IEEE P802.15
Wireless Personal Area Networks

Project	IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)
Title	**XtremeSpectrum CFP Document**
Date Submitted	July 2003
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Re:	Response to CFP 02/372
Abstract	[Detailed information for the XtremeSpectrum proposal. The summary detail is contained in document 03/153.]
Purpose	[Description of what the author wants P802.15 to do with the information in the document.]
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0 Introduction and PDF Draft Text

This document supports the XtremeSpectrum proposal summary (document 02/153) and presents technical details of significant. This document will be periodically revised as details become available.

The XSI proposed draft standard text is presented as an appendix to this document.

1 Proposal Summary

- BPSK & QPSK in two PHY bands
- CDMA coding for multiple access
  - Supports up to 4 piconets per PHY band
- High Band: 8.2 GHz with BW=2.736 GHz
  - 57 Mbps to 800 Mbps
- Low Band: 4.1 GHz with BW=1.368 GHz
  - 28.5 Mbps to 400 Mbps
- Nyquist Filtering with 50% excess bandwidth
- Protection for UNII band
- Constant symbol rate per sub-band
  - High Band 114 Ms/s
  - Low Band 57 Ms/s
- 24 Chip/Symbol Ternary (3 state) Codewords
- CCA Supported
  - Each piconet uses an offset center frequency and chipping rate
- Three FEC options
  - Convolutional (low speeds, moderate coding gain)
  - Reed-Solomon (high speeds, moderate coding gain)
  - Concatenated (low speeds, high coding gain)
- Three preamble length options for QoS dependent PHY overhead
  - Long Preamble for long range and low rates
  - Medium Preamble for nominal range and rates
  - Short Preamble for short range and high rates
- RX link budget summary
  - Provide 114 Mb/s at 10 meters in the low band with 7.0 dB of margin
  - Provide 200 Mb/s at 10 meters in the low band with 5.1 dB of margin
  - Provide 600 Mb/s at 4 meters in the high band with 3.3 dB of margin
- RX uses DFE for ISI mitigation
- RX uses RAKE for ICI mitigation
- The 802.15.3 MAC is used with very little modification
- Ranging enhancement is proposed
- Simple “durable” radio design

    - Worldwide capable
    - Addresses future, potential regulatory differences
- Graceful coexistence with other services
    - Spectral stewardship
- Inexpensive
- Low power consumption
- High throughput with graceful path to higher data rates
    - Maintains graceful backwards compatibility

2 Performance Details

2.1 Power Consumption

The power consumption is <200 mW total for RF and PLCP baseband, based upon 90 nm CMOS (1.0 v).

Chip	Power mW
RF Front End	78 mW (3.3 V) TX, 84 mW (2.5 V) RX
PLCP Baseband	Sleep: 2 mW, Idle: 23 mW, TX: 29 mW, RX: 90 mW

2.2 Die Size Estimates

Process technology is circ. 2002.

Chip	Size Estimate
RF Front End	4.7 mm x 4.1 mm, 0.18 SiGe
PLCP Baseband	4.4 mm x 4.4 mm, 0.18 CMOS, 1.8V core, 3.3V I/O Gate Count Estimate: TBD

2.3 Time to Market

XtremeSpectrum, Inc. proposes a simple durable worldwide radio design via an inexpensive, low power consumption alternative PHY for a higher data rate amendment to standard 802.15.3. This proposal will include IEEE formatted draft amendment standard text for the Alt PHY as well as text for enhanced MAC subclauses, and informative annexes as required. If the IEEE down selection process yields a single proposal by the close of the Session #25/San Francisco 25Jul03 plenary meeting we estimate that P802.15.3a draft standard compliant silicon product is possible for integration by end of calendar year 2003.”

2.4 Antenna Size Estimates

The XSI UWB antennas are planar patch antennas with the following areas.

Band	Area
4.1 GHz	1.1 in. x 1.1 in.
8.2 GHz	0.6 in. x 0.6 in.

Note: the effective aperture is approximately ½ the real aperture and many practical antenna designs should be able to meet this principle. The antenna XtremeSpectrum is using in its demonstration is simply one existence proof showing the practicality of an antenna.

2.5 TX Peak-to-Average Value

PAR (peak to average ratio) is 6.4 dB for either the low or high band, but the waveform is relatively insensitive to transmitter PAR limiting and the peak-to-average can be reduced at the cost of out-of-band rejection.

2.6 Coding Gain

2.6.1 Convolutional FEC

Viterbi Decoder: K = 7 ($G_1 = 171_8$ $G_2 = 133_8$), 5.2 dB coding gain @ 10^{-5} BER (R=1/2)

Reference: STEL2060C Data Sheet, http://www.intel.com/design/digital/STEL-2060/index.htm

