHY frame.
- UWB_OFDM_TxCCDF.dsn: measures the complementary cumulative distribution function of the transmitted signal.
- UWB_OFDM_TxEVM.dsn: measures error vector magnitude and records constellations of the reference signal and the signal to be measured. The transmitter is a UWB RF signal source with frequency hopping that provides a reference signal.
- UWB_OFDM_TxEVM_TruncatedSignal.dsn: measures error vector magnitude and records constellations of the signal to be measured. The transmitter is a UWB RF signal source without frequency hopping and without a reference signal. The signal provided by the transmitter can be arbitrarily truncated when the signal is longer than one frame.
- UWB_TxSpectrum.dsn: measures transmitter signal power spectrum density.

Glossary of Terms

AWGN	additive white Gaussian noise
CCDF	complementary cumulative distribution function
CSMA/CA	carrier sense multiple access/collision avoidance
DS-UWB	direct-sequence UWB
EVM	error vector magnitude
FEC	forward error correction
FFT	fast Fourier transform
IEEE	Institute of Electrical and Electronic Engineering
IFFT	inverse fast Fourier transform
MAC	medium access control
MB-OFDM	multi-band orthogonal frequency division multiplexing
OFDM	orthogonal frequency division multiplexing
PA	power amplifier
PER	packet error rate
PHY	physical layer
PLCP	physical layer convergence protocol
PSDU	PLCP service data unit
QPSK	quadrature phase shift keying
RF	radio frequency
RX	receive or receiver
SDU	service data unit
TFC	time frequency code
TX	transmit or transmitter
UWB	ultra wideband
WPAN	wireless personal-area network

Chapter 2: Channel Coding Components

UWB_FCS



Description UWB frame check sequence
Library UWB, Channel Coding

Parameters

Name	Description	Default	Type	Range
DataLength	Octet number of PSDU	100	int	[1, 4095]

Pin Inputs

Pin	Name	Description	Signal Type
1	PSDU	data	int

Pin Outputs

Pin	Name	Description	Signal Type
2	output	output signals	int

Notes/Equations

1. This subnetwork model appends a frame check sequence after frame body.
2. Frame check sequence is a 32-bit field containing a 32-bit CRC. The FCS is calculated over the frame body field. Some systems in the 802 family use all fields of the MAC header and the frame body field for calculating the FCS; these are referred to as the *calculation fields*.

   FCS calculation using the standard generator polynomial of degree 32:

   $$G(\mathrm{x})=x^{32}+x^{26}+x^{23}+x^{22}+x^{16}+x^{12}+x^{11}+x^{10}+x^{8}+x^{7}+x^{5}+x^{4}+x^{2}+x+1$$

   FCS is the ones complement of the sum (modulo 2) of:

   - the remainder of $x^k(x^{31}+x^{30}+x^{29}+\cdots+x^2+x+1)$ divided (modulo 2) by $G(x)$ (where k is the number of bits in the calculation fields)

     and

- the remainder after multiplication of the contents (treated as a polynomial) of the calculation fields by x^{32}, then division by $G(x)$.

The FCS field is transmitted beginning with the coefficient of the highest-order term.

For a typical transmitter implementation, the initial remainder of the division is preset to all ones, then modified by dividing the calculation fields by generator polynomial $G(x)$. The ones-complement of this remainder is transmitted (with the highest-order bit first) as the FCS field.

3. The schematic for this subnetwork is shown in Figure 2-1.

   The CRC encoder consists of the division circuit and the control part for setting the initial value to all ones, implementing the division operation, exporting the remainder and taking a ones-complement of the remainder. The basic unit of the division circuit includes Delay and UWB_XOR; the Delay component simulates the register in the division circuit.

   UWB_XOR (schematic is shown in Figure 2-2) implements a logic exclusive OR operation for pin 1 and pin 2 inputs and sends the results to the Delay component if its input from pin 3 is 1; it will set the value of Delay to 1 if its input from pin 3 is 0.

4. DataLength is the *calculation field* length. The unit for DataLength is bytes instead of bits; so the length of information bits will be 8×DataLength.

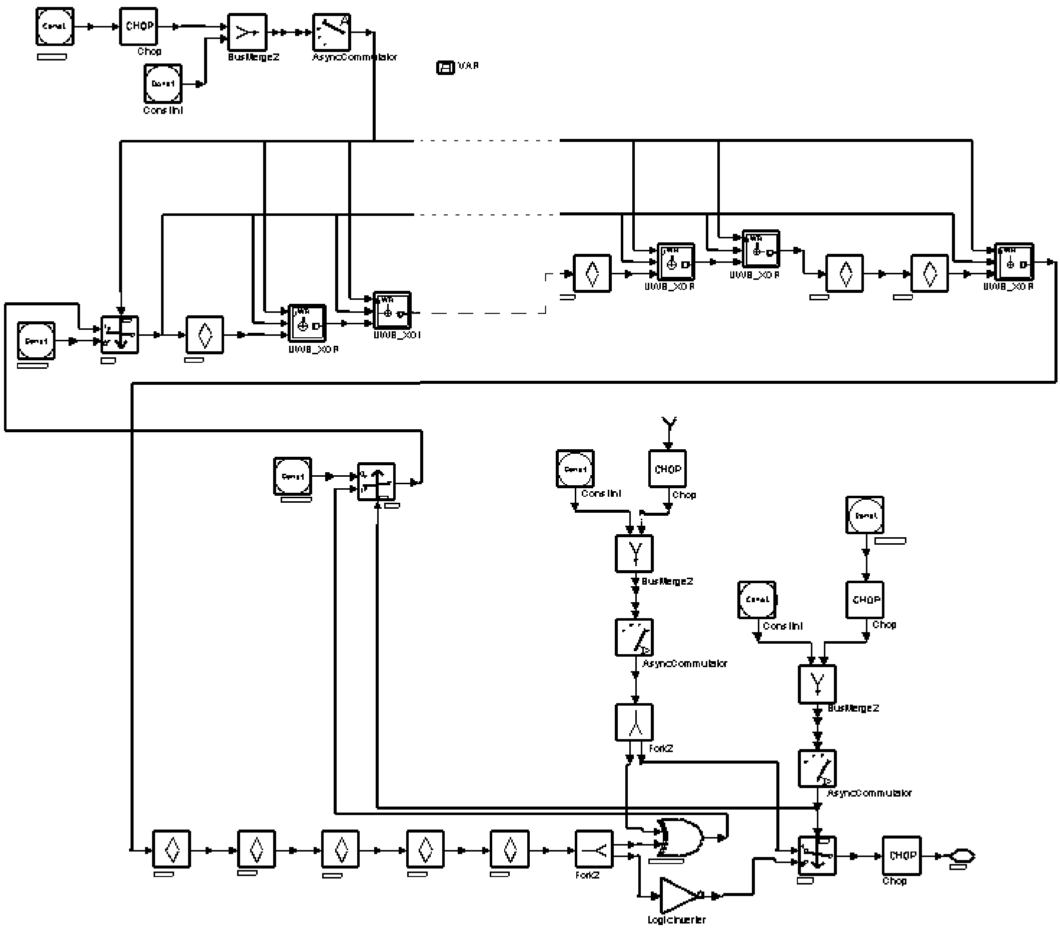


Figure 2-1. UWB_FCS Schematic

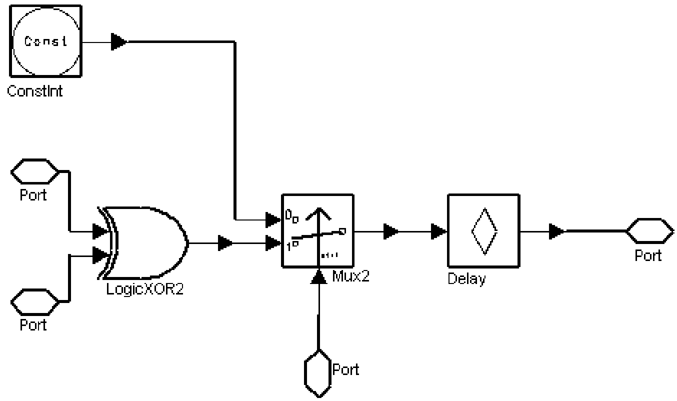


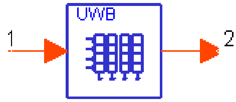
Figure 2-2. UWB_XOR Schematic

References

[1] IEEE P802.15-04/0493r1, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, September 2004.

[2] IEEE Standard 802.11-1999, *Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications*, 1999.

UWB_Interleaver



Description UWB interleaver or de-interleaver
Library UWB, Channel Coding
Class SDFUWB_Interleaver
Derived From UWB_Base

Parameters

Name	Description	Default	Type
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps	enum
InterleavingOption	Interleaving option: Interleaving, Deinterleaving	Interleaving	enum

Pin Inputs

Pin	Name	Description	Signal Type
1	Input	data to be processed	anytype

Pin Outputs

Pin	Name	Description	Signal Type
2	Output	processed data	anytype

Notes/Equations

1. This model performs interleaving or deinterleaving; the coded and padded bit stream is interleaved prior to modulation.
2. Each firing, $6/TSF \times N_{CBPS}$ tokens are consumed and $6/TSF \times N_{CBPS}$ tokens are generated. TSF is the time spreading factor; N_{CBPS} is the number of coded bits

per OFDM symbol. TSF and N_{CBPS} are based on the data rate as shown in Table 2-1.

Table 2-1. Data-Rate-Dependent Parameters

DataRate (Mbps)	Modulation	Coding Rate (R)	Conjugate Symmetric Input to IFFT	Time Spreading Factor (TSF)	Overall Spreading Gain	Coded Bits per OFDM Symbol (N_{CBPS})
53.3	QPSK	1/3	Yes	2	4	100
80	QPSK	1/2	Yes	2	4	100
110	QPSK	11/32	No	2	2	200
160	QPSK	1/2	No	2	2	200
200	QPSK	5/8	No	2	2	200
320	QPSK	1/2	No	1 (no spreading)	1	200
400	QPSK	5/8	No	1 (no spreading)	1	200
480	QPSK	3/4	No	1 (no spreading)	1	200

3. Bit interleaving is performed in three stages: symbol interleaving across the OFDM symbols; intra-symbol tone interleaving; and intra-symbol cyclic shifts. The symbol interleaver permutes bits across OFDM symbols to promote frequency across sub-bands; the tone interleaver permutes bits across the data tones within an OFDM symbol to promote frequency diversity across tones and provide robustness against narrow-band interferers.

   Symbol block interleaving is performed among the $6/TSF \times N_{CBPS}$ coded bits ($6/TSF$ symbols). Let sequences $\{U(i)\}$ and $\{S(i)\}$ represent the input and output bits of the symbol block interleaver, respectively. The input-output relationship of this interleaver is given by:

$$S(i) = U\left\{Floor\left(\frac{i}{N_{CBPS}}\right) + (6/TSF) \times Mod(i, N_{CBPS})\right\}$$

   $i=0, \ldots, (6/TSF \times N_{CBPS}-1)$

   where the function Floor(.) returns the largest integer value less than or equal to its argument value, and where Mod(.) returns the remainder after division of i by N_{CBPS}.

   The output of the symbol block interleaver is then passed through a tone block interleaver.The outputs of the symbol block interleaver are grouped into blocks of N_{CBPS} bits and then permuted using a regular block interleaver of size

$N_{Tint} \times 10$, where $N_{Tint}=N_{CBPS}/10$. Let sequences $\{S(i)\}$ and $\{T(i)\}$ represent the input and output bits of the tone block interleaver, respectively. The input-output relationship of this interleaver is given by:

$$T(i) = S\left\{Floor\left(\frac{i}{N_{Tint}}\right) + 10Mod(i, N_{Tint})\right\}$$

$i=0, \ldots, N_{CBPS}-1$

The output of the tone block interleaver is then passed through the last stage, which consists of a different cyclic shift of each block of N_{CBPS} bits within the span of the symbol block interleaver defined above. Let $\{T(b,i)\}$ and $\{V(b,i)\}$ represent the input and output sequences, respectively. The input-output relationship is given by:

$$V(b, i) = T(b, Mod(i + A(b), N_{CBPS}))$$

$i=0, \ldots, N_{CBPS}-1$

For conjugate symmetric mode, $N_{CBPS}=100$: $A(\mathrm{b})=b \times 33$, $b=0,1,2$

For non-conjugate symmetric mode with TSF=2, $N_{CBPS}=200$: $A(b)=b \times 66$, $b=0,1,2$

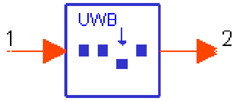
For non-conjugate symmetric mode with TSF=1, $N_{CBPS}=200$: $A(b)=\mathrm{b} \times 33$, $b=0,1,2, \ldots, 5$.

4. When InterleavingOption is set to Interleaving, interleaving is performed; otherwise, the reverse process is performed.

References

[1] IEEE P802.15-04/0493r1, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, September 2004.

UWB_Puncturer



Description UWB puncturer or de-puncturer
Library UWB, Channel Coding
Class SDFUWB_Puncturer
Derived From UWB_Base

Parameters

Name	Description	Default	Type	Range
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps	enum	
DataLength	Octet number of PSDU	100	int	[1, 4095]
InfoType	Information type: Header, PSDU	PSDU	enum	
PunctureMode	Type of puncture mode: Stealing, Inserting: Stealing, Inserting	Stealing	enum	

Pin Inputs

Pin	Name	Description	Signal Type
1	Input	data stream to be punctured or inserted	anytype

Pin Outputs

Pin	Name	Description	Signal Type
2	Output	punctured or inserted data stream	anytype

Notes/Equations

1. This model is used to delete some of the encoded bits on the transmitter side in order to derive various coding rates from R=1/3 convolutional code, or insert dummy 0 bits into the convolutional decoder on the receiver side in place of the omitted bits. For multirate information refer to note 5.

2. Set DataLength only when InfoType=PSDU.
3. If InfoType=Header, the PLCP header is processed; if InfoType=PSDU, the PLCP frame body is processed.
4. If PunctureMode=Stealing, omitting is performed; if PunctureMode=Inserting, inserting is performed.
5. Each firing, if PunctureMode=Stealing, *N1* tokens are consumed and *N2* tokens are output; else if PunctureMode=Inserting, *N2* tokens are consumed and *N1* tokens are output,

   where

   $$N1 = \lceil N_{sym} \times N_{CBPS} \times R \rceil \times 3$$

   $$N2 = N_{sym} \times N_{CBPS}$$

   where R is coding rate, N_{CBPS} is the number of coded bits per OFDM symbol, and $Nsym$ is the number of OFDM symbols of PLCP header or PLCP frame body before time-domain spreading.

   If InfoType=Header, $Nsym$ is 6; if InfoType=PSDU, $Nsym$ is calculated:

   $$Nsym = \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{8 \times DataLength + 32 + 6}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil$$

6. Puncture patterns are shown in Figure 2-3 through Figure 2-6. In each case, the tables are filled left to the right with encoder output bits. For the last block of bits, the process is stopped at the point at which the encoder output bits are exhausted, and the puncturing patterns applied to the partially filled block.

where *TSF* is time spreading factor, *DataLength* is the length, in bytes, of PLCP frame body data. *TSF*, *R*, N_{CBPS} are based on the data rate as shown in Table 2-2.

Table 2-2. Data-Rate-Dependent Parameters

Data Rate (Mbps)	Modulation	Coding Rate (R)	Conjugate Symmetric Input to IFFT	Time Spreading Factor (TSF)	Overall Spreading Gain	Coded bits per OFDM symbol (N_{CBPS})
53.3	QPSK	1/3	Yes	2	4	100
80	QPSK	1/2	Yes	2	4	100
110	QPSK	11/32	No	2	2	200
160	QPSK	1/2	No	2	2	200
200	QPSK	5/8	No	2	2	200
320	QPSK	1/2	No	1 (no spreading)	1	200
400	QPSK	5/8	No	1 (no spreading)	1	200
480	QPSK	3/4	No	1 (no spreading)	1	200

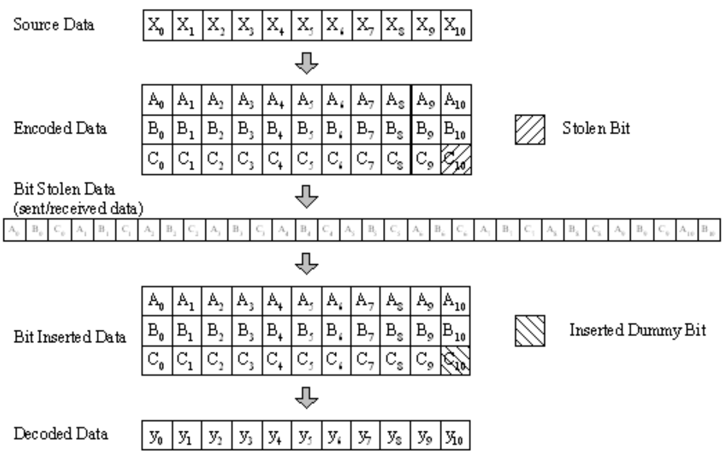


Figure 2-3. Puncture Patterns (R=11/32)

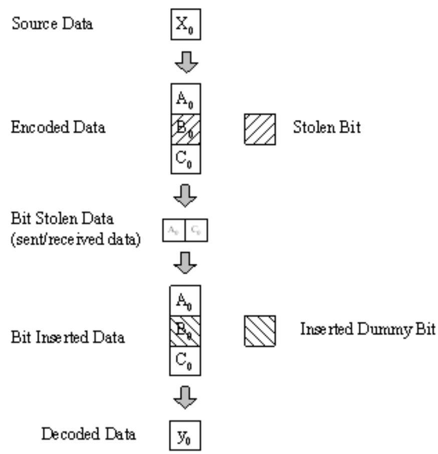


Figure 2-4. Puncture Patterns (R=1/2)

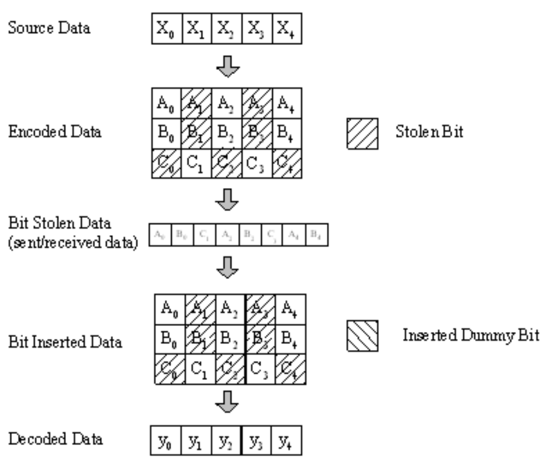


Figure 2-5. Puncture Patterns (R=5/8)

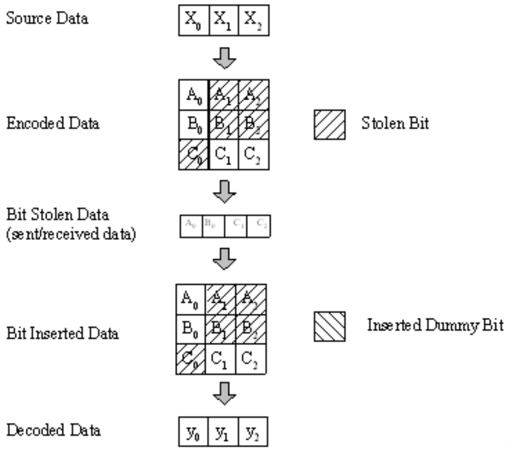
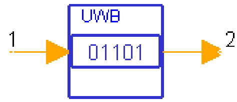


Figure 2-6. Puncture Patterns (R=3/4)

References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

UWB_Scrambler



Description UWB scrambler
Library UWB, Channel Coding
Class SDFUWB_Scrambler
Derived From UWB_Base

Parameters

Name	Description	Default	Type	Range
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps	enum	
DataLength	Octet number of PSDU	100	int	[1, 4095]
InfoType	Information type: Header, PSDU	PSDU	enum	
ScramblerSeed	Scrambler seed selection: Seed 00, Seed 01, Seed 10, Seed 11	Seed 00	enum	

Pin Inputs

Pin	Name	Description	Signal Type
1	Input	bits to be scrambled	int

Pin Outputs

Pin	Name	Description	Signal Type
2	Output	scrambled bits	int

Notes/Equations

1. This model is used to scramble the PLCP header or frame body.

   The PLCP frame format is shown in Figure 2-7.

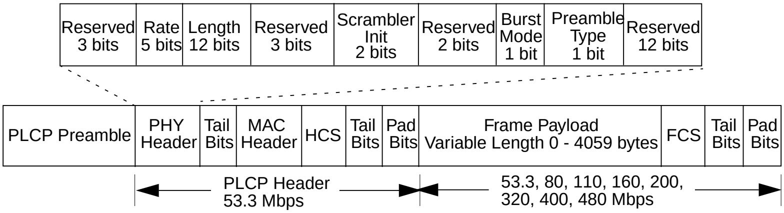


Figure 2-7. PLCP Frame Format

If InfoType=Header, the PLCP header is scrambled. Each firing, 200 tokens are consumed and 200 tokens are output. That is, contents of the entire PLCP header are consumed, but only the combination of the MAC Header, HCS, the tail bits following it, and the pad bits will be scrambled; tail bits following HCS will be reset to zero after scrambling.

If InfoType=PSDU, the PLCP frame body is scrambled. Each firing, N tokens are consumed and N tokens are output That is, contents of the entire PLCP frame body are consumed and all bits are scrambled; tail bits following FCS will be reset to zero after scrambling.

$$N = \lceil Nsym_{PSDU} \times N_{CBPS} \times R \rceil$$

where R is the coding rate of PSDU, N_{CBPS} is the number of coded bits per OFDM symbol, and $Nsym_{PSDU}$ is the number of OFDM symbols of PSDU before time-domain spreading.

$$Nsym_{PSDU} = \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{8 \times DataLength + 32 + 6}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil$$

where TSF is time spreading factor, and $DataLength$ is the length, in bytes, of PLCP frame body data. TSF, R, N_{CBPS} are based on the data rate as shown in Table 2-3.

Table 2-3. Data-Rate-Dependent Parameters

Data Rate (Mbps)	Modulation	Coding Rate (R)	Conjugate Symmetric Input to IFFT	Time Spreading Factor (TSF)	Overall Spreading Gain	Coded bits per OFDM symbol (N_{CBPS})
53.3	QPSK	1/3	Yes	2	4	100
80	QPSK	1/2	Yes	2	4	100

Table 2-3. Data-Rate-Dependent Parameters (continued)

Data Rate (Mbps)	Modulation	Coding Rate (R)	Conjugate Symmetric Input to IFFT	Time Spreading Factor (TSF)	Overall Spreading Gain	Coded bits per OFDM symbol (N_{CBPS})
110	QPSK	11/32	No	2	2	200
160	QPSK	1/2	No	2	2	200
200	QPSK	5/8	No	2	2	200
320	QPSK	1/2	No	1 (no spreading)	1	200
400	QPSK	5/8	No	1 (no spreading)	1	200
480	QPSK	3/4	No	1 (no spreading)	1	200

2. The polynomial generator for PRBS used to scramble the input bits is $g(D)=1+D^{14}+D^{15}$, where D is a single bit delay. The polynomial not only forms a maximal length sequence, but is also a primitive polynomial. Using this generator, the corresponding PRBS, x_n is generated as

$$x_n = x_{n-14} \oplus x_{n-15}$$

where

n=0, 1, 2, ...

The following sequence defines initialization vector x_{init} that is specified by the seed value in Table 2-4.

$$x_{init} = [x^i_{n-1} x^i_{n-1} \ldots x^i_{n-14} x^i_{n-15}]$$

where

$$x^i_{n-k}$$

represents the binary initial value at the output of the kth delay element.

Table 2-4. Scrambler Seed Selection

Seed Identifier (S_1,S_2)	Seed Value ($x_{-1}x_{-2}...x_{-14}x_{-15}$)	Scrambler Output First 16 bits $x_0x_1...x_{15}$
0,0	0011 1111 1111 111	0000000000001000
0,1	0111 1111 1111 111	0000000000000100
1,0	1011 1111 1111 111	0000000000001110
1,1	1111 1111 1111 111	0000000000000010

3. At the first firing, the seed identifier used to initialize the PRBS is specified by ScramblerSeed. At subsequent firings, the PRBS is initialized with seed identifier increased in a 2-bit rollover counter for each PLCP header or frame body.

4. Output scrambled data bits s_m are obtained as follows:

   $$s_m = d_m \oplus x_m$$

   where

   m=0, 1, 2 ...

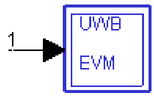
   d_m represents the unscrambled data bits.

References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

Chapter 3: Measurement Components

UWB_EVM



Description UWB EVM measurement without frequency hopping
Library UWB, Measurement

Parameters

Name	Description	Default	Unit	Type	Range
RLoad	Input resistance	DefaultRLoad	Ohm	real	(0, ∞)
RTemp	Temperature	DefaultRTemp	Celsius	real	[-273.15, ∞)
FCarrier	Carrier frequency	3432MHz	Hz	real	(0, ∞)
GainImbalance	Gain imbalance, Q vs I	0.0	dB	real	(-∞, ∞)
PhaseImbalance	Phase imbalance, Q vs I	0.0	deg	real	(-∞, ∞)
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps		enum	
DataLength	Octet number of PSDU	100		int	[1, 4095]
PreambleFormat	PLCP preamble format: Standard Format, Shortened Format	Standard Format		enum	
PreamblePattern	Preamble pattern for Time-domain synchronization sequence: Pattern 1, Pattern 2, Pattern 3, Pattern 4	Pattern 1		enum	
CoverSeq	Cover sequences for time domain preamble	1		int	[1, 2]
OversamplingOption	Oversampling ratio: Ratio 1, Ratio 2, Ratio 4, Ratio 8	Ratio 2		enum	
Bandwidth	Bandwidth	528 MHz	Hz	real	(0, ∞)
CyclicPrefix	Cyclic prefix with zero padding	70.08 nsec	sec	real	[0, ∞)
GuardInterval	Guard interval with zero padding	0.0 nsec	sec	real	[0, ∞)
IdleInterval	Idle Interval	0.0 nsec	sec	real	[0, ∞)

Name	Description	Default	Unit	Type	Range
ScramblerSeed	Scrambler seed selection: Seed 00, Seed 01, Seed 10, Seed 11	Seed 00		enum	
PilotPN_Phase	Phase of pilot PN	0		int	[0, 126]
SearchMode	Searching mode synchronization: EveryFrame, Once	EveryFrame		enum	
SearchWindow	Searching window synchronization	24		int	†
StartFrame	Start frame	0		int	[0, ∞)
FramesToAverage	Number of frames for the average RMSE	1		int	[1, ∞)
FrameLength	Frame length	4096		int	[1, ∞)
DisplayOption	Display option: RMS, dB	RMS		enum	

†The minimum value of this parameter should be the number of OFDM symbols in the synchronization sequences portion of the PLCP preamble, and the maximum value of this parameter should be the number of OFDM symbols in one MB-OFDM frame.

Pin Inputs

Pin	Name	Description	Signal Type
1	RF_Signal	received RF signal to be measured	timed

Notes/Equations

1. This subnetwork model measures the EVM of a UWB RF signal source; frequency hopping is not used, and a source reference signal is not required. Further, it supports the EVM measurement of an arbitrarily truncated UWB RF signal that is longer than one frame, which meets connected solution requirements.
2. The schematic for this subnetwork is shown in Figure 3-1.

   UWB_Receiver_RF extracts the signal to be measured, which is the baseband signal on which the EVM measurement is performed.

   Demapper and Mapper restore the reference signal by hard decision. RMSE calculates the root mean square error between the signal to be measured and the reference signal as the EVM measurement result. NumericSink RxConstellation records the constellation of the signal to be measured and NumericSink TxConstellation records the constellation of the reference signal.

Parameters RLoad through SearchWindow (as listed above) configure UWB_Receiver_RF; parameters StartFrame through DisplayOption configure RMSE.

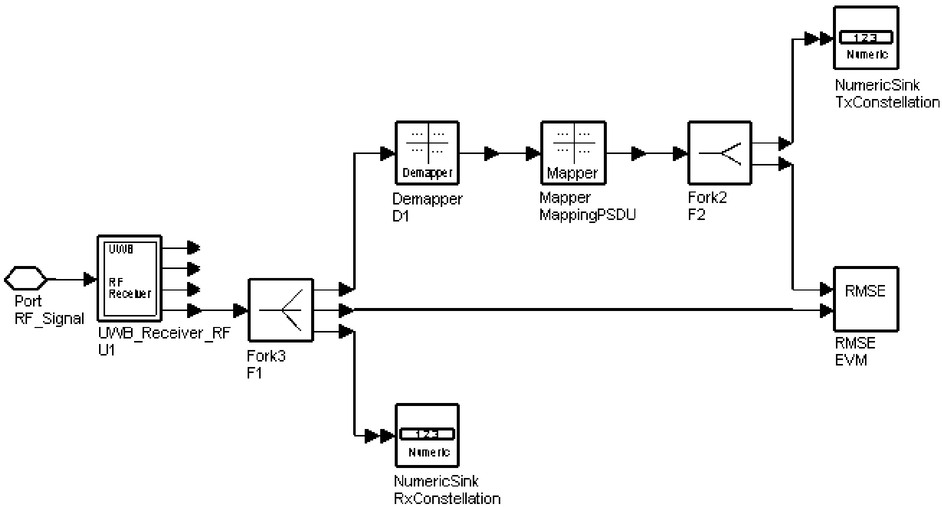
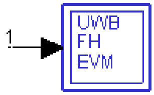


Figure 3-1. UWB_EVM Schematic

References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

UWB_FH_EVM



Description UWB EVM measurement with frequency hopping
Library UWB, Measurement

Parameters

Name	Description	Default	Unit	Type	Range
RLoad	Input resistance	DefaultRLoad	Ohm	real	(0, ∞)
RTemp	Temperature	DefaultRTemp	Celsius	real	[-273.15, ∞)
GainImbalance	Gain imbalance, Q vs I	0.0	dB	real	(-∞, ∞)
PhaseImbalance	Phase imbalance, Q vs I	0.0	deg	real	(-∞, ∞)
Delay	Frequency synthesizer delay	1.8939 nsec	sec	real	[0, ∞)
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps		enum	
DataLength	Octet number of PSDU	100		int	[1, 4095]
PreambleFormat	PLCP preamble format: Standard Format, Shortened Format	Standard Format		enum	
TFC_Number	Time frequency code: TFC1, TFC2, TFC3, TFC4, TFC5, TFC6	TFC1		enum	
OversamplingOption	Oversampling ratio: Ratio 1, Ratio 2, Ratio 4, Ratio 8	Ratio 2		enum	
Bandwidth	Bandwidth	528 MHz	Hz	real	(0, ∞)
CyclicPrefix	Cyclic prefix with zero padding	70.08 nsec	sec	real	[0, ∞)
GuardInterval	Guard interval with zero padding	0.0 nsec	sec	real	[0, ∞)
IdleInterval	Idle Interval	0.0 nsec	sec	real	[0, ∞)
ScramblerSeed	Scrambler seed selection: Seed 00, Seed 01, Seed 10, Seed 11	Seed 00		enum	
PilotPN_Phase	Phase of pilot PN	0		int	[0, 126]

Name	Description	Default	Unit	Type	Range
SearchMode	Searching mode synchronization: EveryFrame, Once	EveryFrame		enum	
SearchWindow	Searching window synchronization	24		int	†
StartFrame	Start frame	0		int	[0, ∞)
FramesToAverage	Number of frames for the average RMSE	1		int	[1, ∞)
FrameLength	Frame length	4096		int	[1, ∞)
DisplayOption	Display option: RMS, dB	RMS		enum	
†The minimum value of this parameter should be the number of OFDM symbols in the synchronization sequences portion of the PLCP preamble, and the maximum value of this parameter should be the number of OFDM symbols in one MB-OFDM frame.					

Pin Inputs

Pin	Name	Description	Signal Type
1	RF_Signal	received RF signal to be measured	timed

Notes/Equations

1. This subnetwork model measures the EVM of a UWB RF signal source; frequency hopping is used, and a source reference signal is not required.
2. The schematic for this subnetwork is shown in Figure 3-2.

   UWB_Receiver_FH_RF extracts the signal to be measured, which is the baseband signal used for the EVM measurement.

   Demapper and Mapper restore the reference signal by hard decision. RMSE calculates the root mean square error between the signal to be measured and the reference signal as the EVM measurement result. NumericSink RxConstellation records the constellation of the signal to be measured and NumericSink TxConstellation records the constellation of the reference signal.

   Parameters RLoad through SearchWindow (as listed above) configure UWB_Receiver_FH_RF; parameters StartFrame through DisplayOption RMSE.

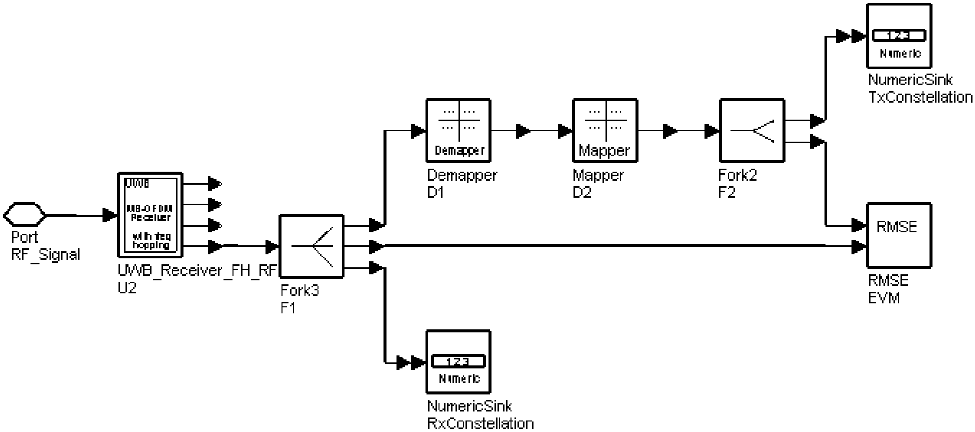
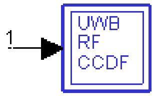


Figure 3-2. UWB_FH_EVM Schematic

References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

UWB_RF_CCDF



Description UWB CCDF measurment
Library UWB, Measurement

Parameters

Name	Description	Default	Unit	Type	Range
RLoad	Input resistance	DefaultRLoad	Ohm	real	(0, ∞)
RTemp	Temperature	DefaultRTemp	Celsius	real	[-273.15, ∞)
StartSym	Symbol from which measurement begin	25740		int	[0, ∞)
BurstLen	length of input signal burst	6600		int	[1, ∞)
BurstNum	Number of bursts	78		int	[1, ∞)
OutputPoint	Indicate output precision	100		int	[1, ∞)
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps		enum	
DataLength	Octet number of PSDU	100		int	[1, 4095]
PreambleFormat	PLCP preamble format: Standard Format, Shortened Format	Standard Format		enum	
PreamblePattern	Preamble pattern for Time-domain synchronization sequence: Pattern 1, Pattern 2, Pattern 3, Pattern 4	Pattern 1		enum	
CoverSeq	Cover sequences for time domain preamble	1		int	[1, 2]
OversamplingOption	Oversampling ratio: Ratio 1, Ratio 2, Ratio 4, Ratio 8	Ratio 2		enum	
Bandwidth	Bandwidth	528 MHz	Hz	real	(0, ∞)
CyclicPrefix	Cyclic prefix with zero padding	70.08 nsec	sec	real	[0, ∞)

Name	Description	Default	Unit	Type	Range
GuardInterval	Guard interval with zero padding	0.0 nsec	sec	real	[0, ∞)
IdleInterval	Idle Interval	0.0 nsec	sec	real	[0, ∞)

Pin Inputs

Pin	Name	Description	Signal Type
1	RF_Signal	received RF signal to be measured	timed

Notes/Equations

1. This subnetwork model measures the complementary cumulative distribution function (CCDF) of the RF signal.

   The schematic for this subnetwork is shown in Figure 3-3.

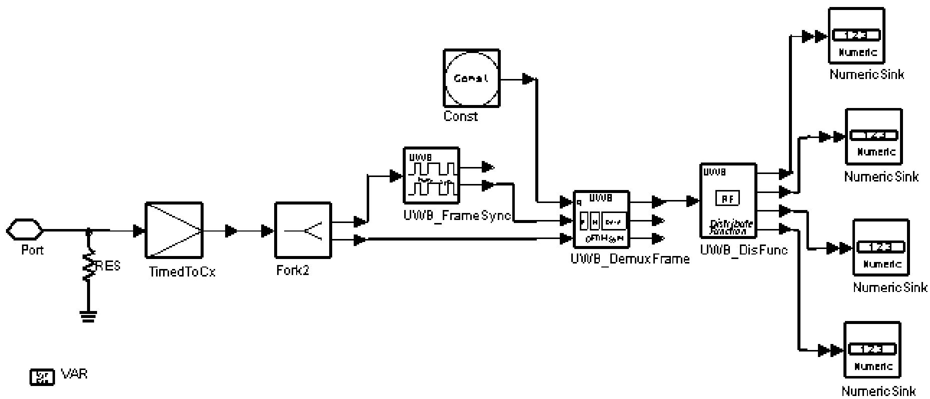


Figure 3-3. UWB_RF_CCDF Schematic

2. UWB_FrameSync performs frame synchronization. DataRate through IdleInterval parameters configure it; these parameter settings must be consistent with that of the UWB signal source.

   UWB_DemuxFrame extracts the synchronized frames, which are output to UWB_DisFunc for CCDF measurement. Measurement results are collected by four NumericSinks. The distribution range is sent to NumericSink *SignalRange_dB* and is divided into segments according to the OutputPoint parameter. The corresponding distribution probability is calculated based on these segments and sent to NumericSink *CCDF*. UWB_DisFunc calculates peak power of 99.9% probability and average power of the input signals. Results are collected by NumericSinks *PeakPower* and *MeanPower*.

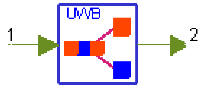
Note that PeakPower, MeanPower, and SignalRange units are dBm; SignalRange is the absolute signal power minus MeanPower.

References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

Chapter 4: Multiplex Components

UWB_Conjugate



Description UWB Conjugator
Library UWB, Multiplex
Class SDFUWB_Conjugate
Derived From UWB_Base

Parameters

Name	Description	Default	Type
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps	enum

Pin Inputs

Pin	Name	Description	Signal Type
1	Input	complex number to be conjugated	complex

Pin Outputs

Pin	Name	Description	Signal Type
2	Output	conjugated complex number	complex

Notes/Equations

1. This model performs a conjugate operation after QPSK mapping.

   Each firing,

   - For 53.3 and 80 Mbps data rates: 50 complex symbols are consumed and 100 complex symbols are generated.
   - For 110, 160, 200, 320, 400, and 480 Mbps data rates: 100 complex symbols are consumed and 100 complex symbols are generated.

2. Let d_n represent the nth input complex symbol each firing and c_n represent the nth output complex symbol each firing.

- For 53.3 and 80 Mbps data rates:

  $c_n = d_n$

  $c_{(n+50)} = d^{\times}_{(49-n)}$

  where $n = 0, 1, \ldots, 49$

- For 110, 160, 200, 320, 400, and 480 Mbps data rates:

  $c_n = d_n$

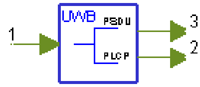
  where $n = 0, 1, \ldots, 99$

References

[1] IEEE P802.15-04/0493r1, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, September 2004.

[2] IEEE P802.15-03/0268r3, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, May 2004.

UWB_DemuxDataPLCP



Description UWB PLCP header and PSDU demultiplexer
Library UWB, Multiplex
Class SDFUWB_DemuxDataPLCP
Derived From UWB_Base

Parameters

Name	Description	Default	Type	Range
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps	enum	
DataLength	Octet number of PSDU	100	int	[1, 4095]

Pin Inputs

Pin	Name	Description	Signal Type
1	Input	data to be demultiplexed	complex

Pin Outputs

Pin	Name	Description	Signal Type
2	PLCPHeader	PLCP header	complex
3	PSDU	PSDU	complex

Notes/Equations

1. This model demultiplexes PLCP header and PSDU in a UWB frame.
2. Each firing, $122 \times Nsym$ tokens are consumed, where $Nsym$ is the number of OFDM symbols in PLCP header and PSDU; $122 \times Nsym_{Header}$ tokens are output at pin PLCPHeader and $122 \times Nsym_{PSDU}$ tokens are output at pin PSDU, where $Nsym_{Header}$ is the number of OFDM symbols in PLCP header, and $Nsym_{PSDU}$ is the number of OFDM symbols in PSDU after time domain despreading.

$Nsym_{Header}$ and $Nsym_{PSDU}$ are calculated as:

$$Nsym_{Header} = 6$$

$$Nsym_{PSDU} = \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{8 \times DataLength + 32 + 6}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil$$

where R is the coding rate; N_{CBPS} is the number of coded bits per OFDM symbol; TSF is the time spreading factor; $DataLength$ is the length, in bytes, of PSDU data. TSF, R, N_{CBPS} are based on the data rate as shown in Table 4-1.

Table 4-1. Data-Rate-Dependent Parameters

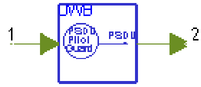
Data Rate (Mbps)	Modulation	Coding Rate (R)	Conjugate Symmetric Input to IFFT	Time Spreading Factor (TSF)	Overall Spreading Gain	Coded bits per OFDM symbol (N_{CBPS})
53.3	QPSK	1/3	Yes	2	4	100
80	QPSK	1/2	Yes	2	4	100
110	QPSK	11/32	No	2	2	200
160	QPSK	1/2	No	2	2	200
200	QPSK	5/8	No	2	2	200
320	QPSK	1/2	No	1 (no spreading)	1	200
400	QPSK	5/8	No	1 (no spreading)	1	200
480	QPSK	3/4	No	1 (no spreading)	1	200

References

[1] IEEE P802.15-04/0493r1, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, September 2004.

[2] IEEE P802.15-03/0268r3, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, May 2004.

UWB_DemuxOFDMSym



Description UWB OFDM symbol demultiplexer
Library UWB, Multiplex
Class SDFUWB_DemuxOFDMSym

Pin Inputs

Pin	Name	Description	Signal Type
1	In	data subcarriers input	complex

Pin Outputs

Pin	Name	Description	Signal Type
2	Data	OFDM symbol output	complex

Notes/Equations

1. This model extracts data from the corresponding subcarriers. Data is sent to the output and the pilot and guard subcarriers are discarded.

   Each firing 100 Data tokens are produced when 122 In tokens consumed.

2. In the transmit end, input data is mapped from indices 0 to 99 to the logical frequency offset indices -56 to 56, excluding the locations reserved for the pilot, guard, and DC subcarriers.

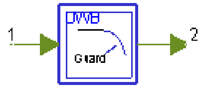
   This model performs the reverse operation as UWB_MuxOFDMSym; for mapping details refer to UWB_MuxOFDMSym.

References

[1] IEEE P802.15-04/0493r1, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, September 2004.

[2] IEEE P802.15-03/0268r3, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, May 2004.

UWB_GuardGain



Description UWB guard subcarriers gain
Library UWB, Multiplex

Parameters

Name	Description	Default	Type	Range
GuardGain	Gain of guard subcarriers	1.0, 1.0, 1.0, 1.0, 1.0	real array	(0, ∞)

Pin Inputs

Pin	Name	Description	Signal Type
1	Input	data subcarriers input	complex

Pin Outputs

Pin	Name	Description	Signal Type
2	Output	OFDM symbol output	complex

Notes/Equations

1. This subnetwork model adjusts the gain of the guard subcarriers. While this function is not defined in the IEEE specification, changing guard subcarrier gain may be required in some cases.

   The schematic for this subnetwork is shown in Figure 4-1.

2. Guard subcarrier amplitude is specified by the GuardGain parameter. Typically, the number of elements in this floating-point array is 5; if < 5, zeros will be appended to make 5 elements; if > 5, the sixth and subsequent elements will be the guard gain of the second OFDM symbol. This parameter specifies positive guard subcarriers values only; negative guard subcarrier gain will be automatically set according to the rule of mirror.

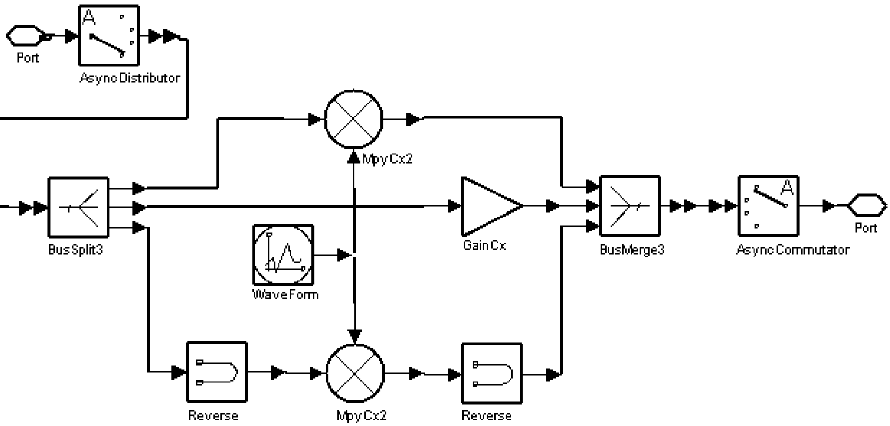


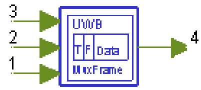
Figure 4-1. UWB_GuardGain Schematic

References

[1] IEEE P802.15-04/0493r1, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, September 2004.

[2] IEEE P802.15-03/0268r3, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, May 2004.

UWB_MuxFrame



Description UWB frame multiplexer
Library UWB, Multiplex

Parameters

Name	Description	Default	Unit	Type	Range
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps		enum	
DataLength	Octet number of PSDU	100		int	[1, 4095]
PreambleFormat	PLCP preamble format: Standard Format, Shortened Format	Standard Format		enum	
CoverSeq	Cover sequences for time domain preamble	1		int	[1, 2]
OversamplingOption	Oversampling ratio: Ratio 1, Ratio 2, Ratio 4, Ratio 8	Ratio 2		enum	
Bandwidth	Bandwidth	528 MHz	Hz	real	(0, ∞)
CyclicPrefix	Cyclic prefix with zero padding	70.08 nsec	sec	real	[0, ∞)
GuardInterval	Guard interval with zero padding	0.0 nsec	sec	real	[0, ∞)
IdleInterval	Idle Interval	0.0 nsec	sec	real	[0, ∞)

Pin Inputs

Pin	Name	Description	Signal Type
1	TimeSeq	time-domain OFDM training sequence	complex
2	FreqSeq	frequency-domain OFDM training sequence	complex
3	FrmBdy	PLCP header and MAC frame payload	complex

Pin Outputs

Pin	Name	Description	Signal Type
4	Out	data after mutiplexing	complex

Notes/Equations

1. This subnetwork model multiplexes PLCP preamble, PLCP header, and PSDU OFDM symbols into one frame.

   The schematic for this subnetwork is shown in Figure 4-2.

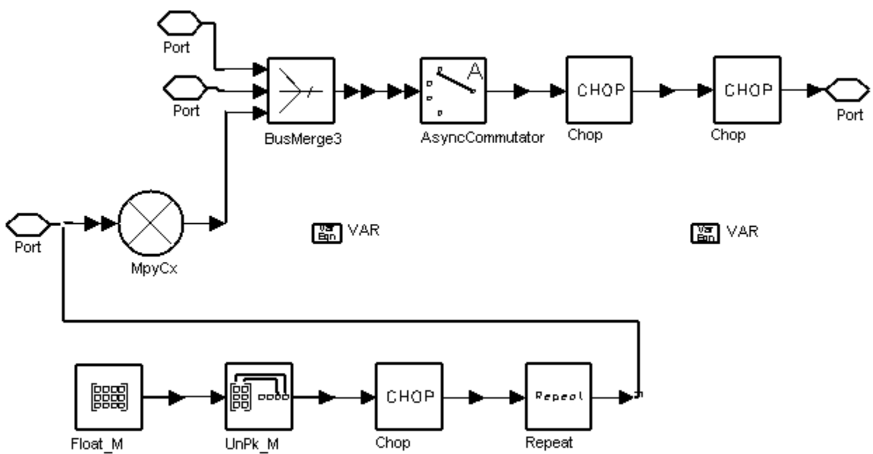


Figure 4-2. UWB_MuxFrame Schematic

2. Each firing:

   - N_{total} tokens are produced at the Out pin.

     where

     N_{total} is the number of samples in one frame

   - $N_{FFTpoint} \times (Nsym_{Header\text{-}TSF} + Nsym_{PSDU\text{-}TSF})$ tokens are consumed at the FrmBdy pin.

     where

     $N_{FFTpoint}$ is the number of samples in one FFT period.

($Nsym_{Header\text{-}TSF}$ + $Nsym_{PSDU\text{-}TSF}$) is the number of PLCP header and PSDU symbols in one frame.

- $Nsym_{FreqSeq} \times N_{FFTpoint}$ tokens are consumed at the FreqSeq pin, which is the frequency domain channel estimation sequence portion of the PLCP preamble.
- $Nsym_{TimeSeq} \times N_{FFTpoint}$ tokens are consumed at the TimeSeq pin, which is the time domain packet and frame synchronization sequence portion of the PLCP preamble.

3. DataRate, DataLength, and PreambleFormat parameters determine the number of OFDM symbols per UWB-OFDM frame.

   Data-rate-dependent parameters (modulation, coding rate, conjugate symmetric Input to IFFT, time spreading factor, overall spreading gain and coded bits per OFDM symbol (NCBPS) will be set according to Table 4-2, which is based on the specification.

Table 4-2. Data-Rate-Dependent Parameters

Data Rate (Mbps)	Modulation	Coding Rate (R)	Conjugate Symmetric Input to IFFT	Time Spreading Factor (TSF)	Overall Spreading Gain	Coded Bits per OFDM Symbol (N_{CBPS})
53.3	QPSK	1/3	Yes	2	4	100
80	QPSK	1/2	Yes	2	4	100
110	QPSK	11/32	No	2	2	200
160	QPSK	1/2	No	2	2	200
200	QPSK	5/8	No	2	2	200
320	QPSK	1/2	No	1 (no spreading)	1	200
400	QPSK	5/8	No	1 (no spreading)	1	200
480	QPSK	3/4	No	1 (no spreading)	1	200
Supported data rates are listed here; 55 and 106.7 Mbps are reserved for future use.						