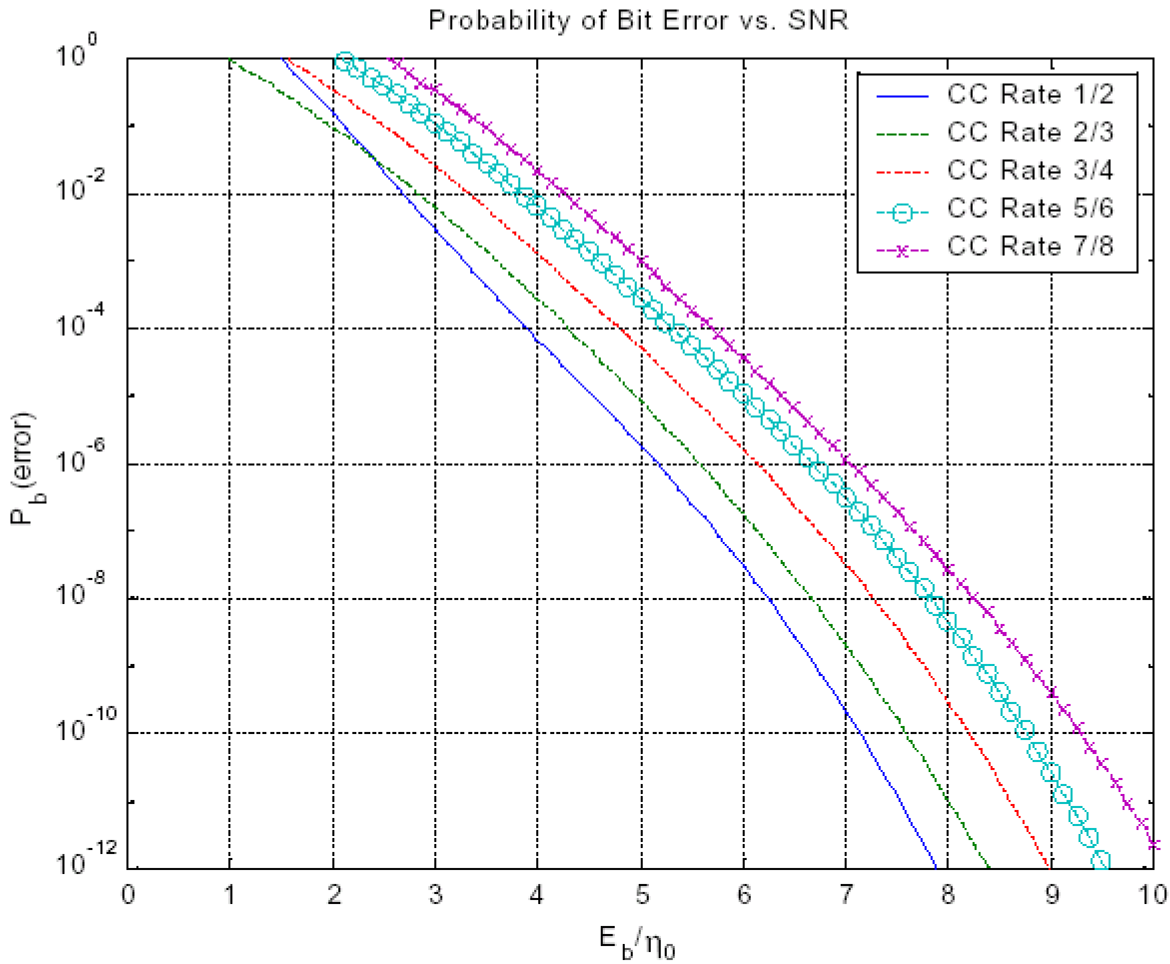


Figure 2: Performance of Convolutional Codes

Source: Document 802161pc-00_33.pdf, contribution to IEEE802.16.1, "FEC Performance of Concatenated Reed-Solomon and Convolutional Coding with Interleaving", Foerster, Jeff and John Liebetreu, June 2000

2.6.2 Reed-Solomon FEC

R-S[223,255], Coding Gain in AWGN @10e-5, 3.4 dB (via Monte-Carlo Simulation)