4. Figure 4-3 shows the PLCP frame format; it includes: PLCP preamble, PLCP header (PHY header, MAC header, header check sequence, tail bits, and pad bits), and MAC frame body (frame payload. FCS, tail bits, and pad bits).

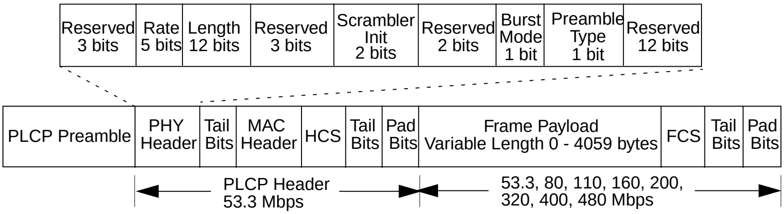


Figure 4-3. PLCP Frame Format

The PLCP preamble consists of the time domain packet and frame synchronization sequence and the frequency domain channel estimation sequence. There are 24 or 12 OFDM symbols in the time domain synchronization sequence portion for the standard or the shortened preamble, respectively:

$$Nsym_{TimeSeq} = \begin{cases} 24 & \text{Standard} \\ 12 & \text{Shortened} \end{cases}$$

The frequency domain channel estimation portion of the preamble is constructed by successively appending 6 periods of an OFDM training sequence, that is $Nsym_{FreqSeq} = 6$. Figure 4-3 shows the PLCP header (53.3 Mbps data rate); it includes PHY header (40 bits), first tail bits (6 bits), MAC header (80 bits), HCS (header check sequence, 16 bits) second tail bits (6 bits), and pad bits. The PLCP header total is 148 bits.

Before time-domain spreading, PLCP header OFDM symbol calculation is:

$$Nsym_{Header} = \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{148}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil = 6$$

where TSF=2, N_{CBPS}=100, and R=1/3 (from Table 4-2) because PLCP header is always 53.3 Mbps. The number of pad bits is 52 (=$6 \times N_{CBPS} \times R - 148$).

After time-domain spreading, PLCP header OFDM symbol calculation is:

$$Nsym_{Header-TSF} = TSF \times \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{148}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil = 12$$

Before time-domain spreading PSDU OFDM symbol calculation is:

$$Nsym_{PSDU} = \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{8 \times DataLength + 32 + 6}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil$$

where R is the data rate of PSDU, TSF and N_{CBPS} determined by DataRate (see Table 4-2).

The number of pad bits is:

$$Nsym_{PSDU} \times N_{CBPS} - \left\lceil \frac{8 \times DataLength + 32 + 6}{R} \right\rceil$$

After time-domain spreading PSDU OFDM symbol calculation is:

$$Nsym_{PSDU-TSF} = TSF \times \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{8 \times DataLength + 32 + 6}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil$$

So, the total number of OFDM symbols $Nsym$ per UWB-OFDM frame is

$$N_{SYM} = Nsym_{preamble} + Nsym_{Header-TSF} + Nsym_{PSDU-TSF}$$

5. CoverSeq, with PreambleFormat, determines the format of the packet and frame synchronization portion of the PLCP preamble.

   Figure 4-4 shows the standard PLCP preamble format for the different time frequency codes (TFCs) defined in Table 4-3.

   In addition to the standard PLCP preamble, a shortened PLCP preamble is also defined in the specification. Figure 4-5 shows the shortened PLCP preamble format.

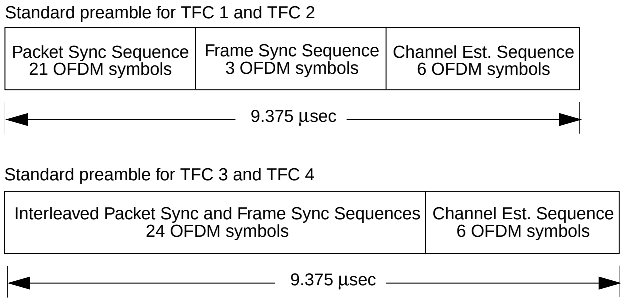


Figure 4-4. Standard PLCP Preamble Format

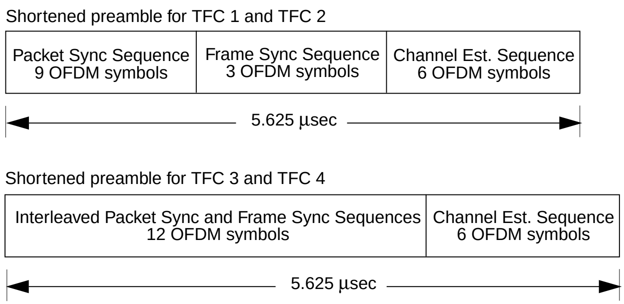


Figure 4-5. Shortened PLCP Preamble Format

Table 4-3. Time Frequency Codes and Associated Preamble Patterns

TFC	**Preamble Pattern**	**Cover Sequence**	**Length 6 Time Frequency Code (BAND ID values for Band Group 1)**					
1	1	1	1	2	3	1	2	3
2	2	1	1	3	2	1	3	2
3	3	2	1	1	2	2	3	3
4	4	2	1	1	3	3	2	2
5	1	2	1	2	1	2	1	2
6	2	2	1	1	1	2	2	2

The packet and frame synchronization sequences are defined based on the time domain synchronization sequences (given in Table 5 through Table 8 of reference [1]) and the preamble cover sequence given in Table 4-4. The packet and frame synchronization sequences are constructed in 3 steps:

- For the TFC under consideration, the appropriate time domain synchronization sequence is chosen (Table 5 through Table 8 of reference [1]).
- Each period of the time domain synchronization sequence, $p_t(n)$, is a 165-sample sequence constructed by appending a zero pad interval of 37 *zero samples* to the 128 length sequence chosen in the first step.
- The appropriate cover sequence $p_c(n)$ corresponding to the TFC in use is chosen (see Table 4-3), and the combined packet and frame synchronization portion of the PLCP preamble is generated as the Kronecker product of the two sequences, that is, $p(n) = p_c(n) \otimes p_t(n)$. This is the equivalent of taking each element of the cover sequence, multiplying it by the synchronization sequence in the second step, and concatenating the resulting sequences to form the combined packet and frame synchronization sequence.

The packet synchronization portion of the preamble can be used for packet detection and acquisition, coarse carrier frequency estimation, and coarse symbol timing.

The frame synchronization portion of the preamble can be used to synchronize the receiver algorithm within the preamble. This portion provides one sequence period per band with an inverted polarity with respect to the packet synchronization portion of the preamble.

The channel estimation portion of the preamble (denoted {CE0, CE1, ... , CE5}) is then constructed by successively appending 6 periods of an OFDM training sequence.

Table 4-4. Time Domain Preamble Cover Sequences

Sample Index	Standard Preamble Sequence Index		Shortened Preamble Sequence Index	
	1 (TFC 1, 2)	2 (TFC 3,4)	1 (TFC 1, 2)	2 (TFC 3,4)
0	1	1	1	1
1	1	1	1	1
2	1	1	1	1

Table 4-4. Time Domain Preamble Cover Sequences (continued)

Sample Index	Standard Preamble Sequence Index		Shortened Preamble Sequence Index	
	1 (TFC 1, 2)	2 (TFC 3,4)	1 (TFC 1, 2)	2 (TFC 3,4)
3	1	1	1	1
4	1	1	1	1
5	1	1	1	1
6	1	1	1	1
7	1	1	1	-1
8	1	1	1	1
9	1	1	-1	-1
10	1	1	-1	1
11	1	1	-1	-1
12	1	1		
13	1	1		
14	1	1		
15	1	1		
16	1	1		
17	1	1		
18	1	1		
19	1	-1		
20	1	1		
21	-1	-1		
22	-1	1		
23	-1	-1		

6. OversamplingOption, Bandwidth, CyclicPrefix, and GuardInterval are used to calculate the number of samples in one OFDM symbol period. The number of samples for one OFDM symbol (N) is calculated as:

$$N = 2^{OversamplingOption} \times (128 + Bandwidth \times (CyclicPrefix + GuardInterval))$$

The number of samples in one FFT period ($N_{FFTpoint}$) is calculated as:

$$N_{FFTpoint} = 2^{OversamplingOption} \times 128$$

7. IdleInterval is used to simulate the arbitrary time interval between two UWB packets. For ADS simulation, the IdleInterval resolution should be (CyclicPrefix+242.42+GuardInterval)×6 nsec.

The length of Idle (N_{idle}) can be calculated as:

$$N_{idle} = IdleInterval \times Bandwidth \times 2^{OversamplingOption}$$

After determining N_{SYM}, N, and N_{idle}, the length of one MB-OFDM frame (N_{total}) can be calculated:

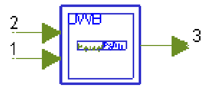
$$N_{total} = N \times N_{SYM} + N_{idle}$$

References

[1] IEEE P802.15-04/0493r1, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, September 2004.

[2] IEEE P802.15-03/0268r3, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, May 2004.

UWB_MuxHeadPSDU



Description UWB PLCP header and PSDU multiplexer
Library UWB, Multiplex

Parameters

Name	Description	Default	Type	Range
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps	enum	
DataLength	Octet number of PSDU	100	int	[1, 4095]

Pin Inputs

Pin	Name	Description	Signal Type
1	Header	PLCP header	complex
2	PSDU	data	complex

Pin Outputs

Pin	Name	Description	Signal Type
3	output	output signals	complex

Notes/Equations

1. This subnetwork model multiplexes PLCP header and PSDU OFDM symbols. The schematic for this subnetwork is shown in Figure 4-6.

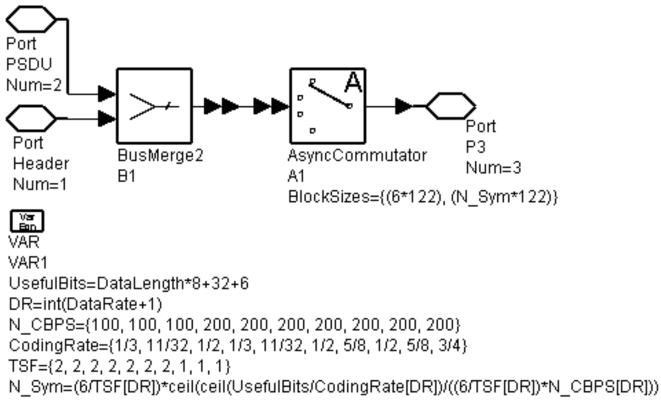


Figure 4-6. UWB_MuxHeadPSDU Schematic

2. Figure 4-7 shows the PLCP frame format.

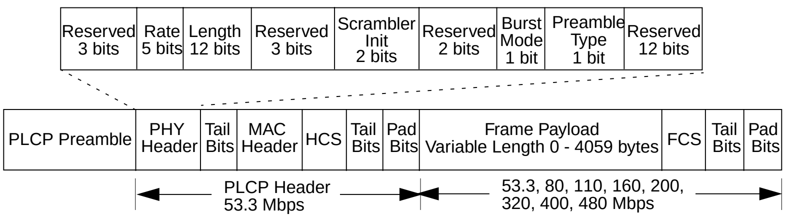


Figure 4-7. PLCP Frame Format

The data rate and length of PLCP header are fixed, so the number of OFDM symbols for PLCP header is fixed to 6; the data rate and length for PSDU is variable, and the number of OFDM symbols is calculated by N_Sym (see Figure 4-6), where N_Sym is the number of OFDM symbols for PSDU and ceil is a function to determine the minimal integer greater than or equal to its argument.

Note that time frequency codes are implemented after this model in the data flow.

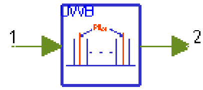
3. Each OFDM symbol includes 122 subcarriers, which means a block of 122 data is transmitted for each OFDM symbol.

References

[1] IEEE P802.15-04/0493r1, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, September 2004.

[2] IEEE P802.15-03/0268r3, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, May 2004.

UWB_MuxOFDMSym



Description UWB OFDM symbol multiplexer
Library UWB, Multiplex
Class SDFUWB_MuxOFDMSym
Derived From UWB_Base

Parameters

Name	Description	Default	Type	Range
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps	enum	
DataLength	Octet number of PSDU	100	int	[1, 4095]
InfoType	Information type: Header, PSDU	PSDU	enum	
PilotPN_Phase	Phase of pilot PN	0	int	[0, 126]

Pin Inputs

Pin	Name	Description	Signal Type
1	Data	data subcarriers input	complex

Pin Outputs

Pin	Name	Description	Signal Type
2	Out	OFDM symbol output	complex

Notes/Equations

1. This model maps the input data and generated pilot and guard into their corresponding subcarriers.

   Each firing 122 Out tokens are produced when 100 Data tokens consumed.

2. Input data is mapped from indices 0 to 99 to the logical frequency offset indices -56 to 56, excluding locations reserved for pilot, guard, and DC subcarriers, as shown:

$$M(n) - \begin{cases} n - 56 & n = 0 \\ n - 55 & 1 \le n \le 9 \\ n - 54 & 10 \le n \le 18 \\ n - 53 & 19 \le n \le 27 \\ n - 52 & 28 \le n \le 36 \\ n - 51 & 37 \le n \le 45 \\ n - 50 & 46 \le n \le 49 \\ n - 49 & 50 \le n \le 53 \\ n - 48 & 54 \le n \le 62 \\ n - 47 & 63 \le n \le 71 \\ n - 46 & 72 \le n \le 80 \\ n - 45 & 81 \le n \le 89 \\ n - 44 & 90 \le n \le 98 \\ n - 43 & n = 99 \end{cases}$$

Twelve of the pilot signal subcarriers are generated (according to 1.13.1 in Reference [1]). They are placed in subcarriers -55, -45, -35, -25, -15 -5, 5, 15, 25, 35, 45, and 55. The value of pilot varies based on DataRate and InfoType parameter settings.

10 guard subcarriers are generated (according to 1.13.2 in Reference [1]). They are placed in subcarriers -61, -60, -59, -58, and -57, and 57, 58, 59, 60, and 61.

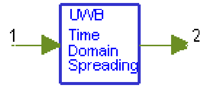
PN_Pilot is the p_l defined in Reference [1]. PN_PilotPhase is the index of PN_Pilot. Phase 0 corresponds to the first OFDM symbol following the PLCP preamble according to Reference [1]. Mapping can be changed by setting PN_PilotPhase to a value other than 0.

References

[1] IEEE P802.15-04/0493r1, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, September 2004.

[2] IEEE P802.15-03/0268r3, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, May 2004.

UWB_TimeSpreading



Description UWB time domain spreader or despreader
Library UWB, Multiplex
Class SDFUWB_TimeSpreading
Derived From UWB_Base

Parameters

Name	Description	Default	Type	Range
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps	enum	
DataLength	Octet number of PSDU	100	int	[1, 4095]
OperationType	Operation type: Spreading, Despreading	Spreading	enum	
PilotPN_Phase	Phase of pilot PN	0	int	[0, 126]

Pin Inputs

Pin	Name	Description	Signal Type
1	Input	symbols to be time-(de)spread	complex

Pin Outputs

Pin	Name	Description	Signal Type
2	Output	time-(de)spread symbols	complex

Notes/Equations

1. This model performs time-domain spreading.

   Each firing,

   $N_{FFTpoint} \times (Nsym_{Header\text{-}TSF} + Nsym_{PSDU\text{-}TSF})$ Output tokens are produced, where $N_{FFTpoint}$ is the number of samples in one FFT period, $Nsym_{Header\text{-}TSF}$ + $Nsym_{PSDU\text{-}TSF}$ is the number of PLCP header and PSDU symbols after time-domain spreading in one UWB MB-OFDM frame

$N_{FFTpoint} \times (Nsym_{Header} + Nsym_{PSDU})$ tokens are consumed at Input pin, which is the number of PLCP header and PSDU symbols before time-domain spreading in one UWB MB-OFDM frame.

2. DataRate and DataLength parameters determine the number of OFDM symbols per UWB-OFDM frame. DataRate also determines the time-domain spreading parameters such as conjugate symmetric input to IFFT, time spreading factor as shown in Table 4-5.

Table 4-5. Data-Rate-Dependent Parameters

DataRate (Mbps)	Modulation	Coding Rate (R)	Conjugate Symmetric Input to IFFT	Time Spreading Factor (TSF)	Overall Spreading Gain	Coded Bits per OFDM symbol (N_{CBPS})
53.3	QPSK	1/3	Yes	2	4	100
80	QPSK	1/2	Yes	2	4	100
110	QPSK	11/32	No	2	2	200
160	QPSK	1/2	No	2	2	200
200	QPSK	5/8	No	2	2	200
320	QPSK	1/2	No	1 (no spreading)	1	200
400	QPSK	5/8	No	1 (no spreading)	1	200
480	QPSK	3/4	No	1 (no spreading)	1	200
Supported data rates are listed here; 55 and 106.7 Mbps are reserved for future use.						

PLCP header, data rate is 53.3 Mbps, includes PHY Header (40 bits), first tail bits (6 bits), MAC header (80 bits), HCS (header check sequence, 16 bits) second tail bits (6 bits), and pad bits. The total PLCP header is 148 bits. The OFDM symbols of PLCP header before time-domain spreading is calculated as:

$$Nsym_{Header} = \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{148}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil = 6$$

where TSF=2, N_{CBPS}=100 and R=1/3 (see Table 4-5) because PLCP header is always 53.3 Mbps. The number of pad bits is 52 (=$6 \times N_{CBPS} \times R - 148$).

After time-domain spreading, PLCP header OFDM symbol calculation is:

$$Nsym_{Header-TSF} = TSF \times \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{148}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil = 12$$

MAC frame body consists of frame payload, FCS, tail bits, and pad bits.

Before time-domain spreading PSDU OFDM symbol calculation is:

$$Nsym_{PSDU} = \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{8 \times DataLength + 32 + 6}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil$$

where R is the data rate of PSDU, TSF and N_{CBPS} are determined by the data rate (see Table 4-5).

The number of pad bits is:

$$Nsym_{PSDU} \times N_{CBPS} - \left\lceil \frac{8 \times DataLength + 32 + 6}{R} \right\rceil$$

After time-domain spreading PSDU OFDM symbol calculation is:

$$Nsym_{PSDU-TSF} = TSF \times \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{8 \times DataLength + 32 + 6}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil$$

3. PilotPN_Phase is used to set the start phase of the pseudo-random binary sequence, p_l. This length 127 sequence p_l is defined as:

   $p_{0...126}$ = {1, 1, 1, 1, -1, -1, -1, 1, -1, -1, -1, -1, 1, 1, -1, 1, -1, -1, 1, 1, -1, 1, 1, -1, 1, 1, 1, 1, 1, 1, -1, 1, 1, 1, -1, 1, 1, -1, -1, 1, 1, 1, -1, 1, -1, -1, -1, 1, -1, 1, -1, -1, 1, -1, -1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, -1, -1, -1, 1, 1, -1, -1, -1, -1, 1, -1, -1, 1, -1, 1, 1, 1, 1, -1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, -1, 1, 1, -1, 1, -1, 1, 1, 1, -1, -1, 1, -1, -1, -1, 1, 1, 1, -1, -1, -1, -1, -1, -1, -1}.

   The start phase of sequence p_l corresponds to the first OFDM symbol following the PLCP preamble (i.e., the first OFDM symbol following channel estimation symbols CE0-CE5). According to Reference [1], PilotPN_Phase must be set to 0.

4. According to Reference [1], for 53.3, 80, 110, 160 and 200 Mbps data rates a time-domain spreading operation is performed with spreading factor *TSF =2* (to improve frequency diversity and SOP performance). Time-domain spreading consists of transmitting the same information over two OFDM symbols. Assume

the kth original OFDM symbol (before time spreading) is represented as $S_k(l)$; the repeated version of this OFDM symbol, represented as $S'_k(l)$, is then obtained in the time domain:

$$S'_k(l) = \begin{cases} \{Im\{S_k(l)\} + jRe\{S_k(l)\}\} \times p_{mod(k+6,\,127)} & \text{no conjugate symmetry} \\ S_k(l) \times p_{mod(k+6,\,127)} & \text{with conjugate symmetry} \end{cases}$$

where k=0 corresponds to the first OFDM symbol following the PLCP preamble, (the first OFDM symbol following channel estimation symbols CE0-CE5), and the values of the index k are OFDM symbol numbers *before* time spreading. Values for p_k are selected from the same pseudo-random sequence used to scramble pilot subcarriers.

The time-domain spreading operation can also be implemented in the frequency domain at the transmitter. This is done by reversing the order of bits in the bit vector obtained after interleaving; this is used as the input for constellation mapping and OFDM modulation operations. Pilot subcarriers for the repeated symbol must be defined such that after processing with the IFFT, the same output is obtained as in the time domain definition given above.

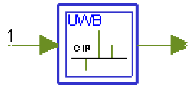
References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

[2] IEEE P802.15-03/0268r3, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, May 2004.

Chapter 5: Receiver Components

UWB_ChEstimator



Description UWB channel estimator
Library UWB, Receiver

Parameters

Name	Description	Default	Type
TFC_Number	Time frequency code: TFC1, TFC2, TFC3, TFC4, TFC5, TFC6	TFC1	enum

Pin Inputs

Pin	Name	Description	Signal Type
1	input	received frequency-domain training sequence	complex

Pin Outputs

Pin	Name	Description	Signal Type
2	Coef	channel impulse response	complex

Notes/Equations

1. This subnetwork model estimates the channel impulse response by comparing the received frequency-domain OFDM training sequence with the original training sequence.

   The schematic for UWB_ChEstimator is shown in Figure 5-1.

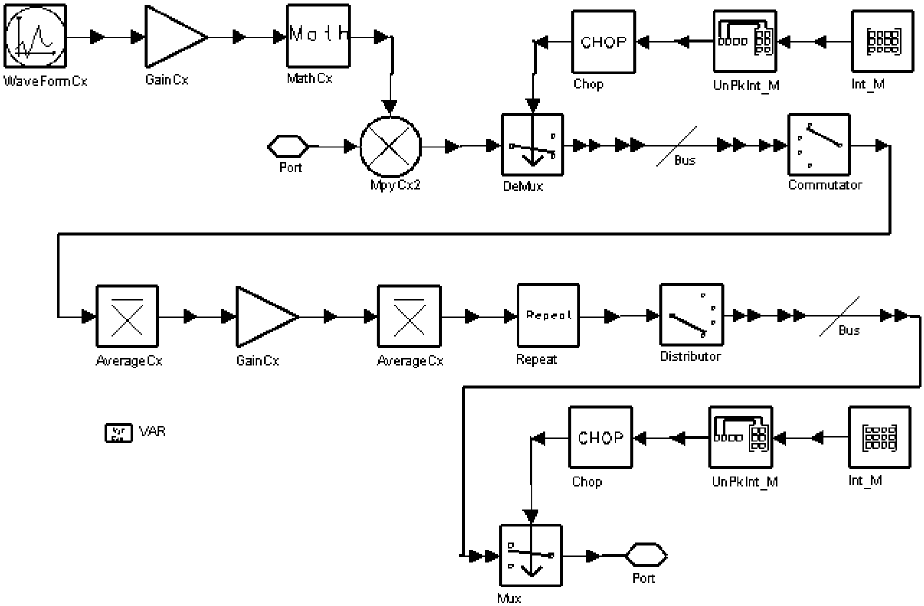


Figure 5-1. UWB_ChEstimator Schematic

2. The CIR h_i for the ith subcarrier is obtained by

$$h_i = \frac{x_i}{L_i}$$

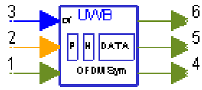
where x_i is the received training sequence on the ith subcarrier and L_i is the original training sequence.

The channel estimation training sequence includes 6 identical OFDM symbols; estimation accuracy can be improved by averaging estimated CIRs on the same sub-band. The DeMux and Bus components separate and collect the h_i for each sub-band, it is then averaged and multiplexed back to the 6 OFDM symbols.

References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

UWB_DemuxFrame



Description UWB frame de-multiplexer with frequency offset compensation, cyclic prefix and guard interval removed
Library UWB, Receiver
Class SDFUWB_DemuxFrame
Derived From UWB_FrameBase

Parameters

Name	Description	Default	Unit	Type	Range
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps		enum	
DataLength	Octet number of PSDU	100		int	[1, 4095]
PreambleFormat	PLCP preamble format: Standard Format, Shortened Format	Standard Format		enum	
OversamplingOption	Oversampling ratio: Ratio 1, Ratio 2, Ratio 4, Ratio 8	Ratio 2		enum	
Bandwidth	Bandwidth	528 MHz	Hz	real	(0, ∞)
CyclicPrefix	Cyclic prefix with zero padding	70.08 nsec	sec	real	[0, ∞)
GuardInterval	Guard interval with zero padding	0.0 nsec	sec	real	[0, ∞)
IdleInterval	Idle Interval	0.0 nsec	sec	real	[0, ∞)
FreqOffset	Actual frequency offset	0.0	Hz	real	(-∞, ∞)

Pin Inputs

Pin	Name	Description	Signal Type
1	input	received frame signals	complex
2	index	synchronization index	int
3	DeltaF	carrier frequency offset	real

Pin Outputs

Pin	Name	Description	Signal Type
4	CE	six channel estimate sequences	complex
5	output	PLCP Header and PSDU OFDM signals	complex
6	frame	Preamble, PLCP Header and PSDU OFDM signals	complex

Notes/Equations

1. This model de-multiplexes the received frame signals into one channel estimate sequence (6 OFDM symbols), PLCP Header, and PSDU OFDM signals; the cyclic prefix and guard interval are removed, and time and carrier frequency offsets are compensated before demultiplexing.
2. Each firing, $N_{FFTpoint} \times (Nsym_{Header\text{-}TSF} + Nsym_{PSDU\text{-}TSF})$ output tokens are produced,

   where

   $N_{FFTpoint}$ is the number of samples in one FFT period,

   $(Nsym_{Header\text{-}TSF} + Nsym_{PSDU\text{-}TSF})$ is the number of PLCP header and PSDU symbols in one frame

   $N \times N_{SYM}$ frame tokens are produced

   where

   N is the number of samples for one OFDM symbol, is calculated as:

   $N = 2^{OversamplingOption} \times (128 + Bandwidth \times (CyclicPrefix + GuardInterval))$

   N_{SYM} is the number of symbols in one frame;

   $6 \times N_{FFTpoint}$ CE tokens are produced, which is the frequency domain channel estimation sequence portion of the PLCP preamble

   N_{total} input tokens are consumed

   where

   N_{total} is the number of samples in one frame

   1 token is consumed at the index pin, which indicates the synchronization index value

6 tokens are consumed at the DeltaF pin, which indicates the carrier frequency offset values.