2.6.3 Concatenated FEC

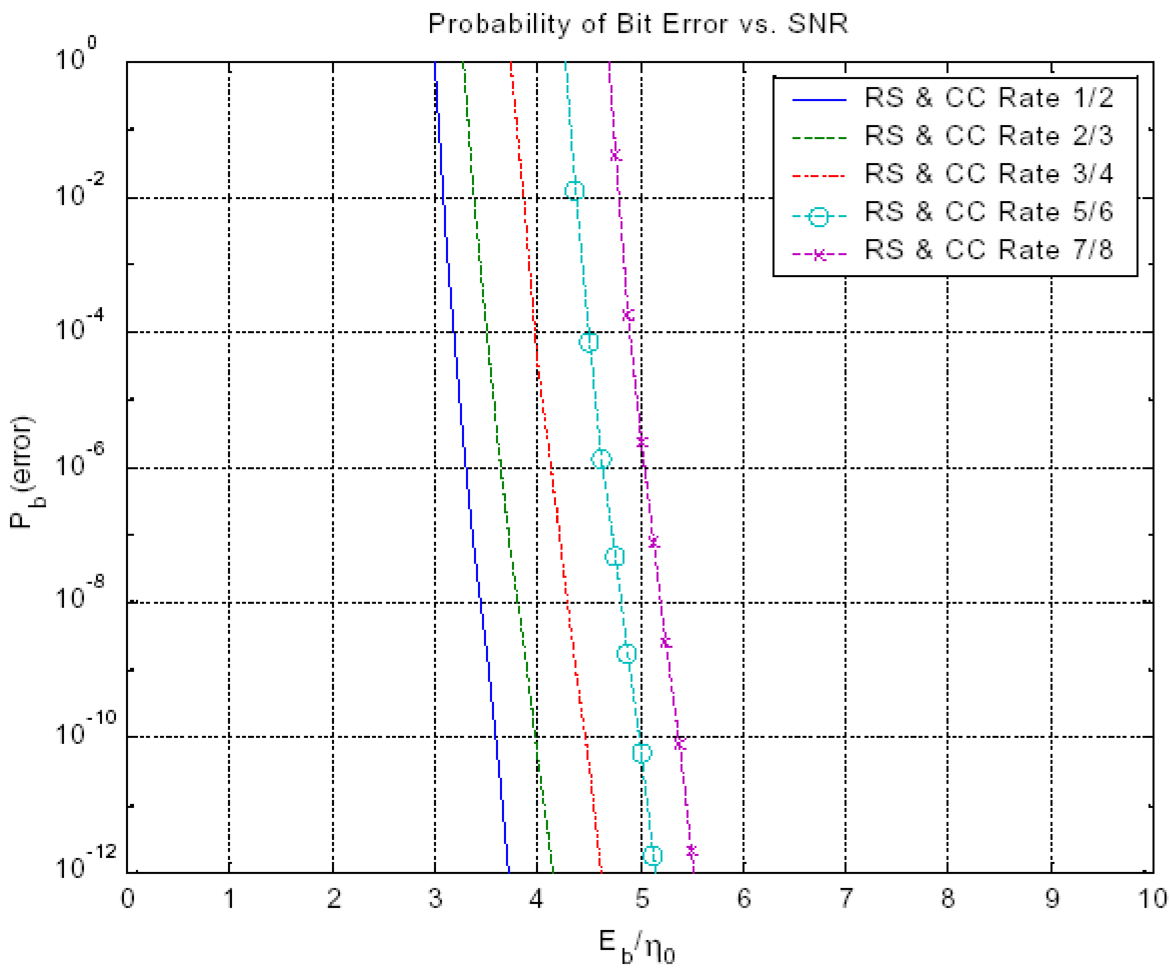
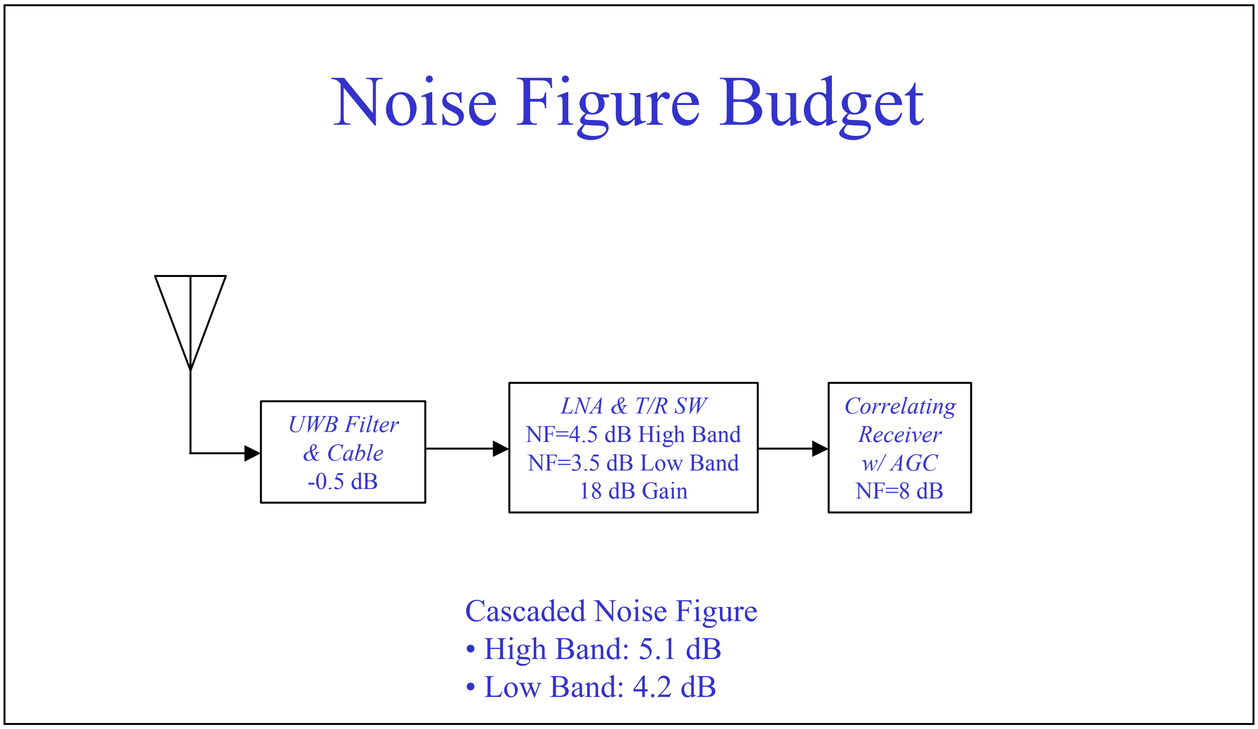


Figure 3: Performance of Concatenated Reed-Solomon with Convolutional Code

Source: Document 802161pc-00_33.pdf, contribution to IEEE802.16.1, "FEC Performance of Concatenated Reed-Solomon and Convolutional Coding with Interleaving", Foerster, Jeff and John Liebetreu, June 2000

2.7 Typical Receiver Sensitivity Tables

2.7.1 Receiver Noise Figure



2.7.2 Low Band

Low Band Symbol Rates and Link Budget

Txpow=-9.9 dBm; Coded Eb/No=9.6 dB, 3 dB implementation loss, 0 dB RAKE gain, NF=4.2 dB, ½ rate code gain: 5.2 dB, 2/3 rate code gain: 4.7 dB, 3/4 rate code gain: 4 dB, RS code gain: 3 dB, concatenated gain: 6.3 dB, 8-BOK coding gain: 1.4 dB, 16-BOK coding gain: 2.4 dB, 2-BOK PSD Backoff: 2.2 dB, 4-BOK PSD Backoff: 2.1 dB, 8-BOK PSD Backoff: 1.7 dB, 16-BOK PSD Backoff: 1.3 dB

Rate	Modulation	CDMA Code Type	FEC	Fc GHz[1]	Range AWGN	Acquisition Range	10 meter margin	RX Sensitivity[2]
28.5 Mbps	BPSK	2-BOK (1 bits/symbol)	½ rate convolutional	4.0	36.8 meters	16.7 meters	11.3 dB	-87.9 dBm
57 Mbps	BPSK	4-BOK (2 bits/symbol)	½ rate convolutional	4.0	26.3 meters	16.9 meters	8.4 dB	-84.8 dBm
75 Mbps	BPSK	8-BOK (3 bits/symbol)	Concatenated	4.0	32.1 meters	17.7 meters	10.1 dB	-86.2 dBm
100 Mbps	BPSK	4-BOK (2 bits/symbol)	RS(255, 223)	4.0	15.5 meters	>15.5 meters	3.8 dB	-80.2 dBm
114 Mbps	BPSK	8-BOK (3 bits/symbol)	2/3 rate convolutional	4.0	21.6 meters	17.7 meters	6.7 dB	-82.7 dBm
200 Mbps (199.4 Mbps)	BPSK	16-BOK (4 bits/symbol)	RS(255, 223)	4.0	15.8 meters	>15.8 meters	4.0 dB	-79.6 dBm
400 Mbps (398.8 Mbps)	QPSK	16-BOK (8 bits/symbol)	RS(255, 223)	4.0	11.2 meters	>11.2 meters	1.0 dB	-76.6 dBm

[1] Center frequency determined as geometric mean in accordance with 03/031r9, clause 5.6
[2] Based upon corrected Eb/No of 9.6 dB after application of all coding gain

Coding Gain References:
- http://www.intel.com/design/digital/STEL-2060/index.htm
- http://grouper.ieee.org/groups/802/16/tg1/phy/contrib/802161pc-00_33.pdf

Table is representative - there are about 28 logical rate combinations offering unique QoS in terms of Rate, BER and latency

2.7.3 High Band

High Band Symbol Rates and Link Budget

Txpow=-6.9 dBm; Coded Eb/No=9.6 dB, 3 dB implementation loss, 0 dB RAKE gain, NF=5.1 dB, ½ rate code gain: 5.2 dB, 2/3 rate code gain: 4.7 dB, 3/4 rate code gain: 4 dB, RS code gain: 3 dB, concatenated gain: 6.3 dB, 8-BOK coding gain: 1.4 dB, 16-BOK coding gain: 2.4 dB, 2-BOK PSD Backoff: 2.2 dB, 4-BOK PSD Backoff: 2.1 dB, 8-BOK PSD Backoff: 1.7 dB, 16-BOK PSD Backoff: 1.3 dB

Rate	Modulation	CDMA Code Type	FEC	Fc GHz	Range AWGN	Acquisition Range	4 meter margin	RX Sensitivity
100 Mbps	BPSK	4-BOK (2 bits/symbol)	Concatenated	8.1	14.2 meters	10.7 meters	11.0 dB	-82.6 dBm
114Mbps	BPSK	4-BOK (2 bits/symbol)	½ rate convolutional	8.1	11.7 meters	10.7 meters	9.3 dB	-80.9 dBm
200 Mbps (199.4 Mbps)	BPSK	4-BOK (2 bits/symbol)	RS(255, 223)	8.1	6.9 meters	>6.9 meters	4.7 dB	-76.3 dBm
300 Mbps (299.1 Mbps)	BPSK	8-BOK (3 bits/symbol)	RS(255, 223)	8.1	6.9 meters	>6.9 meters	4.8 dB	-75.9 dBm
400 Mbps (398.8 Mbps)	BPSK	16-BOK (4 bits/symbol)	RS(255, 223)	8.1	7.0 meters	>7.0 meters	4.9 dB	-75.7 dBm
600 Mbps (598.2 Mbps)	QPSK	8-BOK (6 bits/symbol)	RS(255, 223)	8.1	4.9 meters	>4.9 meters	1.7 dB	-72.9 dBm
800 Mbps (797.6 Mbps)	QPSK	16-BOK (8 bits/symbol)	RS(255, 223)	8.1	5.0 meters	>5.0 meters	1.9 dB	-72.7 dBm

Table is representative - there are about 28 logical rate combinations offering unique QoS in terms of Rate, BER and latency

2.7.4 Complete Range, Rate and Sensitivity Tables

The tables below include "Code Word TX Backoff" and "Acquisition Range Limiting"

"Code Word TX Backoff" is due to the worst case peak spectral ripple associated with a codeword set. "Acquisition Range Limiting" reflects the fact that, due to high coding gain in some modes, we can track farther than we can acquire.