3. DataRate, DataLength, and PreambleFormat parameters determine the number of OFDM symbols per UWB-OFDM frame.

   Data-rate-dependent parameters (modulation, coding rate, conjugate symmetric input to IFFT, time spreading factor, overall spreading gain and coded bits per OFDM symbol (N_{CBPS})) will be set according to Table 5-1, which is based on the specification.

Table 5-1. Data-Rate-Dependent Parameters

DataRate (Mbps)	Modulation	Coding Rate (R)	Conjugate Symmetric Input to IFFT	Time Spreading Factor (TSF)	Overall Spreading Gain	Coded Bits per OFDM symbol (N_{CBPS})
53.3	QPSK	1/3	Yes	2	4	100
80	QPSK	1/2	Yes	2	4	100
110	QPSK	11/32	No	2	2	200
160	QPSK	1/2	No	2	2	200
200	QPSK	5/8	No	2	2	200
320	QPSK	1/2	No	1 (no spreading)	1	200
400	QPSK	5/8	No	1 (no spreading)	1	200
480	QPSK	3/4	No	1 (no spreading)	1	200
Supported data rates are listed here; 55 and 106.7 Mbps are reserved for future use.						

4. Figure 5-2 shows the PLCP frame format; it includes: PLCP preamble, PLCP header (PHY header, MAC header, header check sequence, tail bits, and pad bits), MAC frame body (frame payload plus FCS, tail bits, and pad bits).

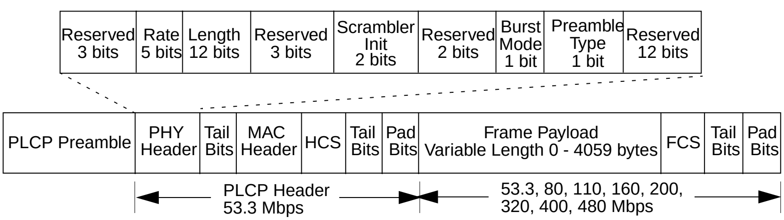


Figure 5-2. PLCP Frame Format

In the UWB Library, one UWB frame consists of idle, PLCP preamble (standard or shortened), PLCP header, and PSDU.

The PLCP preamble consists of the time domain packet and frame synchronization sequence and the frequency domain channel estimation sequence. There are 24 or 12 OFDM symbols in the time domain synchronization sequence portion for the standard or shortened preamble, respectively:

$$Nsym_{TimeSeq} = \begin{cases} 24 & \text{Standard} \\ 12 & \text{Shortened} \end{cases}$$

The frequency domain channel estimation portion of the preamble is constructed by successively appending 6 periods of an OFDM training sequence; that is, $Nsym_{FreqSeq}$=6. So, there are 30 or 18 OFDM symbols for the standard or the shortened preamble, respectively:

$$Nsym_{preamble} = \begin{cases} 30 & \text{Standard} \\ 18 & \text{Shortened} \end{cases}$$

Figure 5-2 shows the PLCP header (data rate is 53.3 Mbps); it includes PHY Header (40 bits), first Tail Bits (6 bits), MAC header (80 bits), HCS (header check sequence, 16 bits) second tail bits (6 bits), and pad bits. The total bits of PLCP header is 148 bits. The OFDM symbols of PLCP header before time-domain spreading is calculated as:

$$Nsym_{Header} = \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{148}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil = 6$$

where TSF=2, N_{CBPS}=100 and R=1/3 from Table 5-1 because PLCP header is always 53.3 Mbps. The number of pad bits is 52 (=$6 \times N_{CBPS} \times R - 148$).

After time-domain spreading PLCP header OFDM symbol calculation is:

$$Nsym_{Header-TSF} = TSF \times \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{148}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil = 12$$

Before time-domain spreading PSDU OFDM symbol calculation is:

$$Nsym_{PSDU} = \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{8 \times DataLength + 32 + 6}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil$$

where R is the data rate of PSDU, TSF and NCBPS determined by DataRate (see Table 5-1).

The number of pad bits is:

$$Nsym_{PSDU} \times N_{CBPS} - \left\lceil \frac{8 \times DataLength + 32 + 6}{R} \right\rceil$$

After time-domain spreading PSDU OFDM symbol calculation is:

$$Nsym_{PSDU-TSF} = TSF \times \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{8 \times DataLength + 32 + 6}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil$$

So, the total number of OFDM symbols N_{SYM} per UWB-OFDM frame is

$$N_{SYM} = Nsym_{preamble} + Nsym_{Header\text{-}TSF} + Nsym_{PSDU\text{-}TSF}$$

5. OversamplingOption, Bandwidth, CyclicPrefix, and GuardInterval are used for calculating the number of samples in one OFDM symbol period. The number of samples for one OFDM symbol (N) is calculated as:

   $$N = 2^{OversamplingOption} \times (128 + Bandwidth \times (CyclicPrefix + GuardInterval))$$

   The number of samples in one FFT period ($N_{FFTpoint}$) is calculated as:

   $$N_{FFTpoint} = 2^{OversamplingOption} \times 128$$

   The time step per sample is:

   $$T_{Step} = 1/(Bandwidth)/2^{OversamplingOption}$$

   The duration of one OFDM symbol is:

   $$T_{SYM} = 128/(Bandwidth) + CyclicPrefix + GuardInterval$$

6. IdleInterval is used to simulate the arbitrary time interval between two UWB packets. For ADS simulation, the resolution of IdleInterval must be $(CyclicPrefix + 242.42 + GuardInterval) \times 6$ nsec.

   The length of Idle (N_{idle}) can be calculated as:

   $$N_{idle} = IdleInterval \times Bandwidth \times 2^{OversamplingOption}$$

   After determining N_{SYM}, N, and N_{idle}, the number of input tokens N_{total} can be calculated:

$$N_{total} = N \times N_{SYM} + N_{idle}$$

Because of transmission delay, a detected frame usually falls into 2 consecutive received blocks, so the buffer length for input pin is $2 \times N_{total}$. The start of the detected frame is determined by the input signal at index pin. This model outputs only one actual frame after receiving the second input block; so this model causes one frame delay.

7. The DeltaF pin inputs the estimated frequency offset (Δf_i) of each received frame. This estimated frequency offset does not effect the next frames in the frequency compensator. The FreqOffset parameter is set as the actual frequency offset between the transmitter and the receiver; when the *i*th frame is processed, the actual phase of previous *i-1* frames is calculated and removed. The *i*th estimated frequency offset (Δf_i) compensates for the phase in the current frame only.

   Assume $x_0, x_1, \ldots, x_{2 \times N-1}$ sequences are the input signals from input pin after removing the actual phase of previous *i-1* frames caused by the actual frequency offset from FreqOffset parameter. $y_0, y_1, \ldots, y_{2 \times N-1}$ are the sequences, whose phase caused by frequency offset, are removed:

$$y_k = x_k \times e^{-j2\pi \Delta f_i k T_{Step}}$$

   where

   Δf_i is frequency offset of *i*th received frame, which is the input at DeltaF pin

   and

$$T_{Step} = \frac{1}{Bandwidth \times 2^{OversamplingOption}}$$

   is the sample time interval in MB-OFDM system.

   After frequency offset compensation, the actual MB-OFDM frame will be output at frame pin. The Idle part is discarded when outputting the actual frame. Index pin inputs the start of a detected MB-OFDM frame (including Idle). The equation is:

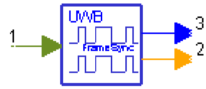
$$z_k = y_{k + Index + N_{idle}}, k = 0, \ldots, N_{FFTpoint} \times N_{SYM} - 1$$

   $z_0, z_1, \ldots, z_{N_{FFTpoint} \times N_{SYM} - 1}$ sequences are output at frame pin.

References

[1] IEEE P802.15-04/0493r1, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, September 2004.

UWB_FrameSync



Description UWB coarse timing synchronizer
Library UWB, Receiver
Class SDFUWB_FrameSync
Derived From UWB_FrameBase

Parameters

Name	Description	Default	Unit	Type	Range
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps		enum	
DataLength	Octet number of PSDU	100		int	[1, 4095]
PreambleFormat	PLCP preamble format: Standard Format, Shortened Format	Standard Format		enum	
OversamplingOption	Oversampling ratio: Ratio 1, Ratio 2, Ratio 4, Ratio 8	Ratio 2		enum	
Bandwidth	Bandwidth	528 MHz	Hz	real	(0, ∞)
CyclicPrefix	Cyclic prefix with zero padding	70.08 nsec	sec	real	[0, ∞)
GuardInterval	Guard interval with zero padding	0.0 nsec	sec	real	[0, ∞)
IdleInterval	Idle Interval	0.0 nsec	sec	real	[0, ∞)
PreamblePattern	Preamble pattern for time domain synchronization sequence: Pattern 1, Pattern 2, Pattern 3, Pattern 4	Pattern 1		enum	
CoverSeq	Cover sequences for time domain preamble	1		int	[1, 2]
SearchMode	Searching mode synchronization: EveryFrame, Once	EveryFrame		enum	

Name	Description	Default	Unit	Type	Range
SearchWindow	Searching window synchronization	24		int	†

† The minimum value of this parameter should be the number of OFDM symbols in the synchronization sequences portion of the PLCP preamble, and the maximum value of this parameter should be the number of OFDM symbols in one MB-OFDM frame.

Pin Inputs

Pin	Name	Description	Signal Type
1	input	input signals for synchronization	complex

Pin Outputs

Pin	Name	Description	Signal Type
2	index	synchronization index	int
3	corr	correlation output	real

Notes/Equations

1. This model synchronizes UWB OFDM systems.

   Each firing, 1 token is produced at the index pin; N_{total} tokens are produced at the corr pin; N_{total} tokens are consumed at the input pin. N_{total} is the number of samples in one frame.

2. Correlation values between the received and the reference signals, and the specific autocorrelation values of the received signals are calculated for synchronization. The maximum correlation value is searched for and the corresponding index is selected as the frame start point. The frame start point is output at the index pin.

3. DataRate, PreambleFormat, and DataLength parameters determine the number of OFDM symbols per UWB-OFDM frame.

   When DataRate is set, data-rate-dependent parameters such as modulation, coding rate, conjugate symmetric Input to IFFT, time spreading factor, overall spreading gain and coded bits per OFDM symbol (N_{CBPS}) will be set according to specification as shown in Table 5-2.

Table 5-2. Data-Rate-Dependent Parameters

DataRate (Mbps)	Modulation	Coding Rate (R)	Conjugate Symmetric Input to IFFT	Time Spreading Factor (TSF)	Overall Spreading Gain	Coded Bits per OFDM symbol (N_{CBPS})
53.3	QPSK	1/3	Yes	2	4	100
80	QPSK	1/2	Yes	2	4	100
110	QPSK	11/32	No	2	2	200
160	QPSK	1/2	No	2	2	200
200	QPSK	5/8	No	2	2	200
320	QPSK	1/2	No	1 (no spreading)	1	200
400	QPSK	5/8	No	1 (no spreading)	1	200
480	QPSK	3/4	No	1 (no spreading)	1	200
Supported data rates are listed here; 55 and 106.7 Mbps are reserved for future use.						

4. Figure 5-3 shows the format for the PLCP frame; it includes PLCP preamble, PLCP header (PHY header, MAC header, header check sequence, tail bits, and pad bits), MAC frame body (frame payload plus FCS, tail bits, and pad bits).

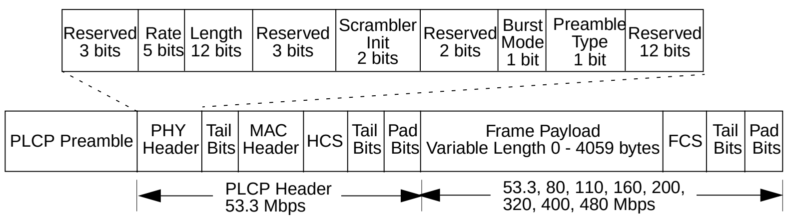


Figure 5-3. PLCP Frame Format

The PLCP preamble consists of the time domain packet and frame synchronization sequence and the frequency domain channel estimation sequence. There are 24 or 12 OFDM symbols in the time domain synchronization sequence portion for the standard or shortened preamble, respectively:

$$Nsym_{TimeSeq} = \begin{cases} 24 & \text{Standard} \\ 12 & \text{Shortened} \end{cases}$$

The frequency domain channel estimation portion of the preamble is constructed by successively appending 6 periods of an OFDM training sequence, that is, $Nsym_{FreqSeq}$=6. Figure 5-3 shows the PLCP header (data rate is 53.3 Mbps); it includes PHY header (40 bits), first tail bits (6 bits), MAC header (80 bits), HCS (header check sequence, 16 bits) second tail bits (6 bits), and pad bits. PLCP header is 148 bits total.

Before time-domain spreading, PLCP header OFDM symbol calculation is:

$$Nsym_{Header} = \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{148}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil = 6$$

where TSF=2, N_{CBPS}=100 and R=1/3 (from Table 5-2) because PLCP header is always 53.3 Mbps. The number of pad bits is 52 (=$6 \times N_{CBPS} \times R - 148$).

After time-domain spreading, PLCP header OFDM symbol calculation is:

$$Nsym_{Header-TSF} = TSF \times \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{148}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil = 12$$

Before time-domain spreading PSDU OFDM symbol calculation is:

$$Nsym_{PSDU} = \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{8 \times DataLength + 32 + 6}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil$$

where R is the PSDU data rate, TSF and N_{CBPS} determined by DataRate (see Table 5-2).

The number of pad bits is:

$$Nsym_{PSDU} \times N_{CBPS} - \left\lceil \frac{8 \times DataLength + 32 + 6}{R} \right\rceil$$

After time-domain spreading PSDU OFDM symbol calculation is:

$$Nsym_{PSDU-TSF} = TSF \times \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{8 \times DataLength + 32 + 6}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil$$

So, the total number of OFDM symbols $Nsym$ per UWB-OFDM frame is

$$N_{SYM} = Nsym_{preamble} + Nsym_{Header-TSF} + Nsym_{PSDU-TSF}$$

5. CoverSeq, with PreambleFormat, determines the format of the packet and frame synchronization portion of the PLCP preamble.

   Figure 5-4 shows the standard PLCP preamble format for the different time frequency codes (TFCs) defined in Table 5-3.

   In addition to the standard PLCP preamble, a shortened PLCP preamble is also defined in the specification. Figure 5-5 shows the shortened PLCP preamble format.

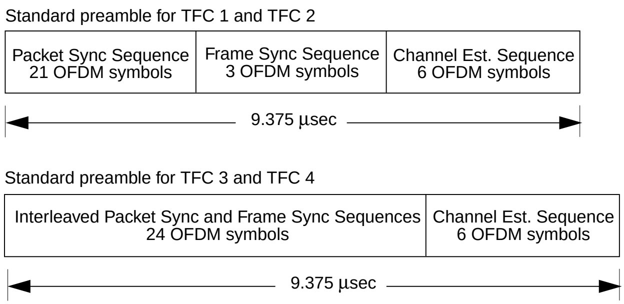


Figure 5-4. Standard PLCP Preamble Format

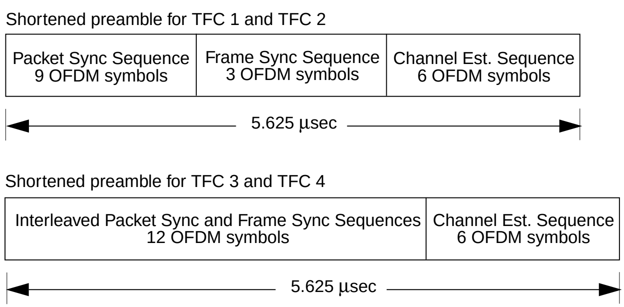


Figure 5-5. Shortened PLCP Preamble Format

Table 5-3. Time Frequency Codes and Associated Preamble Patterns

TFC	Preamble Pattern	Cover Sequence	Length 6 Time Frequency Code (BAND ID values for Band Group 1)					
1	1	1	1	2	3	1	2	3
2	2	1	1	3	2	1	3	2
3	3	2	1	1	2	2	3	3
4	4	2	1	1	3	3	2	2
5	1	2	1	2	1	2	1	2
6	2	2	1	1	1	2	2	2

The packet and frame synchronization sequences are defined based on the time domain synchronization sequences shown in Table 5 through Table 8 of Reference [1] and the preamble cover sequence shown in Table 5-4. The packet and frame synchronization sequences are constructed in 3 steps:

- For the TFC under consideration, the appropriate time domain synchronization sequence is chosen from Table 5 through Table 8 of reference [1].
- Each period of the time domain synchronization sequence $p_t(n)$ is a 165-sample sequence constructed by appending a zero pad interval of 37 *zero samples* to the 128 length sequence chosen in the first step.
- The appropriate cover sequence $p_c(n)$ corresponding to the TFC in use is chosen based on Table 5-4 from Table 5-3, and the combined packet and frame synchronization portion of the PLCP preamble is generated as the Kronecker product of the two sequences, that is, $p(n) = p_c(n) \otimes p_t(n)$. This is equivalent to taking each element of the cover sequence, multiplying the synchronization sequence in the second step with it, and concatenating the resulting sequences to form the combined packet and frame synchronization sequence.

The packet synchronization portion of the preamble is used for packet detection and acquisition, coarse carrier frequency estimation, and coarse symbol timing. The frame synchronization portion of the preamble is used to synchronize the receiver algorithm within the preamble.

The frame synchronization portion provides one sequence period per band with an inverted polarity with respect to the packet synchronization portion of the preamble.

The channel estimation portion of the preamble (denoted as {CE0, CE1, ... , CE5}) is then constructed by successively appending 6 periods of an OFDM training sequence.

Table 5-4. Time Domain Preamble Cover Sequences

Sample Index	Standard Preamble Sequence Index		Shortened Preamble Sequence Index	
	1 (TFC 1, 2)	2 (TFC 3,4)	1 (TFC 1, 2)	2 (TFC 3,4)
0	1	1	1	1
1	1	1	1	1
2	1	1	1	1
3	1	1	1	1
4	1	1	1	1
5	1	1	1	1
6	1	1	1	1
7	1	1	1	-1
8	1	1	1	1
9	1	1	-1	-1
10	1	1	-1	1
11	1	1	-1	-1
12	1	1		
13	1	1		
14	1	1		
15	1	1		
16	1	1		
17	1	1		
18	1	1		
19	1	-1		
20	1	1		
21	-1	-1		
22	-1	1		
23	-1	-1		

6. OversamplingOption, Bandwidth, CyclicPrefix, and GuardInterval calculate the number of samples in one OFDM symbol period. The number of samples for one OFDM symbol (N) is calculated as:

$$N = 2^{OversamplingOption} \times (128 + Bandwidth \times (CyclicPrefix + GuardInterval))$$

The number of samples in one FFT period ($N_{FFTpoint}$) is calculated as:

$$N_{FFTpoint} = 2^{OversamplingOption} \times 128$$

7. IdleInterval is used to simulate the arbitrary time interval between two UWB packets. For ADS simulation, IdleInterval resolution must be (CyclicPrefix+242.42+GuardInterval)×6 nsec.

   The length of Idle (N_{idle}) can be calculated as:

   $$N_{idle} = IdleInterval \times Bandwidth \times 2^{OversamplingOption}$$

   After determining N_{SYM}, N, and N_{idle}, the length of one MB-OFDM frame (N_{total}) can be calculated:

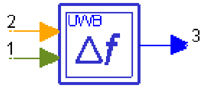
   $$N_{total} = N \times N_{SYM} + N_{idle}$$

8. SearchMode specifies the type of search: *EveryFrame* means searching every frame; *Once* means searching once in the entire simulation.
9. SearchWindow specifies the number of symbols (units of OFDM symbols) for searching. The minimum value would be 24 for standard preamble or 12 for shortened preamble; the maximum value would be the number of OFDM symbols in a UWB frame.

References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

UWB_FreqSync



Description UWB frequency synchronizer
Library UWB, Receiver

Parameters

Name	Description	Default	Unit	Type	Range
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps		enum	
DataLength	Octet number of PSDU	100		int	[1, 4095]
PreambleFormat	PLCP preamble format: Standard Format, Shortened Format	Standard Format		enum	
TFC_Number	Time frequency code: TFC1, TFC2, TFC3, TFC4, TFC5, TFC6	TFC1		enum	
OversamplingOption	Oversampling ratio: Ratio 1, Ratio 2, Ratio 4, Ratio 8	Ratio 2		enum	
Bandwidth	Bandwidth	528 MHz	Hz	real	(0, ∞)
CyclicPrefix	Cyclic prefix with zero padding	70.08 nsec	sec	real	[0, ∞)
GuardInterval	Guard interval with zero padding	0.0 nsec	sec	real	[0, ∞)
IdleInterval	Idle Interval	0.0 nsec	sec	real	[0, ∞)

Pin Inputs

Pin	Name	Description	Signal Type
1	input	received frame signals	complex
2	index	synchronization index	int

Pin Outputs

Pin	Name	Description	Signal Type
3	DeltaF	carrier frequency offset	real

Notes/Equations

1. This subnetwork model estimates the carrier frequency offset for the UWB receiver. The schematic for UWB_FreqSync is shown in Figure 5-6.

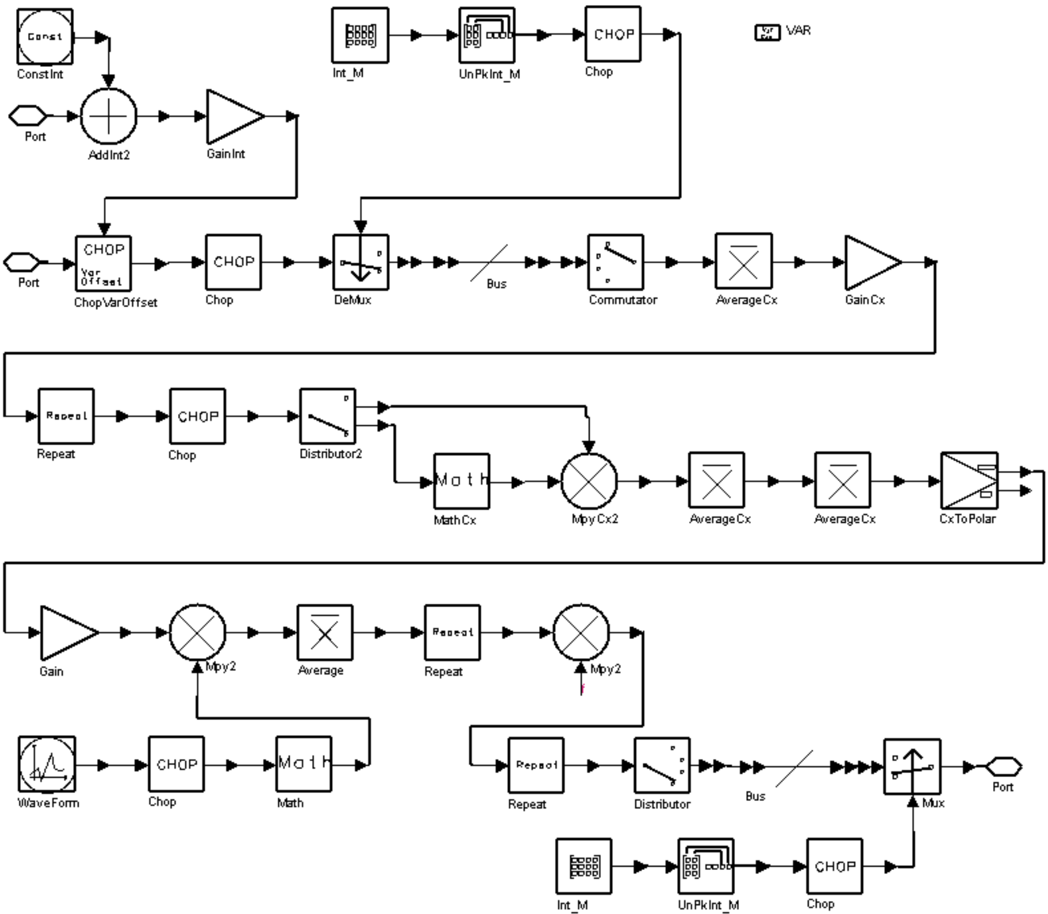


Figure 5-6. UWB_FreqSync Schematic

2. The modulating signal for different sub-bands is generated from the same clock oscillator, so the frequency offset for each sub-band is correlated and used to estimate the same clock oscillator frequency offset.