FEC:	**Gain**	**Rate**		**BOK:**	**Gain**	**Rate**	**Back Off dB**
None	0	1					
1/2 rate	5.2	0.5		2-BOK	0	1	2.2
2/3 rate	4.7	0.66666667		4_BOK	0	2	2.1
3/4 rate	4	0.75		8-BOK	1.4	3	1.7
R_S	3	0.8745098		16-BOK	2.4	4	1.3
Concat	6.3	0.4372549					

Acq Eb/No dB	Acq Rate Mbps
1.13E+01	2.85E+01

LOW BAND

5-Jun-03

NBW	PSD dBm/MHz	Total TX Power dBm	RX Noise Figure dB	Imp Loss	Fo MHz	Symbol Rate Ms/s	10 Meter Path Loss dB
1.37E+09	-41.24949	-9.89E+00	4.2	3	4.00E+03	5.70E+01	6.44E+01

BOK	**FEC**	**FEC Chip Rate Mc/s**	**Bit Rate Mb/s**	**Range**	**10 meter margin dB**	**4 meter margin dB**	**Sensitivity**	Effective Eb/No	Acquisition Eb/No min	Est. Acq Limited Range
2	None	57	57.0	14.3	3.1	11.1	-79.6	9.6	8.2	**14.3**
4	None	114	114.0	10.2	0.2	8.2	-76.6	9.6	5.2	**10.2**
8	None	171	171.0	10.3	0.2	8.2	-76.3	8.2	3.5	**10.3**
16	None	228	228.0	10.5	0.4	8.3	-76.0	7.2	2.2	**10.5**
2	Concat	57	24.9	44.7	13.0	21.0	-89.5	3.3	11.8	**16.7**
4	Concat	114	49.8	32.0	10.1	18.1	-86.5	3.3	8.8	**16.9**
8	Concat	171	74.8	32.1	10.1	18.1	-86.2	1.9	7.1	**17.7**
16	Concat	228	99.7	32.7	10.3	18.2	-85.9	0.9	5.8	**18.6**
2	1/2 rate	57	28.5	36.8	11.3	19.3	-87.9	4.4	11.3	**16.7**
4	1/2 rate	114	57.0	26.3	8.4	16.4	-84.8	4.4	8.2	**16.9**
8	1/2 rate	171	85.5	26.5	8.5	16.4	-84.5	3.0	6.5	**17.7**
16	1/2 rate	228	114.0	26.9	8.6	16.6	-84.2	2.0	5.2	**18.6**
2	2/3 rate	57	38.0	30.1	9.6	17.5	-86.1	4.9	10.0	**16.7**
4	2/3 rate	114	76.0	21.5	6.7	14.6	-83.1	4.9	7.0	**16.9**
8	2/3 rate	171	114.0	21.6	6.7	14.7	-82.7	3.5	5.2	**17.7**
16	2/3 rate	228	152.0	22.0	6.9	14.8	-82.5	2.5	4.0	**18.6**
2	3/4 rate	57	42.8	26.2	8.4	16.3	-84.9	5.6	9.5	**16.7**
4	3/4 rate	114	85.5	18.7	5.5	13.4	-81.9	5.6	6.5	**16.9**
8	3/4 rate	171	128.3	18.8	5.5	13.4	-81.5	4.2	4.7	**17.7**
16	3/4 rate	228	171.0	19.1	5.6	13.6	-81.3	3.2	3.5	**18.6**
2	R_S	57	49.8	21.6	6.7	14.7	-83.2	6.6	8.8	**16.7**
4	R_S	114	99.7	15.5	3.8	11.7	-80.2	6.6	5.8	**15.5**
8	R_S	171	149.5	15.5	3.8	11.8	-79.9	5.2	4.1	**15.5**
16	R_S	228	199.4	15.8	4.0	11.9	-79.6	4.2	2.8	**15.8**
QPSK - 2	R_S	114	99.7	15.3	3.7	11.6	-80.2	6.6	5.8	**15.3**
QPSK - 4	R_S	228	199.4	10.9	0.8	8.7	-77.2	6.6	2.8	**10.9**
QPSK - 8	R_S	342	299.1	11.0	0.8	8.8	-76.8	5.2	1.0	**11.0**
QPSK - 16	R_S	456	398.8	11.2	1.0	8.9	-76.6	4.2	-0.2	**11.2**