Assume f_i is the carrier frequency for the ith sub-band and Δf_i is its frequency offset, f_o is the oscillator frequency and Δf_o is its offset, then $\Delta f_i / f_i = \Delta f_o / f_o$.

3. The input signal is synchronized and separated into each sub-band. The ith sub-band phase offset $\Delta\theta_i$ can then be determined by correlating consecutive OFDM symbols and is averaged on the same sub-band.

$$\Delta\theta_i = \arg\left(\sum_{j=1}^{N-1}\sum_{k=1}^{M} x_j((j-1)\times M+k)\times x_j^*(j\times M+k)\right), i = 1 \ldots N_b$$

where x_j is the received preamble samples sequence, N is the number of preambles OFDM symbols for each sub-band, M is the number of samples per OFDM symbol (except GP and CP), and N_b is the number of sub-bands.

Frequency offset per Hz for the clock oscillator can then be estimated by

$$(\Delta f_o)/f_o = \sum_{i=1}^{Nb} (\Delta\theta_i/2\pi T)/f_i/N_b$$

where T is the time interval between two consecutive preamble OFDM symbols on the same sub-band.

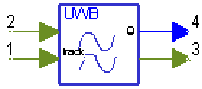
Frequency offset is then averaged over all sub-bands to improve estimation accuracy.

$$\Delta f_i = f_i \times (\Delta f_o)/f_o, i = 1, \ldots, N_b$$

References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

UWB_PhaseTracker



Description UWB Phase tracker
Library UWB, Receiver
Class SDFUWB_PhaseTracker
Derived From UWB_Base

Parameters

Name	Description	Default	Type	Range
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps	enum	
DataLength	Octet number of PSDU	100	int	[1, 4095]
PilotPN_Phase	Phase of pilot PN	10	int	[0, 126]

Pin Inputs

Pin	Name	Description	Signal Type
1	input	all sub-carriers in one OFDM symbol	complex
2	CIR	estimated channel impulse response	complex

Pin Outputs

Pin	Name	Description	Signal Type
3	coef	channel coefficient in active subcarriers	complex
4	theta	phase difference between current CIR and estimated CIR	real

Notes/Equations

1. This model tracks the common phase shift of each OFDM symbol and outputs the updated channel impulse response with the estimated phase shift compensation. Each firing, 122×NSYM tokens are produced at the input coef pin and NSYM tokens are produced at theta pin; 122×NSYM tokens are

consumed at the input pin and CIR pin; where NSYM is the number of OFDM symbol in PSDU.

2. According to [1], in each OFDM symbol following the PLCP preamble, twelve of the subcarriers are dedicated to pilot signals in order to make coherent detection robust against frequency offsets and phase noise. these pilots single are in subcarriers numbered -55, -45, -35, -25, -15, -5, 5, 15, 25, 35, 45, and 55. Assume $P(n,k)$ is the pilot on the nth subcarrier for the kth OFDM symbol and $CE(n)$ is the frequency-domain OFDM training sequence on the nth subcarrier. Then for data rate less than 110Mbps:

   $P(n,k) = CE(n), n = 5, 15, 25, 35, 45, 55$

   $P(n,k) = \mathrm{conj}(P(-n,k)), n = -5, -15, -25, -35, -45, -55$

   For data rate higher than 110Mbps:

   $P(n,k) = CE(n), n = 5, 15, 25, 35, 45, 55$

   $P(n,k) = P(-n,k), n = -5, -15, -25, -35, -45, -55$

   Pilot subcarriers are further BPSK-modulated by a pseudo-random binary sequence to prevent the generation of spectral lines.

3. When the pilot signal is received, it is BPSK-demodulated, and de-conjugated if necessary. For the time-domain spread OFDM symbol, the pilot subcarrier is also time de-spread so that it is the same as the original one. Channel estimation on the nth subcarrier for the kth symbol $CIR(n,k)$ can then be obtained. Assume $CIR_{CE}(n)$ is the estimated channel impulse response on the nth subcarrier, then the common phase shift for the kth symbol can be estimated by

   $$\tilde{\phi}(k) = \arg\left(\sum_n CIR(n,k) \times conj(CIR_{CE}(n))\right)$$

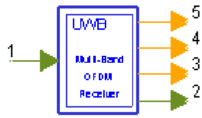
4. The output update channel impulse response for the kth OFDM symbol will be

   $$CIR_{out}(n,k) = CIR_{CE}(n) \times e^{j\tilde{\phi}(k)}$$

References

[1] IEEE P802.15-04/0493r1, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, September 2004.

UWB_Receiver



Description UWB receiver
Library UWB, Receiver

Parameters

Name	Description	Default	Unit	Type	Range
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps		enum	
DataLength	Octet number of PSDU	100		int	[1, 4095]
PreambleFormat	PLCP preamble format: Standard Format, Shortened Format	Standard Format		enum	
PreamblePattern	Preamble pattern for Time-domain synchronization sequence: Pattern 1, Pattern 2, Pattern 3, Pattern 4	Pattern 1		enum	
CoverSeq	Cover sequences for time domain preamble	1		int	[1, 2]
TFC_Number	Time frequency code: TFC1, TFC2, TFC3, TFC4, TFC5, TFC6	TFC1		enum	
OversamplingOption	Oversampling ratio: Ratio 1, Ratio 2, Ratio 4, Ratio 8	Ratio 2		enum	
Bandwidth	Bandwidth	528 MHz	Hz	real	(0, ∞)
CyclicPrefix	Cyclic prefix with zero padding	70.08 nsec	sec	real	[0, ∞)
GuardInterval	Guard interval with zero padding	0.0 nsec	sec	real	[0, ∞)
IdleInterval	Idle Interval	0.0 nsec	sec	real	[0, ∞)
ScramblerSeed	Scrambler seed selection: Seed 00, Seed 01, Seed 10, Seed 11	Seed 11		enum	
PilotPN_Phase	Phase of pilot PN	0		int	[0, 126]

Name	Description	Default	Unit	Type	Range
FreqOffset	Actual frequency offset	0.0	Hz	real	(-∞, ∞)
SearchMode	Searching mode synchronization: EveryFrame, Once	EveryFrame		enum	
SearchWindow	Searching window synchronization	24		int	†
†The minimum value of this parameter should be the number of OFDM symbols in the synchronization sequences portion of the PLCP preamble, and the maximum value of this parameter should be the number of OFDM symbols in one MB-OFDM frame.					

Pin Inputs

Pin	Name	Description	Signal Type
1	input	received signal to be demodulated	complex

Pin Outputs

Pin	Name	Description	Signal Type
2	For_EVM	undemapped signal after FFT used for EVM	complex
3	UnDecodedBits	deinterleaved data bits before decoding	int
4	PSDUFCS	PSDU and FCS bits	int
5	PSDU	PSDU bits	int

Notes/Equations

1. This subnetwork model implements baseband receiver algorithm for MB-OFDM according to Reference [1].
2. The schematic UWB_Receiver is shown in Figure 5-7.

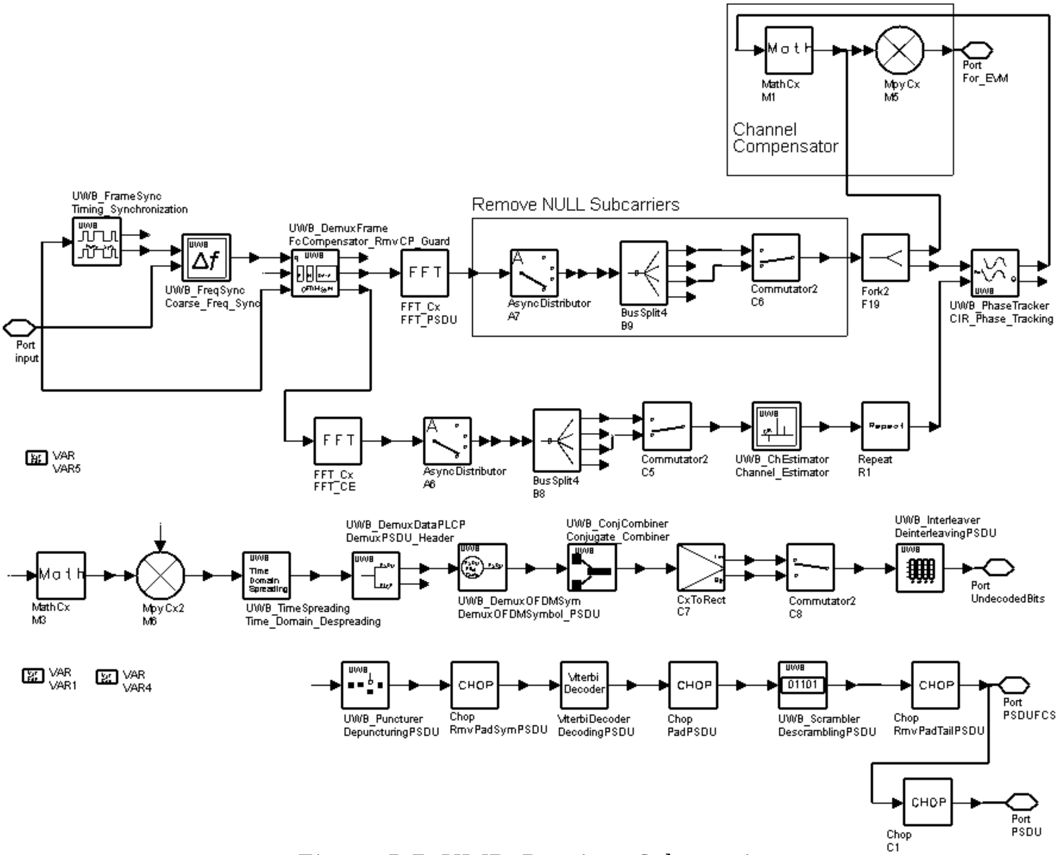


Figure 5-7. UWB_Receiver Schematic

3. Receiver Functions

Start of frame is detected. UWB_FrameSync correlates the received signal with the preambles and selects the index with the maximum correlation value as the start of frame. The transition from the time-domain to the channel estimation sequence is detected and timing (with one sample resolution) is established (packet synchronization). The frequency offset for each sub-band is then estimated by UWB_FreqSync with the time-domain sequence. The time and frequency offset are compensated by UWB_DemuxFrame, which outputs six channel estimation sequences and the OFDM symbols for PLCP header and payload frame (PSDU) demodulation. UWB_DemuxFrame introduces one frame delay.

Channel response coefficients are estimated for each subcarrier (channel estimation) on each sub-band. The estimated channel response coefficients are duplicated to compensate the PLCP header and frame payload in the same frame.

Each OFDM symbol is transformed into 122 subcarriers by FFT. Common phase variation of the pilot subcarriers are estimated, then all subcarrier values are de-rotated according to the estimated phase. UWB_PhaseTracker implements these functions.

The received signal on each subcarrier is divided by the estimated channel response coefficient (phase tracking, phase synchronization, and equalization). This simple one-tap frequency domain channel response compensation method is an advantage of OFDM systems.

After one-tap frequency equalization, the demodulated OFDM symbols for PLCP header and PSDU are output at pin For_EVM. The signal can be used to demonstrate the demodulated constellation and to calculate the EVM.

The equalized OFDM symbols of PLCP header and frame payload are de-spread by UWB_TimeSpreading in de-spreading mode. 12 OFDM symbols of PLCP header are de-spread to 6 OFDM symbols. Based on PSDU data rates, PSDU OFDM symbols are also de-spread.

After de-spreading, PLCP header and frame payload OFDM symbols are de-multiplexed by UWB_DemuxDataPLCP. There are two branches of output: frame payload and PLCP header. (PLCP header de-mapping and decoding are not implemented in this release.)

After de-spreading, UWB_DemuxOFDMSym de-multiplexes 122 subcarriers into 100 data, 12 pilot, and 10 guard subcarriers. UWB_DemuxOFDMSym outputs 100 data subcarriers.

For 53.3, 55 and 80 Mbps, the conjugate combiner is implemented before QPSK demodulation.

The frame payload bits are then de-interleaved, decoded and de-scrambled.

The PSDU with FCS is the output at pin PSDUFCS and PSDU is the output at Pin PSDU, respectively.

The de-interleaved frame payload signal is output at pin UndecodedBits, which is the signal before Viterbi decoding.

4. Parameter details

GainImbalance and PhaseImbalance add certain impairments to the ideal output RF signal.

The unimpaired RF I and Q envelope voltages have gain and phase imbalance applied. The RF is given by:

$$V_3(t) = A\left(V_1(t)\cos(\omega_c t) - g V_2(t)\sin\left(\omega_c t + \frac{\phi\pi}{180}\right)\right)$$

where $V_1(t)$ is the in-phase RF envelope, $V_2(t)$ is the quadrature phase RF envelope, and g is the gain imbalance

$$g = 10^{\frac{GainImbalance}{20}}$$

and, ϕ (in degrees) is the phase imbalance.

DataRate is for data rate of UWB-OFDM system. This release supports 53.3, 55, 80, 106.67, 110, 160, 200, 320, 400 and 480 Mbps.

DataLength represents the bytes of PSDU (MAC frame body). Its value range is 1 to 4095 bytes.

TFC_Number specifies the time-frequency code, which controls the frequency hopping sequence.

PreambleFormat specifies the standard or shortened PLCP preamble format as defined in UWB-OFDM.

OversamplingOption specifies the oversampling ratio of the transmission signal. Ratios 1, 2, 4, 8, 16, 32, 64 are supported in this receiver. For example, if OversamplingOption=Ratio 2, the IFFT size is 256.

Bandwidth specifies the UWB-OFDM spectrum bandwidth. The default value is 528 MHz.

CyclicPrefix and GuardInterval specify cyclic prefix and guard interval; default values are 70.08 ns and 0.0 ns according to Reference [1]. CyclicPrefix represents zero pad duration T_{ZP}. CyclicPrefix=60.61 nsec and GuardInterval=9.47 nsec for IEEE P802.15-03/r0268r3. Users can customize their OFDM symbols by setting both parameters.

ScramblerSeed specifies the seed identifier, which controls the 15-bit initialization vector. Because the receiver has a fixed one-frame delay, ScramblerSeed values in UWB-OFDM signal sources (UWB_SignalSource, UWB_SignalSource_RF and UWB_Source_FH_RF) and receivers

(UWB_Receiver, UWB_Receiver_RF and UWB_Receiver_FH_RF) must be two consecutive values for BER calculation. For example, ScramblerSeed=Seed 00 in the signal source and ScramblerSeed=Seed 11 in the receiver.

PilotPN_Phase is to set the start phase of pilot (PRBS). The specification requires PilotPN_Phase=0.

References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

UWB_Receiver_FH_RF

Description UWB RF frequency hopping receiver
Library UWB, Receiver

Parameters

Name	Description	Default	Unit	Type	Range
RLoad	Input resistance	DefaultRLoad	Ohm	real	(0, ∞)
RTemp	Temperature	DefaultRTemp	Celsius	real	[-273.15, ∞)
GainImbalance	Gain imbalance, Q vs I	0.0	dB	real	(-∞, ∞)
PhaseImbalance	Phase imbalance, Q vs I	0.0	deg	real	(-∞, ∞)
Sensitivity	voltage output sensitivity, Vout/Vin	1		real	(-∞, ∞)
Delay	Frequency synthesizer delay	1.8939 nsec	sec	real	[0, ∞)
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps		enum	
DataLength	Octet number of PSDU	100		int	[1, 4095]
PreambleFormat	PLCP preamble format: Standard Format, Shortened Format	Standard Format		enum	
TFC_Number	Time frequency code: TFC1, TFC2, TFC3, TFC4, TFC5, TFC6	TFC1		enum	
OversamplingOption	Oversampling ratio: Ratio 1, Ratio 2, Ratio 4, Ratio 8	Ratio 2		enum	
Bandwidth	Bandwidth	528 MHz	Hz	real	(0, ∞)
CyclicPrefix	Cyclic prefix with zero padding	70.08 nsec	sec	real	[0, ∞)
GuardInterval	Guard interval with zero padding	0.0 nsec	sec	real	[0, ∞)
IdleInterval	Idle Interval	0.0 nsec	sec	real	[0, ∞)

Name	Description	Default	Unit	Type	Range
ScramblerSeed	Scrambler seed selection: Seed 00, Seed 01, Seed 10, Seed 11	Seed 11		enum	
PilotPN_Phase	Phase of pilot PN	0		int	[0, 126]
SearchMode	Searching mode synchronization: EveryFrame, Once	EveryFrame		enum	
SearchWindow	Searching window synchronization	24		int	†
†The minimum value of this parameter should be the number of OFDM symbols in the synchronization sequences portion of the PLCP preamble, and the maximum value of this parameter should be the number of OFDM symbols in one MB-OFDM frame.					

Pin Inputs

Pin	Name	Description	Signal Type
1	RF_Signal	received RF signal to be demodulated	timed

Pin Outputs

Pin	Name	Description	Signal Type
2	For_EVM	undemapped signal after FFT used for EVM	complex
3	UnDecodedBits	deinterleaved data bits before decoding	int
4	PSDUFCS	PSDU bits with FCS	int
5	PSDU	PSDU bits	int

Notes/Equations

1. This subnetwork model implements a UWB-OFDM RF receiver with frequency hopping function according to IEEE P802.15-04/0493r1. The received RF signal with frequency hopping is demodulated by QAM_DemodExtOsc; the demodulated signal is then fed to the baseband receiver.

   The schematic for this subnetwork is shown in Figure 5-8.

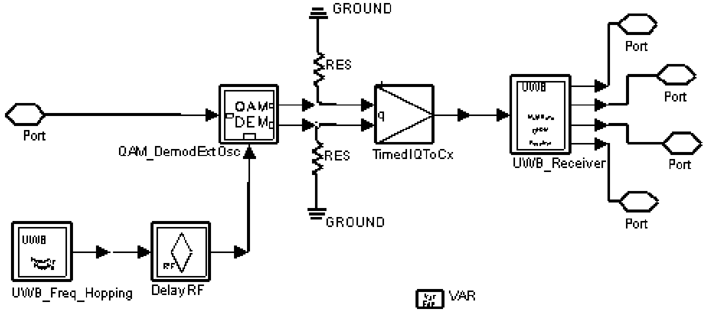
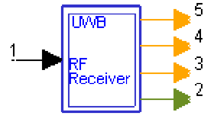


Figure 5-8. UWB_Receiver_FH_RF Schematic

References

[1] IEEE P802.15-04/0493r1, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, September 2004.

UWB_Receiver_RF



Description UWB RF receiver
Library UWB, Receiver

Parameters

Name	Description	Default	Unit	Type	Range
RLoad	Input resistance	DefaultRLoad	Ohm	real	(0, ∞)
RTemp	Temperature	DefaultRTemp	Celsius	real	[-273.15, ∞)
FCarrier	Carrier frequency	3432MHz	Hz	real	(0, ∞)
GainImbalance	Gain imbalance, Q vs I	0.0	dB	real	(-∞, ∞)
PhaseImbalance	Phase imbalance, Q vs I	0.0	deg	real	(-∞, ∞)
Sensitivity	voltage output sensitivity, Vout/Vin	1		real	(-∞, ∞)
Phase	Reference phase in degrees	0.0	deg	real	(-∞, ∞)
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps		enum	
DataLength	Octet number of PSDU	100		int	[1, 4095]
PreambleFormat	PLCP preamble format: Standard Format, Shortened Format	Standard Format		enum	
PreamblePattern	Preamble pattern for Time-domain synchronization sequence: Pattern 1, Pattern 2, Pattern 3, Pattern 4	Pattern 1		enum	
CoverSeq	Cover sequences for time domain preamble	1		int	[1, 2]
OversamplingOption	Oversampling ratio: Ratio 1, Ratio 2, Ratio 4, Ratio 8	Ratio 2		enum	
Bandwidth	Bandwidth	528 MHz	Hz	real	(0, ∞)

Name	Description	Default	Unit	Type	Range
CyclicPrefix	Cyclic prefix with zero padding	70.08 nsec	sec	real	[0, ∞)
GuardInterval	Guard interval with zero padding	0.0 nsec	sec	real	[0, ∞)
IdleInterval	Idle Interval	0.0 nsec	sec	real	[0, ∞)
ScramblerSeed	Scrambler seed selection: Seed 00, Seed 01, Seed 10, Seed 11	Seed 11		enum	
PilotPN_Phase	Phase of pilot PN	0		int	[0, 126]
FreqOffset	Actual frequency offset	0.0	Hz	real	(-∞, ∞)
SearchMode	Searching mode synchronization: EveryFrame, Once	EveryFrame		enum	
SearchWindow	Searching window synchronization	24		int	†
†The minimum value of this parameter should be the number of OFDM symbols in the synchronization sequences portion of the PLCP preamble, and the maximum value of this parameter should be the number of OFDM symbols in one MB-OFDM frame.					

Pin Inputs

Pin	Name	Description	Signal Type
1	RF_Signal	received RF signal to be demodulated	timed

Pin Outputs

Pin	Name	Description	Signal Type
2	For_EVM	undemapped signal after FFT used for EVM	complex
3	UnDecodedBits	deinterleaved data bits before decoding	int
4	PSDUFCS	PSDU bits with FCS	int
5	PSDU	PSDU bits	int

Notes/Equations

1. This subnetwork model demodulates and decodes single-band UWB-OFDM RF signals without frequency hopping.

   The schematic for this subnetwork is shown in Figure 5-9.

2. The received RF signal is demodulated by QAM_Demod; the demodulated signal is then fed to the baseband receiver for baseband processing.

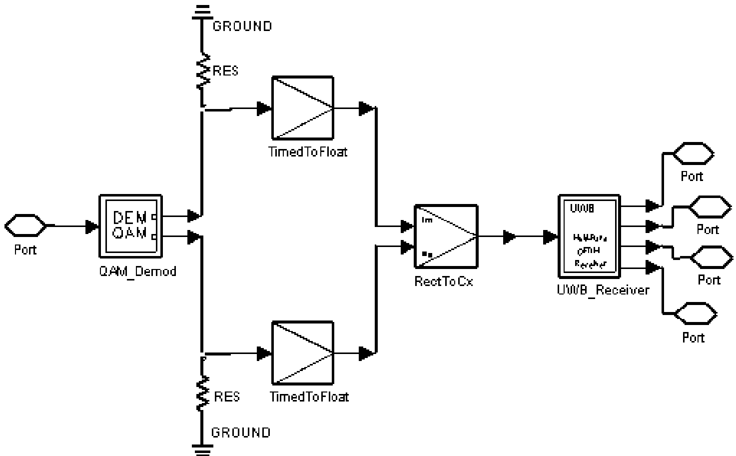


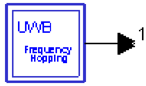
Figure 5-9. UWB_Receiver_RF Schematic

References

[1] IEEE P802.15-04/0493r1, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a,* September 2004.

Chapter 6: Signal Source Components

UWB_Freq_Hopping



Description UWB frequency hopping synthesizer
Library UWB, Signal Source

Parameters

Name	Description	Default	Unit	Type	Range
ROut	Source resistance	DefaultROut	Ohm	real	(0, ∞)
RTemp	Temperature	DefaultRTemp	Celsius	real	[-273.15, ∞)
TFC_Number	Time frequency code: TFC1, TFC2, TFC3, TFC4, TFC5, TFC6	TFC1		enum	
OversamplingOption	Oversampling ratio: Ratio 1, Ratio 2, Ratio 4, Ratio 8	Ratio 2		enum	
Bandwidth	Bandwidth	528 MHz	Hz	real	(0, ∞)
CyclicPrefix	Cyclic prefix with zero padding	70.08 nsec	sec	real	[0, ∞)
GuardInterval	Guard interval with zero padding	0.0 nsec	sec	real	[0, ∞)
DeltaF	Oscillator frequency offset	0.0	Hz	real	(-∞, ∞)

Pin Outputs

Pin	Name	Description	Signal Type
1	output	local Oscillator Out	timed

Notes/Equations

1. This subnetwork model implements a frequency hopping function in Band Group 1. The schematic for this subnetwork is shown in Figure 6-1.

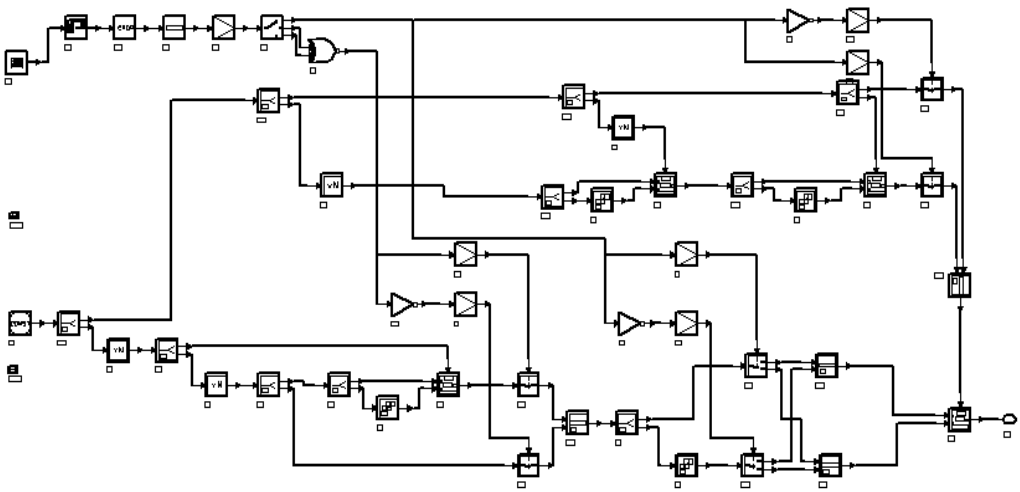


Figure 6-1. UWB_Freq_Hopping Schematic

2. UWB_Freq_Hopping has five main parameters: TFC_Number, OversamplingOption, Bandwidth, CyclicPrefix, and GuardInterval. TFC_Number specifies the time frequency code; OversamplingOption, Bandwidth, CyclicPrefix, and GuardInterval are used for calculating the number of samples in one OFDM symbol because frequency hopping is based on one OFDM symbol period. The number of samples in one OFDM symbol (N) is calculated as:

$$N = 2^{OversamplingOption} \times (128 + Bandwidth \times (CyclicPrefix + GuardInterval))$$

The time step per sample is:

$$T_{Step} = 1/(Bandwidth)/2^{OversamplingOption}$$

The duration of one OFDM symbol is:

$$T_{SYM} = 128/(Bandwidth) + CyclicPrefix + GuardInterval$$

UWB_Freq_Hopping generates N samples with a fixed carrier frequency, then shifts to output N samples with another fixed carrier frequency. For example, according to Table 6-1 when TFC_Number=1, UWB_Freq_Hopping first generates N samples with 3432 MHz, then N samples with 3960 MHz, then N samples with 4488MHz periodically.

3. The frequency of operation for Mode 1 devices is shown in Figure 6-2.

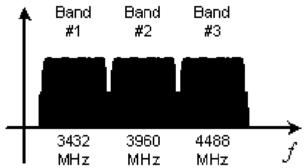


Figure 6-2. Mode 1 Device Frequency of Operation

Unique logical channels corresponding to different piconets are defined using up to four different time-frequency codes (TFCs) for each band group. The TFCs and the preamble patterns associated with them are defined in Table 6-1 using BAND_ID values for Band Group 1; similarly, they are defined for Band Groups 2, 3, and 4 by substituting the appropriate BAND_ID values. For example, for Band Group 2, BAND_ID values 4, 5, 6 replace 1, 2, 3, respectively, to generate the TFCs. For Band Groups 1, 2, 3, and 4, only TFCs 1 through 4 will be defined; for Band Group 5, only TFC 5 and 6 will be defined.

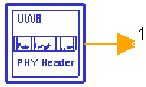
Table 6-1. Time Frequency Codes and Associated Preamble Patterns

TFC	Preamble Pattern	Cover Sequence	Length 6 Time Frequency Code (BAND ID values for Band Group 1)					
1	1	1	1	2	3	1	2	3
2	2	1	1	3	2	1	3	2
3	3	2	1	1	2	2	3	3
4	4	2	1	1	3	3	2	2
5	1	2	1	2	1	2	1	2
6	2	2	1	1	1	2	2	2

References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

UWB_PHY_Header



Description UWB physical header generator
Library UWB, Signal Source

Parameters

Name	Description	Default	Type	Range
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps	enum	
DataLength	Octet number of PSDU	100	int	[1, 4095]
ScramblerSeed	Scrambler seed selection: Seed 00, Seed 01, Seed 10, Seed 11	Seed 00	enum	

Pin Outputs

Pin	Name	Description	Signal Type
1	DataOut	UWB PHY header data	int

Notes/Equations

1. This subnetwork model outputs PLCP header bits.

   The schematic for this subnetwork is shown in Figure 6-3.

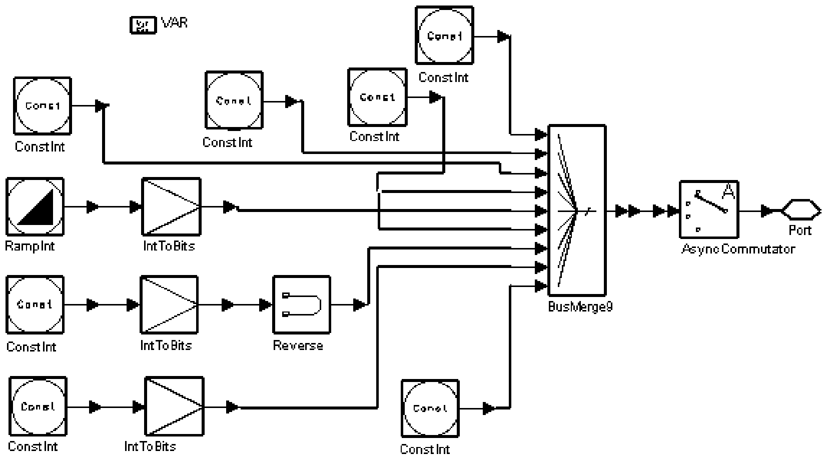


Figure 6-3. UWB_PHY_Header Schematic

2. The PHY header field, composed of 40 bits, is shown in Figure 6-4. Bits 3 through 7 encode the RATE; bits 8 through 19 encode the LENGTH field, with the least significant bit (LSB) being transmitted first; bits 22 and 23 encode the seed value for the initial state of the scrambler, which is used to synchronize the descrambler of the receiver; bit 26 encodes whether the packet is being transmitted in burst (streaming) mode; bit 27 encodes the preamble type (long or short) used in the next packet if in streaming mode. (All other bits are reserved for future use and are set to 0.)

			RATE 5 bits					LENGTH 12 bits														SCRAMBLER 2 bits																	R = Reserved
R	R	R	R1	R2	R3	R4	R5	LSB											MSB	R	R	S1	S2	R	R	BM	PT	R	R	R	R	R	R	R	R	R	R	R	R
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	30	31	32	33	34	35	36	37	38	39

Transmit Order →

Figure 6-4. PHY Header Bit Assignment

3. RATE field bits are set based on DataRate as shown in Table 6-2.

Table 6-2. RATE Bits Settings

DataRate (Mbps)	R1 through R5
53.3	00000
80	00001
110	00010
160	00011
200	00100
320	00101
400	00110
480	00111
Reserved	01000–11111

4. DataLength determines the LENGTH field. The PLCP length field is an unsigned 12-bit integer that indicates the number of bytes in the frame payload (which does not include FCS, tail bits, or pad bits).

5. ScramblerSeed determines the SCRAMBLER field. MAC sets bits S1 and S2 according to the scrambler seed identifier value. This 2-bit value corresponds to the seed value chosen for the data scrambler.

6. The BM and PT fields are set to fixed values in this subnetwork.

   If the user wants to test the MAC layer function, the user can set the BM and PT fields according to section 1.3.5 of [1]. According to the specification, the MAC sets burst mode bit BM to indicate whether the next packet is part of a packet burst (streaming mode transmission); in this mode, the inter-frame spacing is equal to a MIFS *NB*. In burst mode, the minimum packet size is 1 byte; in non-burst mode, the minimum packet size is 0 bytes.

Table 6-3. Burst Mode Field

Burst Mode Bit (BM)	Next Packet Status
0	Next packet not part of burst
1	Next packet is part of burst

The MAC sets preamble type bit PT in streaming mode to indicate the type of PLCP preamble (standard or shortened) used in the next packet as described in Table 6-4. For data rates of 200 Mbps and less, this bit is always set to 0.

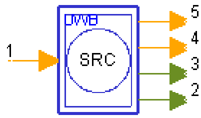
Table 6-4. Preamble Type Field

Preamble Type Bit (PT)	Type of Preamble Used In Next Packet
0	Standard preamble
1	Shortened preamble

References

[1] IEEE P802.15-04/0493r1, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, September 2004.

UWB_SignalSource



Description UWB signal source
Library UWB, Signal Source

Parameters

Name	Description	Default	Unit	Type	Range
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps		enum	
DataLength	Octet number of PSDU	100		int	[1, 4095]
PreambleFormat	PLCP preamble format: Standard Format, Shortened Format	Standard Format		enum	
PreamblePattern	Preamble pattern for Time-domain synchronization sequence: Pattern 1, Pattern 2, Pattern 3, Pattern 4	Pattern 1		enum	
CoverSeq	Cover sequences for time domain preamble	1		int	[1, 2]
OversamplingOption	Oversampling ratio: Ratio 1, Ratio 2, Ratio 4, Ratio 8	Ratio 2		enum	
Bandwidth	Bandwidth	528 MHz	Hz	real	(0, ∞)
CyclicPrefix	Cyclic prefix with zero padding	70.08 nsec	sec	real	[0, ∞)
GuardInterval	Guard interval with zero padding	0.0 nsec	sec	real	[0, ∞)
IdleInterval	Idle Interval	0.0 nsec	sec	real	[0, ∞)
ScramblerSeed	Scrambler seed selection: Seed 00, Seed 01, Seed 10, Seed 11	Seed 00		enum	
MAC_Header	10-byte MAC header	{0XA2, 0X48, 0X22, 0X4F, 0X93, 0X0E, 0XCE, 0X93, 0XBC, 0X34}		int array	(0, 255)

Name	Description	Default	Unit	Type	Range
PilotPN_Phase	Phase of pilot PN	0		int	[0, 126]
GuardGain	Gain of guard subcarriers	1.0, 1.0, 1.0, 1.0, 1.0		real array	(0, ∞)

Pin Inputs

Pin	Name	Description	Signal Type
1	PSDU	PSDU bits	int

Pin Outputs

Pin	Name	Description	Signal Type
2	Signal	signal	complex
3	ForEVM	signal for EVM test	complex
4	Encoded	encoded PSDU	int
5	PSDUFCS	PSDU bits with FCS added	int

Notes/Equations

1. This subnetwork model generates a baseband signal for UWB.

   The schematic for this subnetwork is shown in Figure 6-5.

2. The input of this subnetwork is PSDU data; MAC header data is specified by MAC_Header.

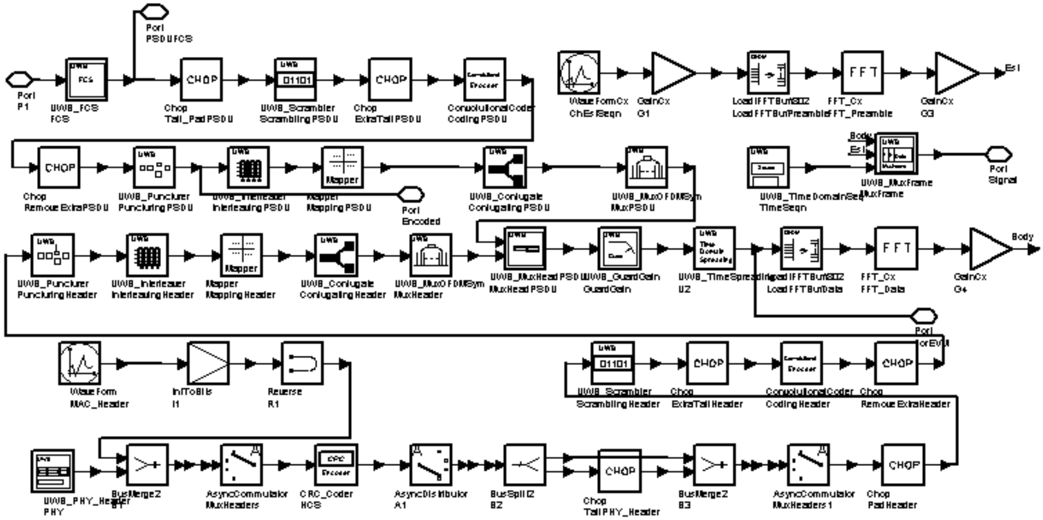


Figure 6-5. UWB_SignalSource Schematic

3. The signal source can be defined by the user by changing parameter settings.

- DataRate, DataLength, ScramblerSeed set the multi-band OFDM PHY specific service parameter. These parameters will be transmitted in the PHY header and also be used to frame the packets.

  When DataRate is set, data rate-dependent parameters such as modulation, coding rate, conjugate symmetric Input to IFFT, time spreading factor, overall spreading gain, and coded bits per OFDM symbol (N_{CBPS}) will be set as shown in Table 6-5.

Table 6-5. Data-Rate-Dependent Parameters

DataRate (Mbps)	Modulation	Coding Rate (R)	Conjugate Symmetric Input to IFFT	Time Spreading Factor (TSF)	Overall Spreading Gain	Coded Bits per OFDM symbol (N_{CBPS})
53.3	QPSK	1/3	Yes	2	4	100
80	QPSK	1/2	Yes	2	4	100
110	QPSK	11/32	No	2	2	200
160	QPSK	1/2	No	2	2	200
200	QPSK	5/8	No	2	2	200
320	QPSK	1/2	No	1 (no spreading)	1	200
Supported data rates are listed here; 55 and 106.7 Mbps are reserved for future use.						

Table 6-5. Data-Rate-Dependent Parameters

DataRate (Mbps)	Modulation	Coding Rate (R)	Conjugate Symmetric Input to IFFT	Time Spreading Factor (TSF)	Overall Spreading Gain	Coded Bits per OFDM symbol (N_{CBPS})
400	QPSK	5/8	No	1 (no spreading)	1	200
480	QPSK	3/4	No	1 (no spreading)	1	200
Supported data rates are listed here; 55 and 106.7 Mbps are reserved for future use.						

- MAC_Header specifies the MAC header content.
- CyclicPrefix, GuardInterval, and IdleInterval specify the timing-related parameters. CyclicPrefix and GuardInterval are part of zero pad duration.

  A CyclicPrefix period of zeros will be inserted before each IFFT symbol, while a GuardInterval period of zeros will be padded after the IFFT symbol. When these parameters are set to nsec, resolution is 1.89 nsec.

  IdleInterval simulates the arbitrary time interval between two UWB packets. For ADS simulation, IdleInterval resolution must be (CyclicPrefix+242.42+GuardInterval)x6 nsec.
- OverSamplingOption and Bandwidth set the simulation TStep.
- GuardGain adjusts the shape of guard subcarrier, which may result in better performance.
- The preamble format can also be set by PreambleFormat.

4. UWB_SignalSource is implemented according to specification (Reference [1]). Figure 6-6 shows the PLCP frame format. It includes the PLCP preamble, PLCP header (PHY header, MAC header, header check sequence, tail bits, and pad bits), MAC frame body (frame payload plus FCS, tail bits, and pad bits).

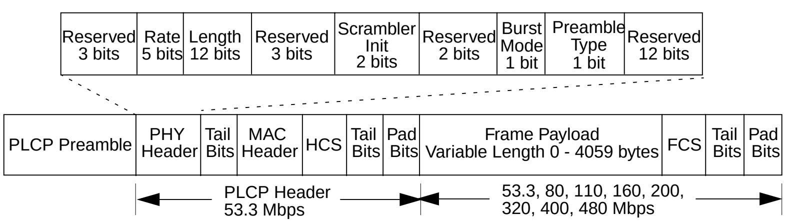


Figure 6-6. PLCP Frame Format.

The standard PLCP preamble consists of the time domain packet and frame synchronization sequence and the frequency domain channel estimation sequence. The basic sequence for time domain packet and frame synchronization sequence is implemented by UWB_TimeDomainSeq. The frequency domain channel estimation sequence is implemented by WaveFormCx. The basic timed domain packet and frame synchronization sequence is repeated and combined with the FFT'd frequency domain channel estimation sequence and the FFT'd frame body in UWB_MuxFrame.

According to the specification, the frame body will be encoded in the following manner. The PLCP header (consisting of the PHY header and associated tail bits, the MAC header plus HCS, and the associated tail bits, followed by the pad bits as in Section 1.3.8 [1]) will be encoded with a rate R = 1/3; the encoder will then be reset to the all-zero state. MAC frame body, tail bits and pad bits appended will be encoded with a specified rate (R = 1/3, 11/32, 1/2, 5/8, or 3/4) corresponding to the desired data rate. The algorithm to reset the encoder after encoding PLCP header is:

- Append 6 extra tail bits after PLCP header.
- Convolutionally encode the PLCP header and extra tail bits with rate R=1/3. The encoder is then reset to the all-zero state.
- Remove 18 symbols generated from the 6 tail bits.

While there is no requirement for the encoder to be reset after encoding the MAC frame body, tail bits and pad bits appended, it is a simulation requirement so the same algorithm is implemented.

The number of OFDM symbols per UWB-OFDM frame also consists of three parts.

There are 30 and 18 OFDM symbols for standard and shortened preamble, respectively.

$$Nsym_{preamble} = \begin{cases} 30 & Standard \\ 18 & Shortened \end{cases}$$

PLCP header, data rate 53.3 Mbps, includes PHY header (40 bits), first tail bits (6 bits), MAC header (80 bits), HCS (header check sequence, 16 bits) second tail bits (6 bits), and pad bits. Total PLCP header is 148 bits.

Before time-domain spreading, PLCP header OFDM symbol calculation is:

$$Nsym_{Header} = \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{148}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil = 6$$

where TSF=2, N_{CBPS}=100 and R=1/3 from Table 2 because PLCP header is always 53.3 Mbps. The number pad bits is 52 (=6 $\times N_{CBPS} \times R - 148$).

After time-domain spreading, PLCP header OFDM symbol calculation is:

$$Nsym_{Header-TSF} = TSF \times \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{148}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil = 12$$

MAC frame body consists of frame payload, FCS, tail bits, and pad bits.

Before time-domain spreading, PSDU OFDM symbol calculation is:

$$Nsym_{PSDU} = \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{8 \times DataLength + 32 + 6}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil$$

where R is the data rate of PSDU, TSF and N_{CBPS} are determined by the data rate (refer to Table 6-5).

The number of pad bits is:

$$Nsym_{PSDU} \times N_{CBPS} - \left\lceil \frac{8 \times DataLength + 32 + 6}{R} \right\rceil$$

Before time-domain spreading, PSDU OFDM symbol calculation is:

$$Nsym_{PSDU-TSF} = TSF \times \frac{6}{TSF} \times \left\lceil \frac{\left\lceil \frac{8 \times DataLength + 32 + 6}{R} \right\rceil}{\frac{6}{TSF} \times N_{CBPS}} \right\rceil$$

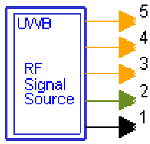
So, the total number of OFDM symbols N_{SYM} per UWB-OFDM frame is:

$$N_{SYM} = Nsym_{preamble} + Nsym_{Header-TSF} + Nsym_{PSDU-TSF}$$

References

[1] IEEE P802.15-04/0493r1, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, September 2004.

UWB_SignalSource_RF



Description UWB RF signal source
Library UWB, Signal Source

Parameters

Name	Description	Default	Unit	Type	Range
ROut	Source resistance	DefaultROut	Ohm	real	(0, ∞)
RTemp	Temperature	DefaultRTemp	Celsius	real	[-273.15, ∞)
TStep	Expression showing how TStep is related to the other source parameters	1/Bandwidth/(2^OversamplingOption)		string	
FCarrier	Carrier frequency	3432MHz	Hz	real	(0, ∞)
Power	Power	0.01	W	real	[0, ∞)
MirrorSpectrum	Mirror spectrum about carrier? NO, YES	NO		enum	
GainImbalance	Gain imbalance, Q vs I	0.0	dB	real	(-∞, ∞)
PhaseImbalance	Phase imbalance, Q vs I	0.0	deg	real	(-∞, ∞)
I_OriginOffset	I origin offset (percent)	0.0		real	(-∞, ∞)
Q_OriginOffset	Q origin offset (percent)	0.0		real	(-∞, ∞)
IQ_Rotation	IQ rotation	0.0	deg	real	(-∞, ∞)
DataPattern	Data pattern: PN9, PN15, FIX4, _4_1_4_0, _8_1_8_0, _16_1_16_0, _32_1_32_0, _64_1_64_0	PN9		enum	
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps		enum	
DataLength	Octet number of PSDU	100		int	[1, 4095]
PreambleFormat	PLCP preamble format: Standard Format, Shortened Format	Standard Format		enum	

Name	Description	Default	Unit	Type	Range
PreamblePattern	Preamble pattern for Time-domain synchronization sequence: Pattern 1, Pattern 2, Pattern 3, Pattern 4	Pattern 1		enum	
CoverSeq	Cover sequences for time domain preamble	1		int	[1, 2]
OversamplingOption	Oversampling ratio: Ratio 1, Ratio 2, Ratio 4, Ratio 8	Ratio 2		enum	
Bandwidth	Bandwidth	528 MHz	Hz	real	(0, ∞)
CyclicPrefix	Cyclic prefix with zero padding	70.08 nsec	sec	real	[0, ∞)
GuardInterval	Guard interval with zero padding	0.0 nsec	sec	real	[0, ∞)
IdleInterval	Idle Interval	0.0 nsec	sec	real	[0, ∞)
ScramblerSeed	Scrambler seed selection: Seed 00, Seed 01, Seed 10, Seed 11	Seed 00		enum	
MAC_Header	10-byte MAC header	{0XA2, 0X48, 0X22, 0X4F, 0X93, 0X0E, 0XCE, 0X93, 0XBC, 0X34}		int array	(0, 255)
PilotPN_Phase	Phase of pilot PN	0		int	[0, 126]
GuardGain	Gain of guard subcarriers	1.0, 1.0, 1.0, 1.0, 1.0		real array	(0, ∞)

Pin Outputs

Pin	Name	Description	Signal Type
1	RF	RF signal	timed
2	For_EVM	signal for EVM test	complex
3	EncodedBits	encoded PSDU	int
4	PSDUFCS	PSDU bits with FCS added	int
5	PSDU	PSDU bits	int

Notes/Equations

1. This subnetwork model generates a UWB system RF signal. The subnetwork includes UWB_SignalSource, which generates the baseband signal of UWB system, and the RF_Modulator.

The schematic for this subnetwork is shown in Figure 6-7.

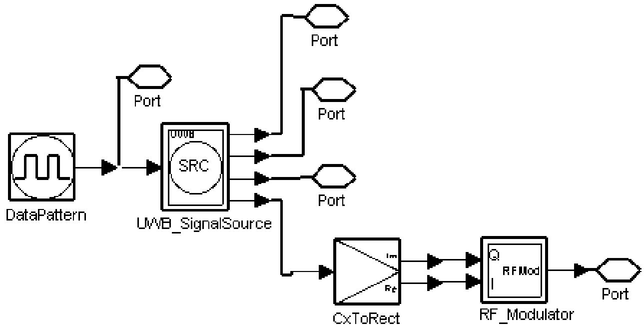


Figure 6-7. UWB_SignalSource_RF Schematic

2. The signal source can be defined by the user by changing parameter settings.
   - ROut, RTemp, Power, GainImbalance, and PhaseImbalance set the RF features of the UWB system.
   - DataRate, DataLength, and ScramblerSeed set the multi-band OFDM PHY specific service parameter. These parameters will be transmitted in the PHY header and will also be used to frame the packets.

     Data-rate-dependent parameters (modulation, coding rate, conjugate symmetric input to IFFT, time spreading factor, overall spreading gain and coded bits per OFDM symbol (N_{CBPS})) will be set according to Table 6-6, which is based on the specification.

Table 6-6. Data-Rate-Dependent Parameters

Data Rate (Mbps)	Modulation	Coding Rate (R)	Conjugate Symmetric Input to IFFT	Time Spreading Factor (TSF)	Overall Spreading Gain	Coded Bits per OFDM Symbol (N_{CBPS})
53.3	QPSK	1/3	Yes	2	4	100
80	QPSK	1/2	Yes	2	4	100
110	QPSK	11/32	No	2	2	200
160	QPSK	1/2	No	2	2	200
200	QPSK	5/8	No	2	2	200
320	QPSK	1/2	No	1 (no spreading)	1	200
400	QPSK	5/8	No	1 (no spreading)	1	200
480	QPSK	3/4	No	1 (no spreading)	1	200
Supported data rates are listed here; 55 and 106.7 Mbps are reserved for future use.						

- MAC_Header specifies the contents of MAC header.
- CyclicPrefix, GuardInterval, IdleInterval set the timing-related parameter. CyclicPrefix and GuardInterval are part of zero pad duration.

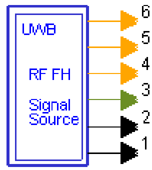
  A CyclicPrefix period of zeros will be inserted before each IFFT symbol, while a GuardInterval period of zeros will be padded after the IFFT symbol. When these parameters are nsec units, their resolution is 1.89 nsec.

  IdleInterval simulates the arbitrary time interval between two UWB packets. For ADS simulation, the resolution of IdleInterval must be (CyclicPrefix+242.42+GuardInterval)$\times$ 6 nsec.
- OverSamplingOption and Bandwidth sets the TStep of simulation.
- GuardGain adjusts the shape of guard subcarrier, which may result in better performance.
- CoverSeq, together with PreambleFormat, determines the format of the packet and frame synchronization portion of the PLCP preamble.

References

[1] IEEE P802.15-04/0493r1, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, September 2004.