HIGH BAND

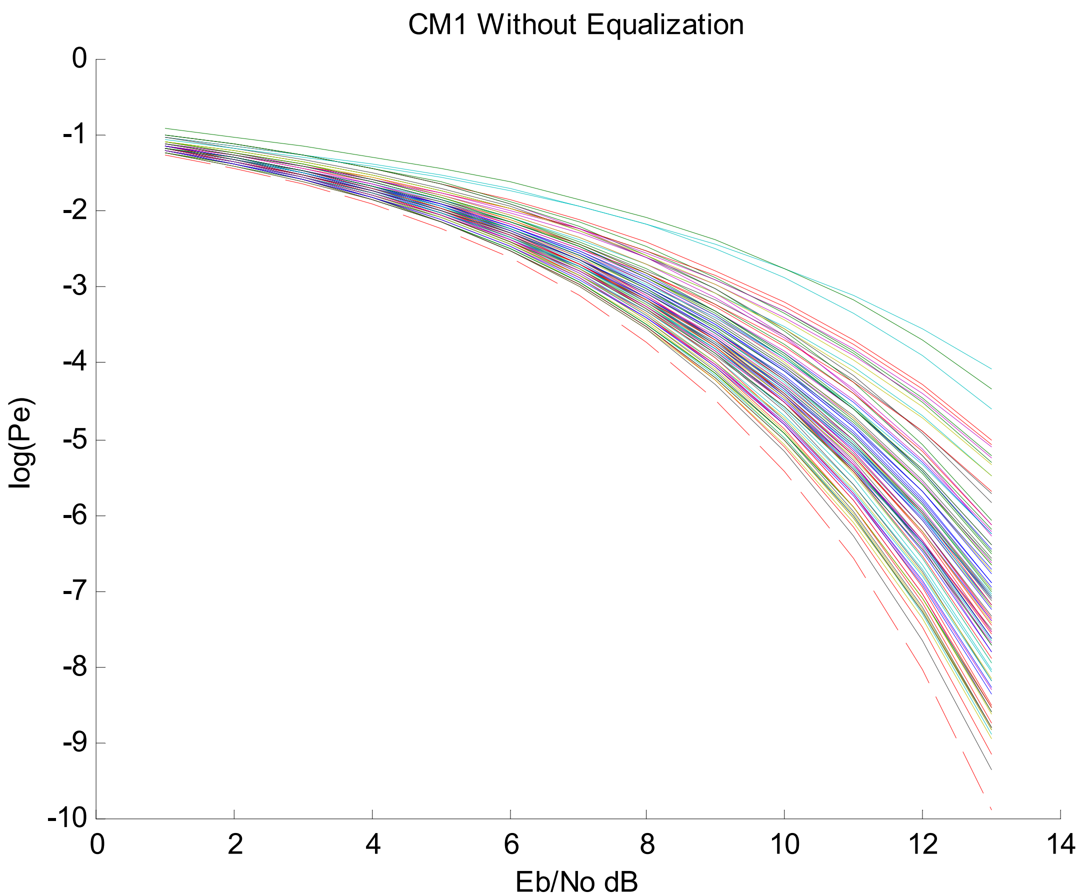
NBW	PSD dBm/MHz	Total TX Power dBm	RX Noise Figure dB	Imp Loss	Fo MHz	Symbol Rate Ms/s	10 Meter Path Loss dB
2.74E+09	-41.24949	-6.88E+00	5.1	3	8.10E+03	1.14E+02	7.06E+01

BOK	**FEC**	**FEC Chip Ra**	**Bit Rate**	**Range**	**10 meter margin dB**	**4 meter margin dB**	**Sensitivity**	Effective Eb/No	Acquisition Eb/No min	Acq Limited Range
2	None	114	114.0	6.4	-3.9	4.0	-75.7	9.6	5.2	**6.4**
4	None	228	228.0	4.6	-6.8	1.1	-72.7	9.6	2.2	**4.6**
8	None	342	342.0	4.6	-6.8	1.2	-72.4	8.2	0.5	**4.6**
16	None	456	456.0	4.7	-6.6	1.3	-72.1	7.2	-0.8	**4.7**
2	Concat	114	49.8	19.9	6.0	13.9	-85.6	3.3	8.8	**10.5**
4	Concat	228	99.7	14.2	3.1	11.0	-82.6	3.3	5.8	**10.7**
8	Concat	342	149.5	14.3	3.1	11.1	-82.3	1.9	4.1	**11.2**
16	Concat	456	199.4	14.5	3.3	11.2	-82.0	0.9	2.8	**11.7**
2	1/2 rate	114	57.0	16.4	4.3	12.3	-83.9	4.4	8.2	**10.5**
4	1/2 rate	228	114.0	11.7	1.4	9.3	-80.9	4.4	5.2	**10.7**
8	1/2 rate	342	171.0	11.8	1.4	9.4	-80.6	3.0	3.5	**11.2**
16	1/2 rate	456	228.0	12.0	1.6	9.5	-80.3	2.0	2.2	**11.7**
2	2/3 rate	114	76.0	13.4	2.5	10.5	-82.2	4.9	7.0	**10.5**
4	2/3 rate	228	152.0	9.6	-0.4	7.6	-79.2	4.9	4.0	**9.6**
8	2/3 rate	342	228.0	9.6	-0.3	7.6	-78.8	3.5	2.2	**9.6**
16	2/3 rate	456	304.0	9.8	-0.2	7.8	-78.6	2.5	1.0	**9.8**
2	3/4 rate	114	85.5	11.7	1.3	9.3	-81.0	5.6	6.5	**10.5**
4	3/4 rate	228	171.0	8.3	-1.6	6.4	-78.0	5.6	3.5	**8.3**
8	3/4 rate	342	256.5	8.4	-1.5	6.4	-77.6	4.2	1.7	**8.4**
16	3/4 rate	456	342.0	8.5	-1.4	6.6	-77.4	3.2	0.5	**8.5**
2	R_S	114	99.7	9.6	-0.3	7.6	-79.3	6.6	5.8	**9.6**
4	R_S	228	199.4	6.9	-3.2	4.7	-76.3	6.6	2.8	**6.9**
8	R_S	342	299.1	6.9	-3.2	4.8	-75.9	5.2	1.0	**6.9**
16	R_S	456	398.8	7.0	-3.1	4.9	-75.7	4.2	-0.2	**7.0**
QPSK - 2	R_S	228	199.4	6.8	-3.3	4.6	-76.3	6.6	2.8	**6.8**
QPSK - 4	R_S	456	398.8	4.9	-6.3	1.7	-73.3	6.6	-0.2	**4.9**
QPSK - 8	R_S	684	598.2	4.9	-6.2	1.7	-72.9	5.2	-2.0	**4.9**
QPSK - 16	R_S	912	797.6	5.0	-6.1	1.9	-72.7	4.2	-3.2	**5.0**