UWB_Source_FH_RF



Description UWB RF frequency hopping signal source
Library UWB, Signal Source

Parameters

Name	Description	Default	Unit	Type	Range
ROut	Source resistance	DefaultROut	Ohm	real	(0, ∞)
RTemp	Temperature	DefaultRTemp	Celsius	real	[-273.15, ∞)
TStep	Expression showing how TStep is related to the other source parameters	1/Bandwidth/(2^OversamplingOption)		string	
Power	Power	0.01	W	real	[0, ∞)
GainImbalance	Gain imbalance, Q vs I	0.0	dB	real	(-∞, ∞)
PhaseImbalance	Phase imbalance, Q vs I	0.0	deg	real	(-∞, ∞)
DataPattern	Data pattern: PN9, PN15, FIX4, _4_1_4_0, _8_1_8_0, _16_1_16_0, _32_1_32_0, _64_1_64_0	PN9		enum	
DataRate	Data rate: _53.3 Mbps, _55 Mbps, _80 Mbps, _106.67 Mbps, _110 Mbps, _160 Mbps, _200 Mbps, _320 Mbps, _400 Mbps, _480 Mbps	_53.3 Mbps		enum	
DataLength	Octet number of PSDU	100		int	[1, 4095]
PreambleFormat	PLCP preamble format: Standard Format, Shortened Format	Standard Format		enum	
TFC_Number	Time frequency code: TFC1, TFC2, TFC3, TFC4, TFC5, TFC6	TFC1		enum	
OversamplingOption	Oversampling ratio: Ratio 1, Ratio 2, Ratio 4, Ratio 8	Ratio 2		enum	
Bandwidth	Bandwidth	528 MHz	Hz	real	(0, ∞)

Name	Description	Default	Unit	Type	Range
CyclicPrefix	Cyclic prefix with zero padding	70.08 nsec	sec	real	[0, ∞)
GuardInterval	Guard interval with zero padding	0.0 nsec	sec	real	[0, ∞)
IdleInterval	Idle Interval	0.0 nsec	sec	real	[0, ∞)
ScramblerSeed	Scrambler seed selection: Seed 00, Seed 01, Seed 10, Seed 11	Seed 00		enum	
MAC_Header	10-byte MAC header	{0XA2, 0X48, 0X22, 0X4F, 0X93, 0X0E, 0XCE, 0X93, 0XBC, 0X34}		int array	(0, 255)
PilotPN_Phase	Phase of pilot PN	0		int	[0, 126]
GuardGain	Gain of guard subcarriers	1.0, 1.0, 1.0, 1.0, 1.0		real array	(0, ∞)

Pin Outputs

Pin	Name	Description	Signal Type
1	RF	RF signal	timed
2	RFCarrier	hopping carrier	timed
3	For_EVM	signal for EVM test	complex
4	EncodedBits	encoded PSDU	int
5	PSDUFCS	PSDU bits with FCS added	int
6	PSDU	PSDU bits	int

Notes/Equations

1. This subnetwork model generates an RF signal for UWB in Band Group 1.

   The schematic for this subnetwork is shown in Figure 6-8.

   UWB_SignalSource generates the baseband signal of an UWB system. QAM_ModExtOsc implements a multi-band OFDM RF system. UWB_Freq_Hopping supports the frequency pattern of Band Group 1. DataPattern simulates PSDU data.

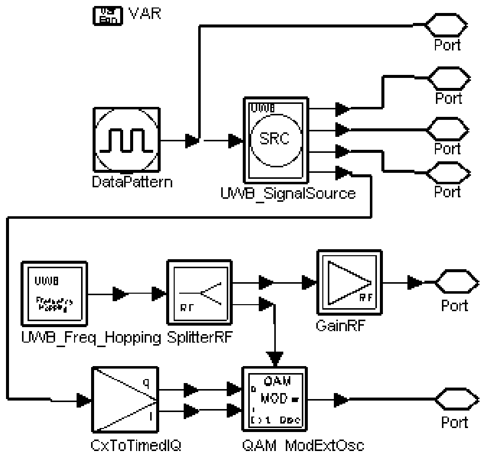


Figure 6-8. UWB_Source_FH_RF Schematic

2. ROut, RTemp, Power, GainImbalance, and PhaseImbalance parameters are used to set the RF features of a UWB system.

3. TFC_Number specifies time-frequency code and also defines the preamble pattern number and cover sequence in a UWB system. TFC_Number 1, 2, 3, or 4 are the only valid numbers because band group 1 is the only supported group.

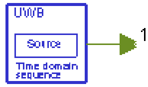
4. Hopping carriers are generated by UWB_Freq_Hopping. Carrier frequency is fixed to 4224 MHz. The effective carrier can be 3432, 3960, and 4488 MHz; refer to UWB_Freq_Hopping for details.

5. GainRF sets RFCarrier output impedance.

References

[1] IEEE P802.15-04/0493r1, *Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*, September 2004.

UWB_TimeDomainSeq



Description UWB time domain synchronization sequence generator
Library UWB, Signal Source
Class SDFUWB_TimeDomainSeq

Parameters

Name	Description	Default	Type
OversamplingOption	Oversampling ratio: Ratio 1, Ratio 2, Ratio 4, Ratio 8	Ratio 2	enum
PreamblePattern	Preamble pattern for Time-domain synchronization sequence: Pattern 1, Pattern 2, Pattern 3, Pattern 4	Pattern 1	enum

Pin Outputs

Pin	Name	Description	Signal Type
1	DataOut	output data	complex

Notes/Equations

1. This model generates the time domain synchronization sequence in the UWB PLCP preamble. Each firing, $N_{FFTpoint}$ DataOut tokens are produced, where $N_{FFTpoint}$ is the number of samples in one FFT period.
2. OversamplingOption calculates the number of samples ($N_{FFTpoint}$) in one FFT period:

   $$N_{FFTpoint} = 2^{OversamplingOption} \times 128$$

   When OversamplingOption>0, the interpolated and filtered time domain synchronization sequence is output at DataOut.
3. PreamblePattern determines the time domain synchronization sequence pattern. Four patterns are defined in Table 5 to Table 8 of Reference [1].

References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

Chapter 7: Receiver Design Examples

Introduction

Design examples for UWB receiver projects are available in ADS at *File* > *Example Project* > *UWB*.

UWB_OFDM_Rx_prj provides UWB receiver test and measurement design examples based on IEEE P802.15-04/0493r1. Designs in this project include:

- UWB_OFDM_RxSensitivity.dsn: minimum receiver sensitivity measurement
- UWB_OFDM_PER_vs_Range_AWGN.dsn: PER performance under an AWGN channel
- UWB_OFDM_PER_vs_Range_Fading.dsn: PER performance under multipath channel

Minimum Receiver Sensitivity Measurements

UWB_OFDM_RxSensitivity.dsn

Features

- 200 Mbps data rate
- 6.6 dB noise factor

Description

Minimum input level sensitivity measurements are demonstrated in this example. Minimum input levels are measured at the antenna connector.

The schematic for this design is shown in Figure 7-1. Users can set parameters in Signal_Generation_VARs, RF_Channel_VARs, and Measurement_VARs.

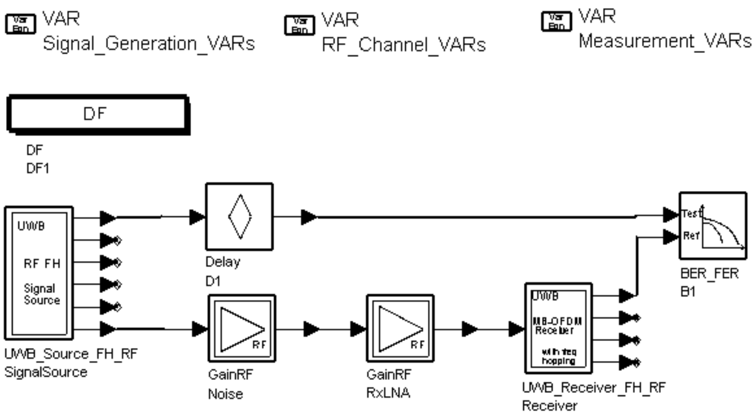


Figure 7-1. UWB_OFDM_RxSensitivity.dsn Schematic

Specification Requirements

According to section 1.6 of Reference [1], the packet error rate must be less than 8% at a PSDU length of 1024 bytes; minimum receiver sensitivity levels are listed in Table 7-1.

Table 7-1. Receiver Sensitivity Levels

Data Rate (Mbps)	Minimum Sensitivity (dBm) for Mode 1
53.3	-83.6
80	-81.6
110	-80.5
160	-78.6
200	-77.2
320	-75.5
400	-74.2
480	-72.6

Simulation Results

BER and PER at given input levels are simulated; results displayed in UWB_OFDM_RxSensitivity.dds are shown in Figure 7-2.

Index	BER	PER
0	6.584E-5	0.060

Figure 7-2. Simulation Results

Benchmark

- Hardware Platform: Pentium IV 2.26 GHz, 512 MB memory
- Software Platform: Windows 2000, ADS 2004A
- Simulation Time: approximately 6 hours

References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

PER vs. Range in an AWGN Environment

UWB_OFDM_PER_vs_Range_AWGN.dsn

Features

- -9.9 dBm signal power
- 6.6 dB noise factor

Description

System performance in an AWGN environment is demonstrated in this example. Simulation is performed for at least 500 packets with a payload of 1K bytes each. Performance includes packet acquisition accuracy, channel estimation accuracy, and carrier offset recovery accuracy.

The schematic for this design is shown in Figure 7-3. Users can set parameters in Signal_Generation_VARs, RF_Channel_VARs, and Measurement_VARs.

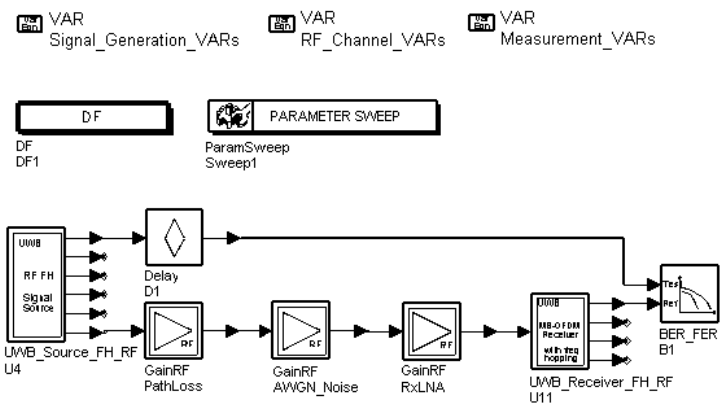


Figure 7-3. UWB_OFDM_PER_vs_Range_AWGN.dsn

Specification Requirements

The PER requirement as specified in Reference [1] for Mode 1 as a function of distance and information data rate in an AWGN environment is shown in Figure 7-4.

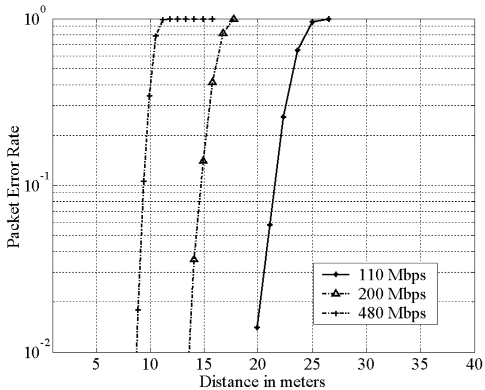


Figure 7-4. PER vs. Range in an AWGN Environment

Simulation Results

Simulation result displayed in UWB_OFDM_PER_vs_Range_AWGN.dds are shown in Figure 7-5.

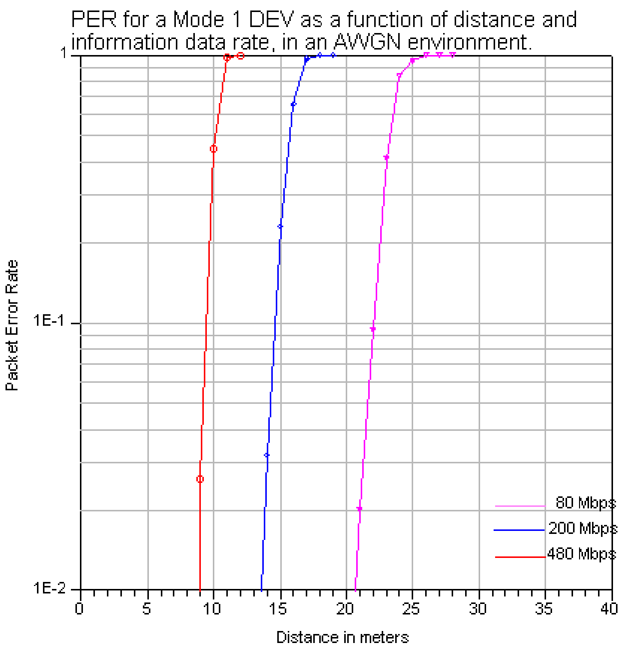


Figure 7-5. Simulation Results

Benchmark

- Hardware Platform: Pentium IV 2.26 GHz, 512 MB memory
- Software Platform: Windows 2000, ADS 2004A
- Simulation Time: approximately 6 hours

References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

PER vs. Range in a Fading Environment

UWB_OFDM_PER_vs_Range_Fading.dsn

Features

- Signal power is -9.9 dBm
- NF is 6.6 dB

Description

This design evaluates multi-band OFDM system performance in a fading environment. Simulation is performed with at least 500 packets with a payload of 1K bytes each. The performance simulation incorporates losses due to packet acquisition accuracy, channel estimation accuracy, carrier offset recovery accuracy, etc.

The schematic is shown in Figure 7-6. Users can set parameters in Signal_Generation_VARs, RF_Channel_VARs, and Measurement_VARs.

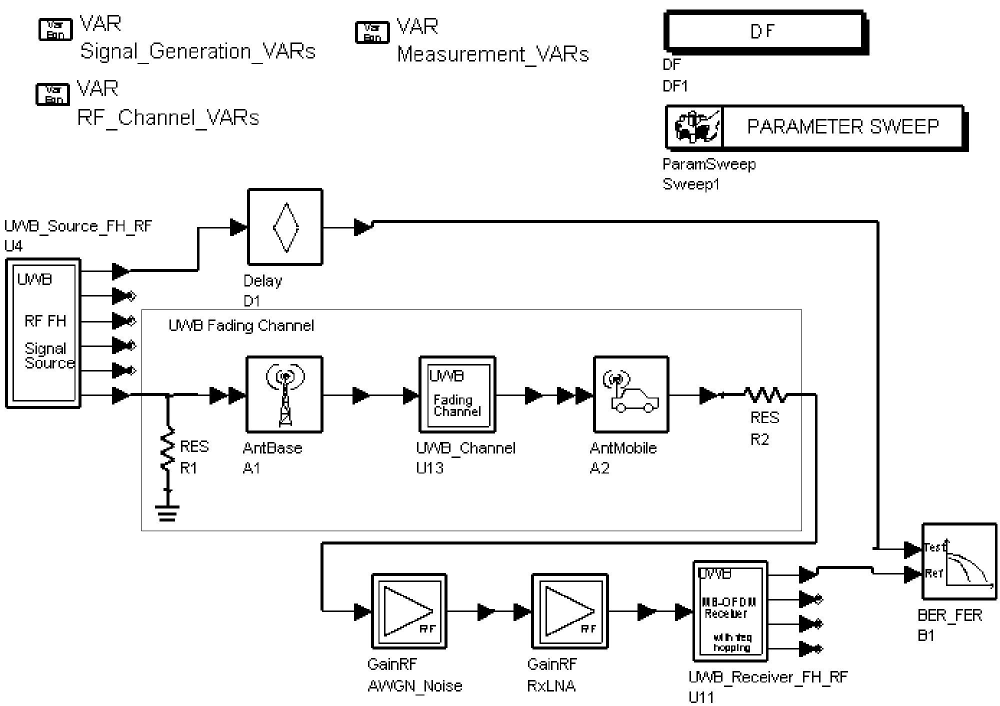


Figure 7-6. UWB_OFDM_PER_vs_Range_Fading.dsn

Specification Requirements

The PER requirement for a Mode 1 DEV as a function of distance and information data rate in a fading environment as specified in Reference [1] is shown in Figure 7-7.

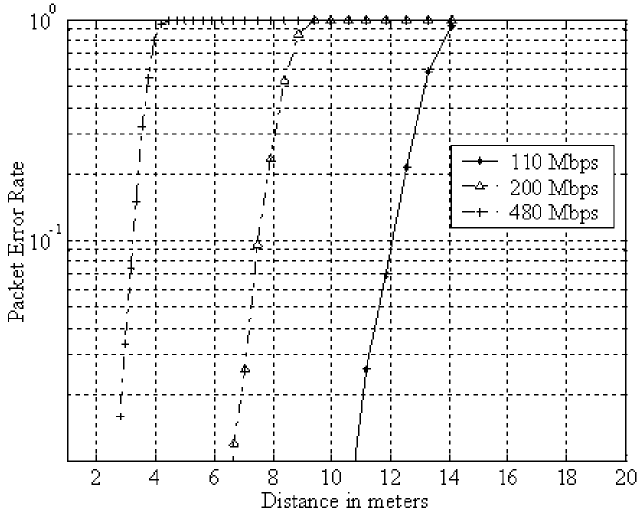


Figure 7-7. PER in CM1 Channel Environment

Simulation Results

Simulation results displayed in *UWB_OFDM_PER_vs_Range_Fading.dds* are shown in Figure 7-8.

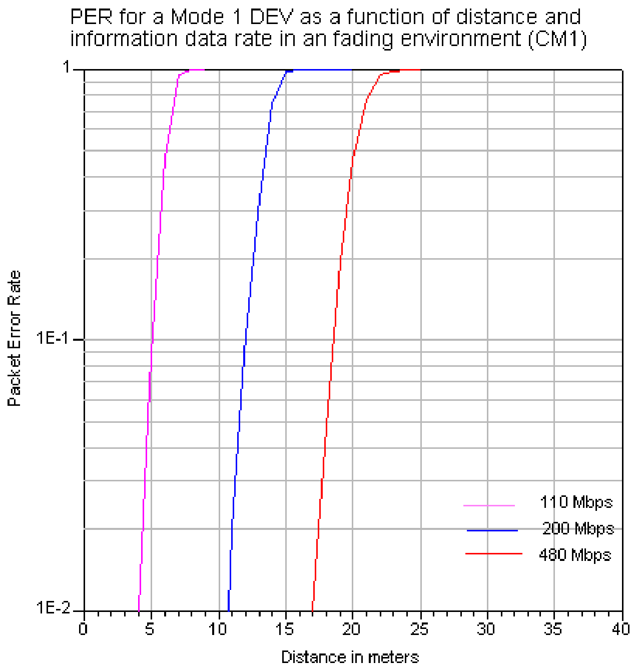


Figure 7-8. Simulation Results

Benchmark

- Hardware Platform: Pentium IV 2.26 GHz, 512 MB memory
- Software Platform: Windows 2000, ADS 2004A
- Simulation Time: approximately 6 hours

References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

Chapter 8: Transmitter Design Examples

Introduction

Design examples for UWB transmitter projects are available in ADS at *File > Example Project > UWB*.

UWB_OFDM_Tx_prj provides UWB transmitter test and measurement design examples based on IEEE P802.15-04/0493r1. Designs in this project include:

- UWB_OFDM_Demo.dsn: encodes a multi-band OFDM PHY frame.
- UWB_OFDM_TxCCDF.dsn: measures the complementary cumulative distribution function of the transmitted signal.
- UWB_OFDM_TxEVM.dsn: measures error vector magnitude and records constellations of the reference signal and the signal to be measured. The transmitter is a UWB RF signal source with frequency hopping that provides a reference signal.
- UWB_OFDM_TxEVM_TruncatedSignal.dsn: measures error vector magnitude and records constellations of the signal to be measured. The transmitter is a UWB RF signal source without frequency hopping and without a reference signal. The signal provided by the transmitter can be arbitrarily truncated when the signal is longer than one frame.
- UWB_TxSpectrum.dsn: measures transmitter signal power spectrum density.

Packet Encoding

UWB_OFDM_Demo.dsn

Features

- 53.3 Mbps PHY header rate
- 200 Mbps payload data rate
- Complete packet output

Description

This design is used to verify signal generator UWB_SignalSource using settings based on the example in IEEE P802.15-04/0493r1 (Annex A). The schematic for this design is shown on Figure 8-1.

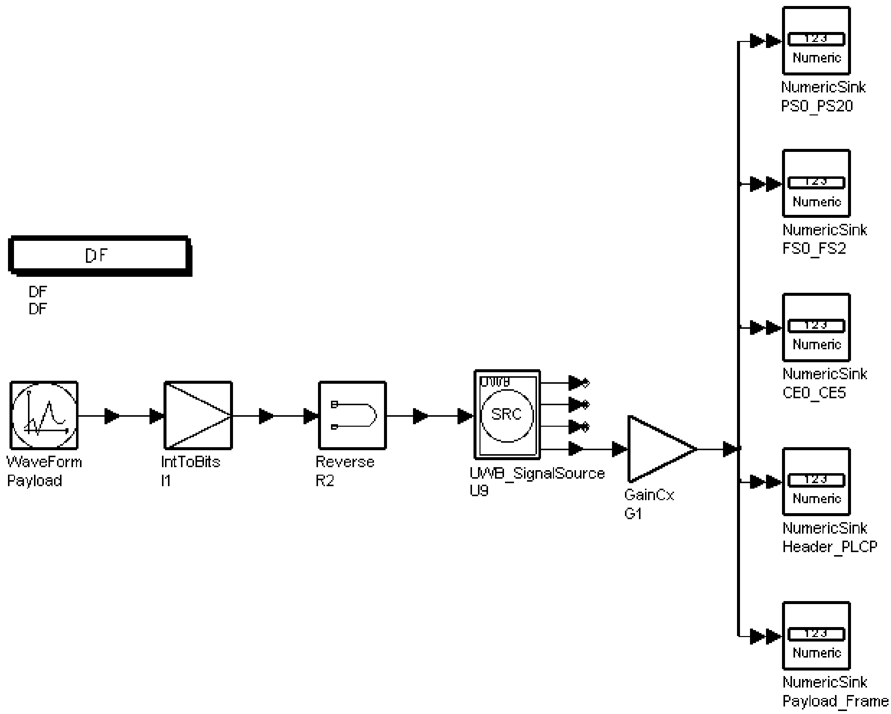


Figure 8-1. UWB_OFDM_Demo Schematic

Waveform generates the 40-byte packet for transmission shown in Table A10.1 in [1]. IntToBits converts the signal to bits.

In ADS, the MSB is transmitted first; according to the specification, the LSB is transmitted first; so, the Reverse component is used in this design to ensure the correct transmission order.

The signal is normalized in UWB_SignalSource; data in IEEE P802.15-04/0493r1 Table A12 is not normalized; so the GainCx component is added to match them.

The NumericSinks record packet synchronization, frame synchronization, and channel estimation sequences, PLCP Header, and PLCP PSDU data.

Parameter settings for this design are shown in Table 8-1.

Table 8-1. System Parameter Example Settings

Parameter	Setting
Time Frequency Code	1
Preamble Format	Standard
Data Rate	200 Mbps
Modulation	QPSK
Coding Rate	5/8
Conjugate Symmetry	No
Time Spreading Factor	2
Number of Coded Bits per OFDM Symbol (Ncbps)	200
PHY header: rate bits R1:R5	00100
PHY header: PLCP Length (bytes)	40
PLCP Scrambler Field S1:S2	01
Preamble Bit	0
Burst mode bit	1

Simulation Results

Simulation results displayed in UWB_OFDM_Demo.dds are shown on Figure 8-2. Results agree with IEEE P802.15-04/0493r1 Table A12.

PLCP Preamble

Index	PS0_PS20	Index	FS0_FS2	Index	CE0_CE5
0	0.0000 + j0.0000	3465	0.0000 + j0.0000	3960	0.0000 + j0.0000
1	0.0000 + j0.0000	3466	0.0000 + j0.0000	3961	0.0000 + j0.0000
2	0.0000 + j0.0000	3467	0.0000 + j0.0000	3962	0.0000 + j0.0000
3	0.0000 + j0.0000	3468	0.0000 + j0.0000	3963	0.0000 + j0.0000
4	0.0000 + j0.0000	3469	0.0000 + j0.0000	3964	0.0000 + j0.0000
5	0.0000 + j0.0000	3470	0.0000 + j0.0000	3965	0.0000 + j0.0000
6	0.0000 + j0.0000	3471	0.0000 + j0.0000	3966	0.0000 + j0.0000
7	0.0000 + j0.0000	3472	0.0000 + j0.0000	3967	0.0000 + j0.0000
8	0.0000 + j0.0000	3473	0.0000 + j0.0000	3968	0.0000 + j0.0000
9	0.0000 + j0.0000	3474	0.0000 + j0.0000	3969	0.0000 + j0.0000
10	0.0000 + j0.0000	3475	0.0000 + j0.0000	3970	0.0000 + j0.0000
11	0.0000 + j0.0000	3476	0.0000 + j0.0000	3971	0.0000 + j0.0000
12	0.0000 + j0.0000	3477	0.0000 + j0.0000	3972	0.0000 + j0.0000
13	0.0000 + j0.0000	3478	0.0000 + j0.0000	3973	0.0000 + j0.0000
14	0.0000 + j0.0000	3479	0.0000 + j0.0000	3974	0.0000 + j0.0000
15	0.0000 + j0.0000	3480	0.0000 + j0.0000	3975	0.0000 + j0.0000
16	0.0000 + j0.0000	3481	0.0000 + j0.0000	3976	0.0000 + j0.0000
17	0.0000 + j0.0000	3482	0.0000 + j0.0000	3977	0.0000 + j0.0000
18	0.0000 + j0.0000	3483	0.0000 + j0.0000	3978	0.0000 + j0.0000
19	0.0000 + j0.0000	3484	0.0000 + j0.0000	3979	0.0000 + j0.0000
20	0.0000 + j0.0000	3485	0.0000 + j0.0000	3980	0.0000 + j0.0000
21	0.0000 + j0.0000	3486	0.0000 + j0.0000	3981	0.0000 + j0.0000
22	0.0000 + j0.0000	3487	0.0000 + j0.0000	3982	0.0000 + j0.0000
23	0.0000 + j0.0000	3488	0.0000 + j0.0000	3983	0.0000 + j0.0000
24	0.0000 + j0.0000	3489	0.0000 + j0.0000	3984	0.0000 + j0.0000
25	0.0000 + j0.0000	3490	0.0000 + j0.0000	3985	0.0000 + j0.0000
26	0.0000 + j0.0000	3491	0.0000 + j0.0000	3986	0.0000 + j0.0000
27	0.0000 + j0.0000	3492	0.0000 + j0.0000	3987	0.0000 + j0.0000
28	0.0000 + j0.0000	3493	0.0000 + j0.0000	3988	0.0000 + j0.0000
29	0.0000 + j0.0000	3494	0.0000 + j0.0000	3989	0.0000 + j0.0000
30	0.0000 + j0.0000	3495	0.0000 + j0.0000	3990	0.0000 + j0.0000
31	0.0000 + j0.0000	3496	0.0000 + j0.0000	3991	0.0000 + j0.0000
32	7.2502 + j0.0000	3497	-7.2502 + j0.0000	3992	9.8995 + j0.0000

Note:These tables are the same as Table A12:Entire packet for transmision(PS-FS-CE-Header-Payload) in IEEE P802.15-04/0493r1 except that the index starts from 0.