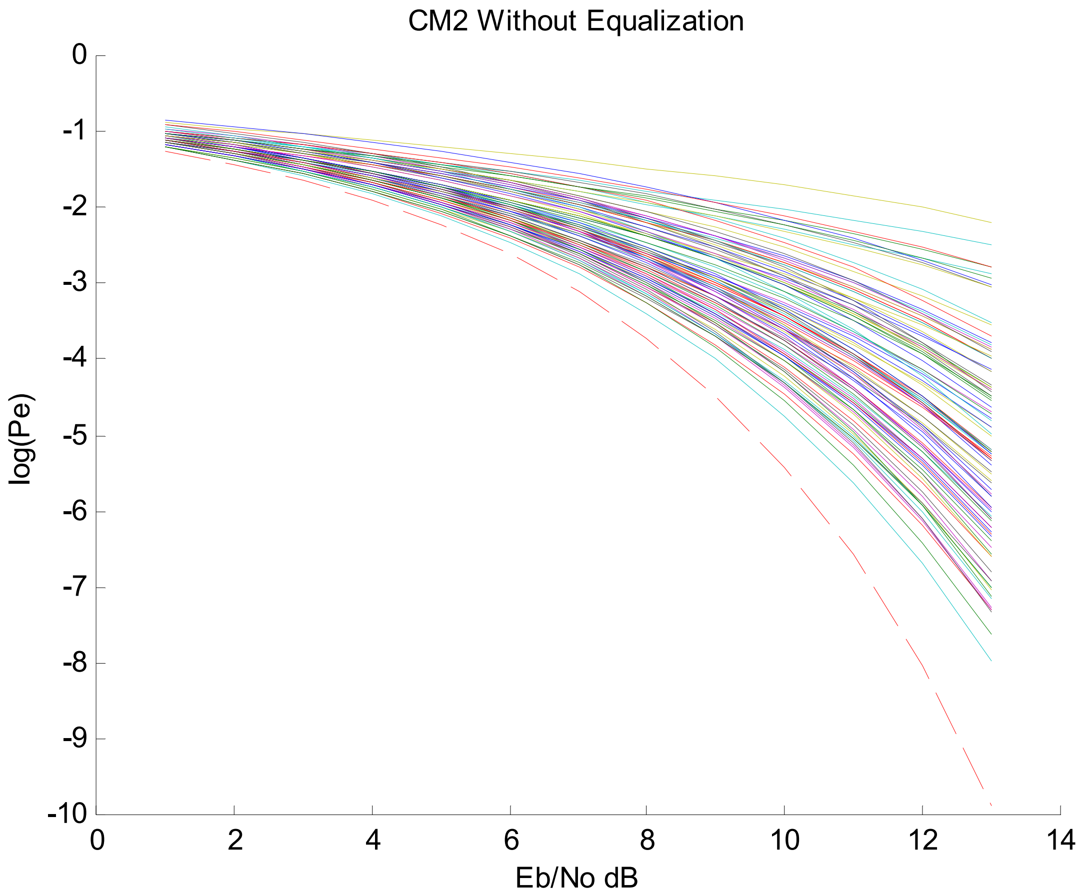
2.8 2-BOK BER Curves with Multipath Channels

In this section we'll look at performance with various equalizer residual error. Obviously, an ideal equalizer would provide performance mimicking the theoretical curve. The equalizer used here is a modified DFE that provides two feed forward taps that are activated after the feedback taps have opened up the eye pattern. Each plot shows all 100 channels associated with the channel model in question.