PLCP Header and Frame payload

Index	Header_PLCP	Index	Payload_Frame
4982	-24.0416 + j0.0000	7855	-3.8134 - j0.2436
4983	15.2471 + j1.0910E-...	7856	-5.4338 - j5.8385
4984	-14.3738 - j1.2579E-...	7857	6.6373 + j1.6003
4985	-8.7005 - j1.4601E-14	7858	8.4388 - j18.0218
4986	17.8584 + j1.1546E-...	7859	5.2877 + j2.2115
4987	5.1731 + j8.3838E-15	7860	-3.1613 - j11.1159
4988	3.1290 + j1.2544E-15	7861	5.9572 - j11.8331
4989	-19.2864 - j4.3078E-...	7862	-7.5309 + j12.3796
4990	-11.3713 - j4.4409E-...	7863	-2.0231 + j1.2109
4991	17.4293 + j2.8423E-...	7864	16.4959 - j7.5921
4992	13.0085 + j1.8119E-...	7865	-3.8144 + j2.7067
4993	0.9226 + j3.7176E-15	7866	-6.4060 + j2.2549
4994	-6.0404 - j1.1713E-14	7867	-8.2426 + j2.4853
4995	-10.1471 - j1.4487E-...	7868	1.4754 + j8.8485
4996	2.6132 - j2.3954E-15	7869	-2.1587 + j1.7437
4997	-7.7390 - j2.8923E-14	7870	7.4088 - j4.8297
4998	13.3137 + j8.9865E-...	7871	2.4711 + j6.6665
4999	3.1079 + j3.4988E-15	7872	-5.4126 - j5.3988
5000	-2.8727 - j8.8595E-15	7873	-1.8586 - j11.1103
5001	20.7512 + j3.8690E-...	7874	-1.6352 + j0.0804
5002	-14.4348 - j2.3606E-...	7875	7.3086 + j1.1291
5003	-16.2725 - j3.7357E-...	7876	0.0365 - j6.2764
5004	25.5593 + j4.8827E-...	7877	6.2194 - j0.3119
5005	-0.7844 - j2.8882E-15	7878	-5.9257 + j23.2870
5006	-20.1451 - j2.4425E-...	7879	-15.1899 - j2.1994
5007	-3.3529 - j5.6605E-15	7880	0.6060 + j1.2982
5008	-12.7806 - j3.2729E-...	7881	-5.2302 - j7.2359
5009	-7.8615 - j2.1595E-14	7882	4.2858 + j5.0211
5010	1.9726 - j5.5511E-16	7883	-1.4142 + j9.8995
5011	-11.5203 - j3.7135E-...	7884	-3.6324 + j4.7330
5012	9.0568 + j2.6512E-14	7885	4.6085 - j1.6681
5013	5.9107 + j9.4630E-15	7886	-0.7662 + j4.9639
5014	7.0711 + j7.9977E-15	7887	-4.9827 + j8.2454

Figure 8-2. Simulation Results

Benchmark

- Hardware platform: Pentium IV 1.7 GHz, 512 MB memory
- Software platform: Windows 2000 Workstation, ADS 2004A
- Simulation time: 20 seconds

References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

Complementary Cumulative Distribution Function Measurement

UWB_OFDM_TxCCDF.dsn

Features

- CCDF measurement
- UWB RF signal source with frequency hopping
- 80 Mbps data rate
- Transmit signal waveforms

Description

This design measures the CCDF of an UWB RF signal source with frequency hopping. The schematic for this design is shown on Figure 8-3.

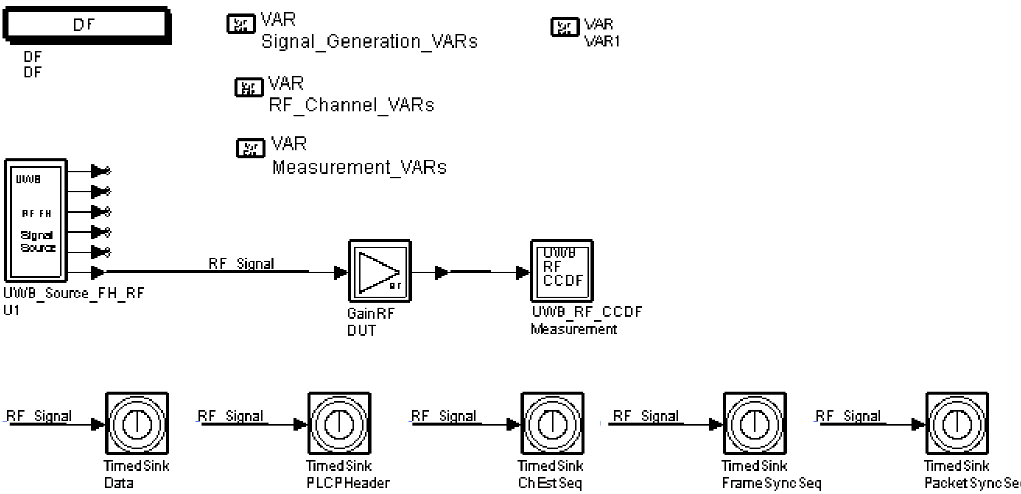


Figure 8-3. UWB_OFDM_TxCCDF.dsn Schematic

Signal_Generation_VARs parameters are used to configure UWB_Source_FH_RF; Measurement_VARs parameters are used to configure UWB_RF_CCDF (the CCDF measurement model).

TimedSink components record the waveforms of packet synchronization, frame synchronization, channel estimation, PLCP Header, and PLCP PSDU sequences.

Simulation Results

Simulation results displayed in UWB_OFDM_TxCCDF.dds are shown on Figure 8-4 and Figure 8-5.

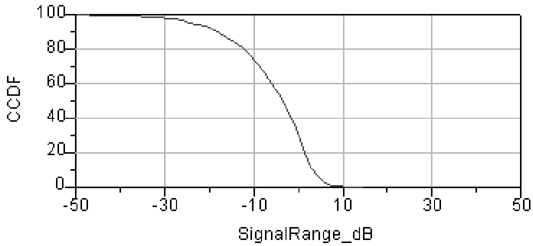


Figure 8-4. CCDF Simulation Results

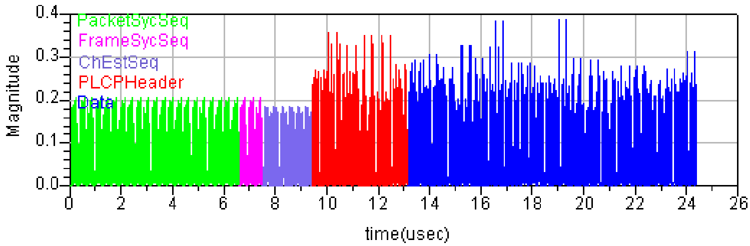


Figure 8-5. Waveform Simulation Results

Benchmark

- Hardware platform: Pentium IV 2.26 GHz, 1024 MB memory
- Software platform: Windows 2000 Workstation, ADS 2005A
- Simulation time: approximately 10 minutes

References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

Error Vector Magnitude with Reference Signal

UWB_OFDM_TxEVM.dsn

Features

- EVM measurement with reference signal
- UWB RF signal source with frequency hopping
- 480 Mbps data rate
- Records constellations of reference signal and signal to be measured
- EVM vs subcarrier

Description

This design tests the transmit modulation accuracy of an UWB RF signal source with frequency hopping by measuring the RMSE between the reference signal and the signal to be measured. The schematic for this design is shown in Figure 8-6.

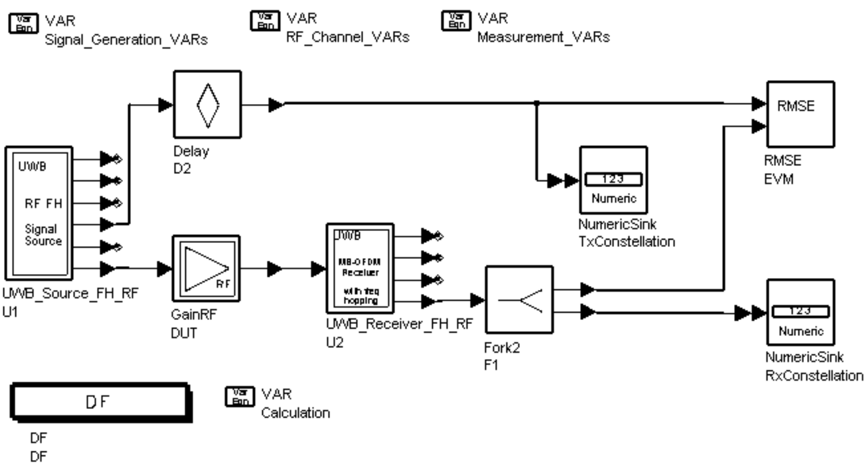


Figure 8-6. UWB_OFDM_TxEVM.dsn Schematic

UWB_Source_FH_RF with frequency hopping provides transmitted and reference signals. GainRF adds AWGN and nonlinear distortion to the transmitted signal. UWB_Receiver_FH_RF extracts the signal to be measured. RMSE calculates the root mean square error between the reference signal and the signal to be measured as the EVM measurement result. TxConstellation and RxConstellation record the constellations of the reference signal and the signal to be measured, respectively.

Simulation Results

EVM measurement results are shown in Figure 8-7; constellation of the signal to be measured is shown in Figure 8-8; the constellation of the signal to be measured and that of the reference signal at each subcarrier are shown in Figure 8-9.

Index	EVM_dB	EVM_Percentage
0	-23.984	6.314

Figure 8-7. EVM Results

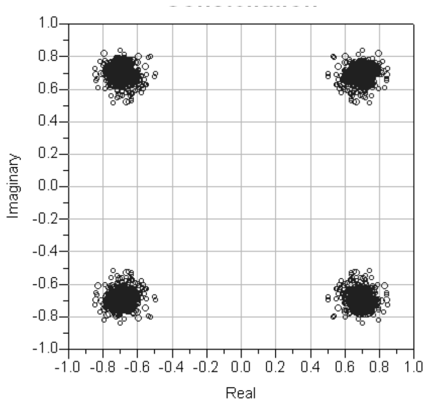


Figure 8-8. Constellation of Signal to be Measured

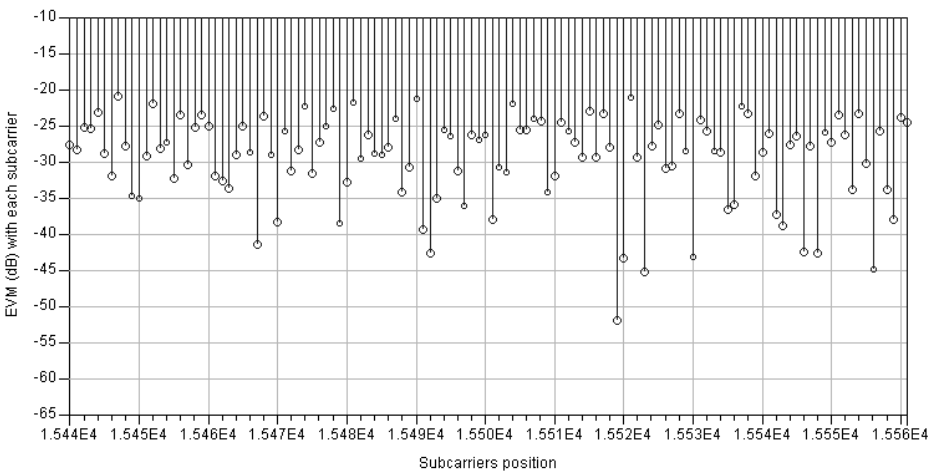


Figure 8-9. EVM vs Subcarrier Simulation Results of First OFDM Symbol

Benchmark

- Hardware platform: Pentium IV 2.26 GHz, 1024 MB memory
- Software platform: Windows 2000 Workstation, ADS 2005A
- Simulation time: 100 seconds

References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

Error Vector Magnitude without Reference Signal

UWB_OFDM_TxEVM_TruncatedSignal.dsn

Features

- EVM measurement without reference signal
- UWB RF signal source without frequency hopping
- UWB RF signal arbitrarily truncated
- 480 Mbps data rate
- Records constellation of signal to be measured
- EVM vs subcarrier

Description

This design tests the transmit modulation accuracy of a signal source without frequency hopping by measuring the RMSE between the reference signal and the signal to be measured. The signal source does not provide a reference signal and the transmitted signal can be arbitrarily truncated.

The schematic for this design is shown in Figure 8-10. SDFRead is used to read the data file generated by instrument. UWB_EVM is used to measure the EVM of the received signal without frequency hopping (a reference signal is not needed for it).

The UWB_EVM schematic is shown on Figure 8-11. UWB_Receiver_RF extracts the signal to be measured. Demapper and Mapper restore the reference signal. RMSE calculates the root mean square error between the reference signal and the signal to be measured as the EVM measurement result. TxConstellation records the constellation of the restored reference signal; RxConstellation records the constellation of the signal to be measured.

Figure 8-10. UWB_OFDM_TxEVM_TruncatedSignal.dsn Schematic

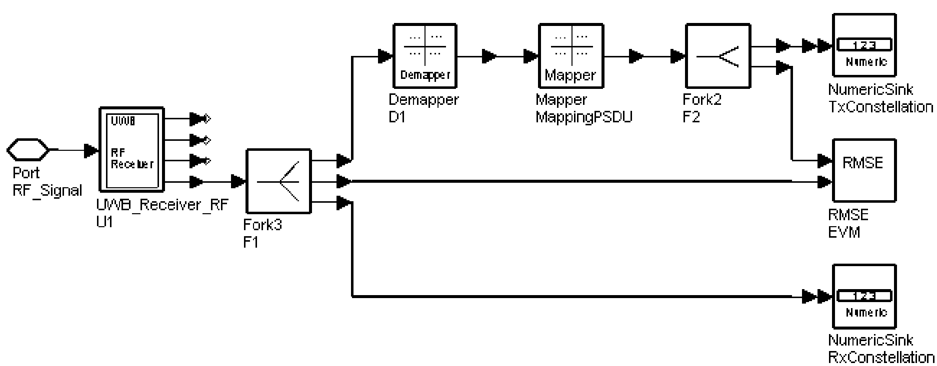


Figure 8-11. UWB_EVM Schematic

Simulation Results

Simulation results in Figure 8-12 shows the EVM measurement results. Figure 8-13 shows the constellation of the signal to be measured. Figure 8-14 shows the difference between the constellation of the signal to be measured and that of the reference signal at each subcarrier.

Index	EVM_dB	EVM_Percentage
0	-24.678	5.836

Figure 8-12. EVM Results

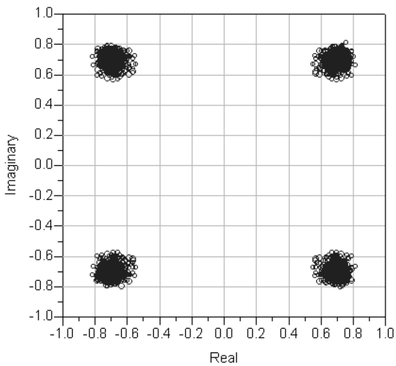


Figure 8-13. Constellation of Signal to be Measured

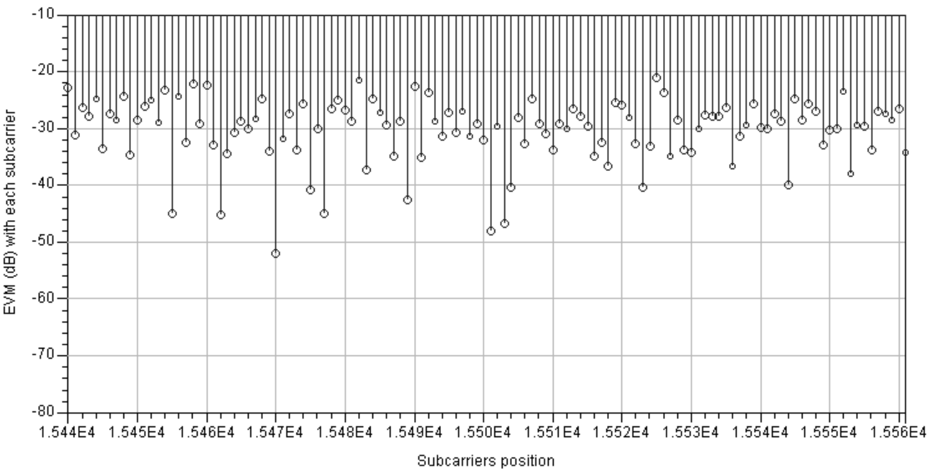


Figure 8-14. EVM vs Subcarrier Results of First OFDM Symbol

Benchmark

- Hardware platform: Pentium IV 2.26 GHz, 1024 MB memory
- Software platform: Windows 2000 Workstation, ADS 2005A
- Simulation time: 100 seconds

References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

Transmitter Spectrum Measurement

UWB_OFDM_TxSpectrum.dsn

Features

- Configurable signal source
- Adjustable sampling rate
- Spectrum analysis
- Integrated RF section

Description

This design measures transmitter signal power spectrum density. The schematic for this design is shown in Figure 8-15.

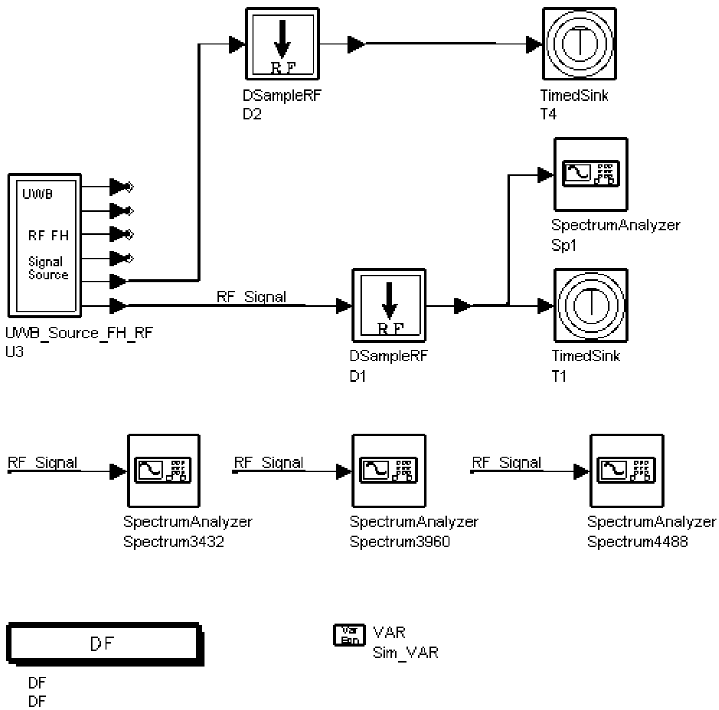


Figure 8-15. UWB_OFDM_TxSpectrum.dsn Schematic

TFC 1 is used for this test; other patterns can be tested by setting Sim_VAR. For example, to measure spectrum density in band 2 when TFC number=1 and Preamble Format=Standard Format, the start time for data recording of the SpectrumAnalyzer can be (312.5 × 46 + 70.08) nsec, and the stop time for data recording of the SpectrumAnalyzer can be (312.5 × 46 + 70.08 + 242.424242) nsec, where 312.5 nsec is the symbol interval, 70.08 nsec is the zero pad duration, 242.424242 nsec is the IFFT/FFT period, and 46 is the symbol number that points to band 2.

Measurements in this design are based on section 1.5.1 of Reference [1]. The transmitted spectrum has a 0 dBr (dB relative to the maximum spectral density of the signal) bandwidth not exceeding 260 MHz, –12 dBr at 285 MHz frequency offset, –20 dBr at 330 MHz frequency offset and above. The transmitted signal spectral density must fall within the spectral mask, as shown in Figure 8-16.

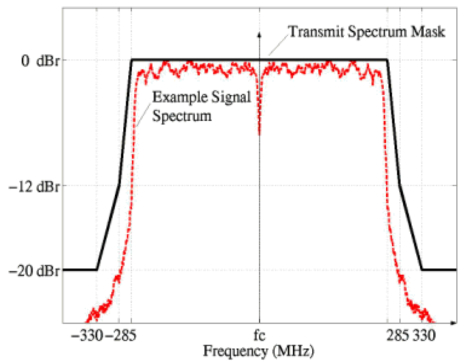


Figure 8-16. Transmit Spectrum Mask

Simulation Results

Simulation results displayed in UWB_OFDM_TxSpectrum.dds are shown here.

Figure 8-17 shows the power spectrum density of the transmitted signals at 3 different bands with the spectrum mask (blue lines); Figure 8-18 shows the power spectrum density of the multi-band signals at 1MHz resolution bandwidth with the FCC mask.

Figure 8-19 shows the LO instantaneous frequency versus time, the TX signal instantaneous frequency versus time, and the real part of the baseband signal versus time.

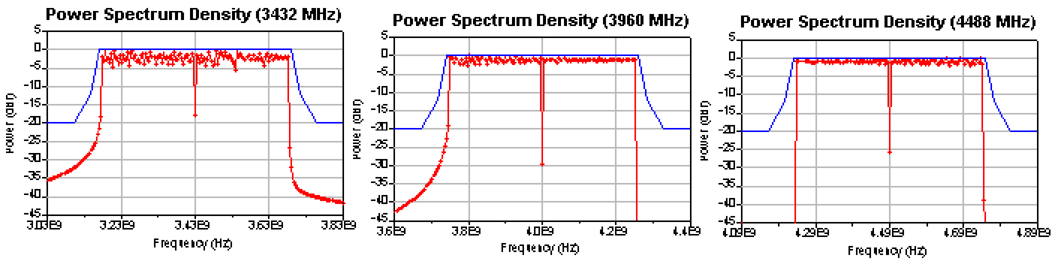


Figure 8-17. Power Spectrum Densities

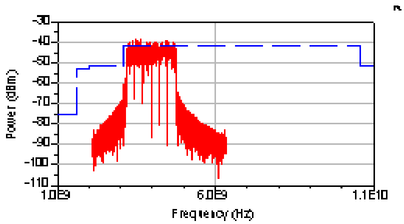


Figure 8-18. Power Spectrum at 1MHz RBW

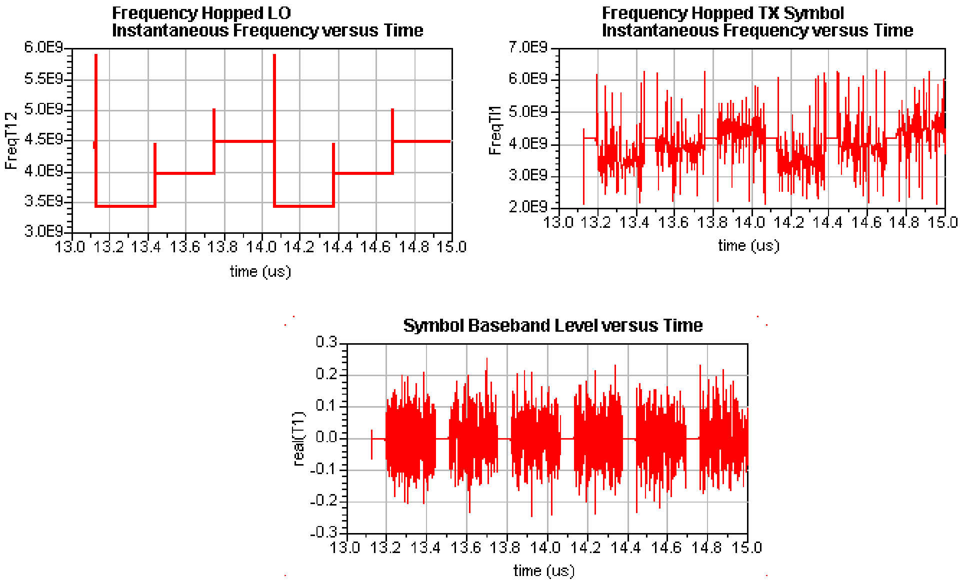


Figure 8-19. Instantaneous Frequencies and Symbol Baseband vs Time

Benchmark

- Hardware Platform: Pentium IV 2.26 GHz, 512 MB memory
- Software Platform: Windows 2000, ADS 2004A
- Simulation Time: 77 seconds

References

[1] IEEE P802.15-04/0493r1, Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, September 2004.

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