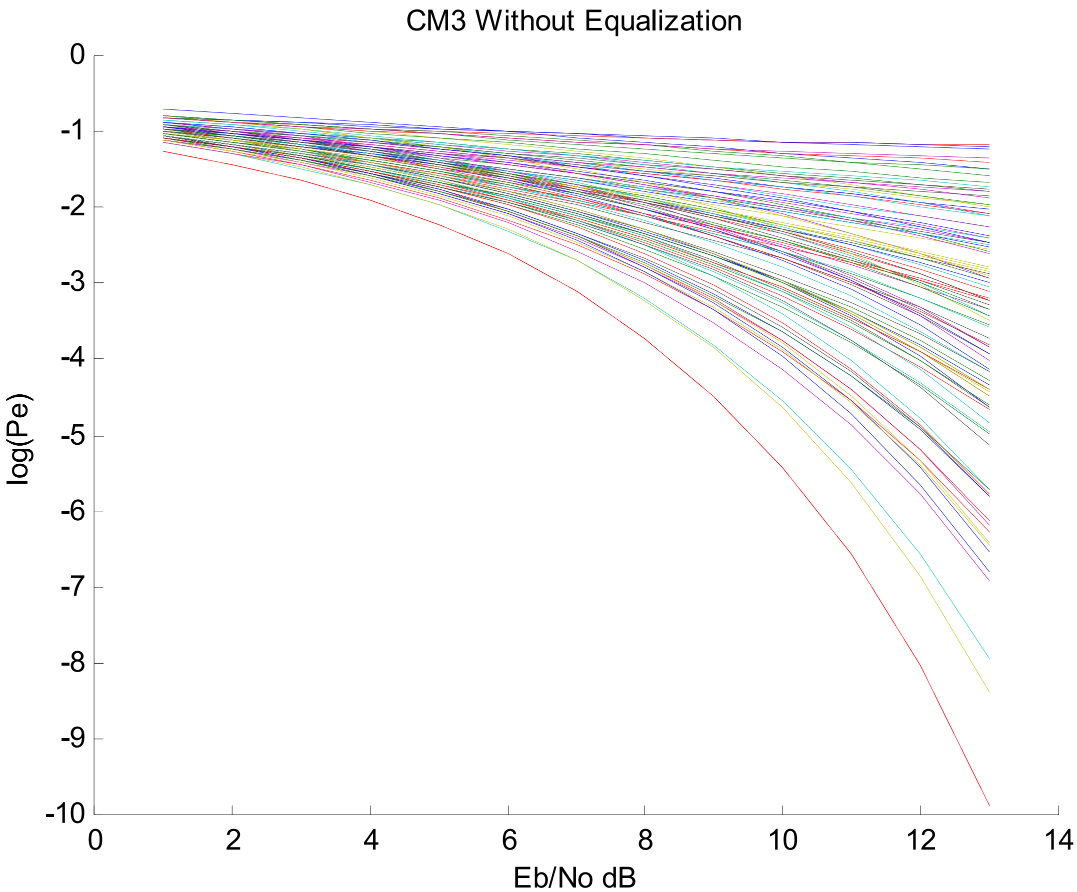
2.8.1 No Equalizer High Band (1/114e6 symbol duration)



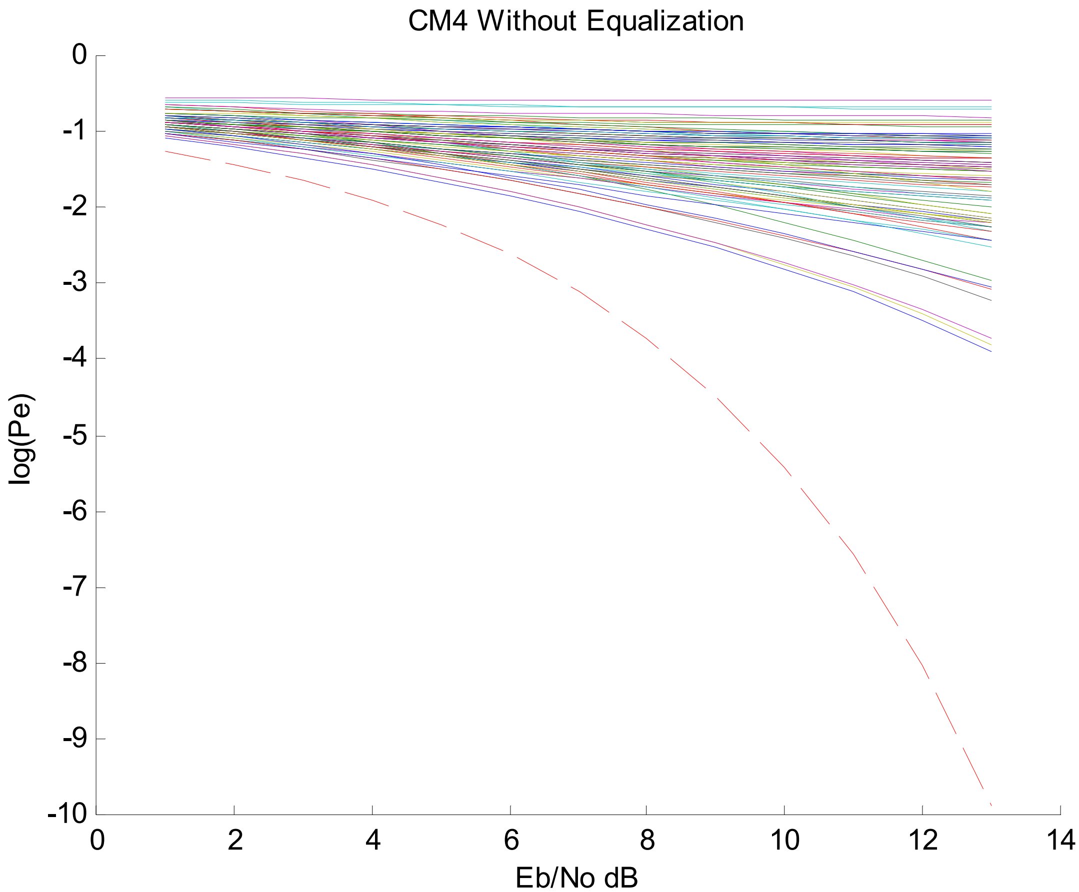
2.8.2 No Equalizer High Band (1/114e6 symbol duration)



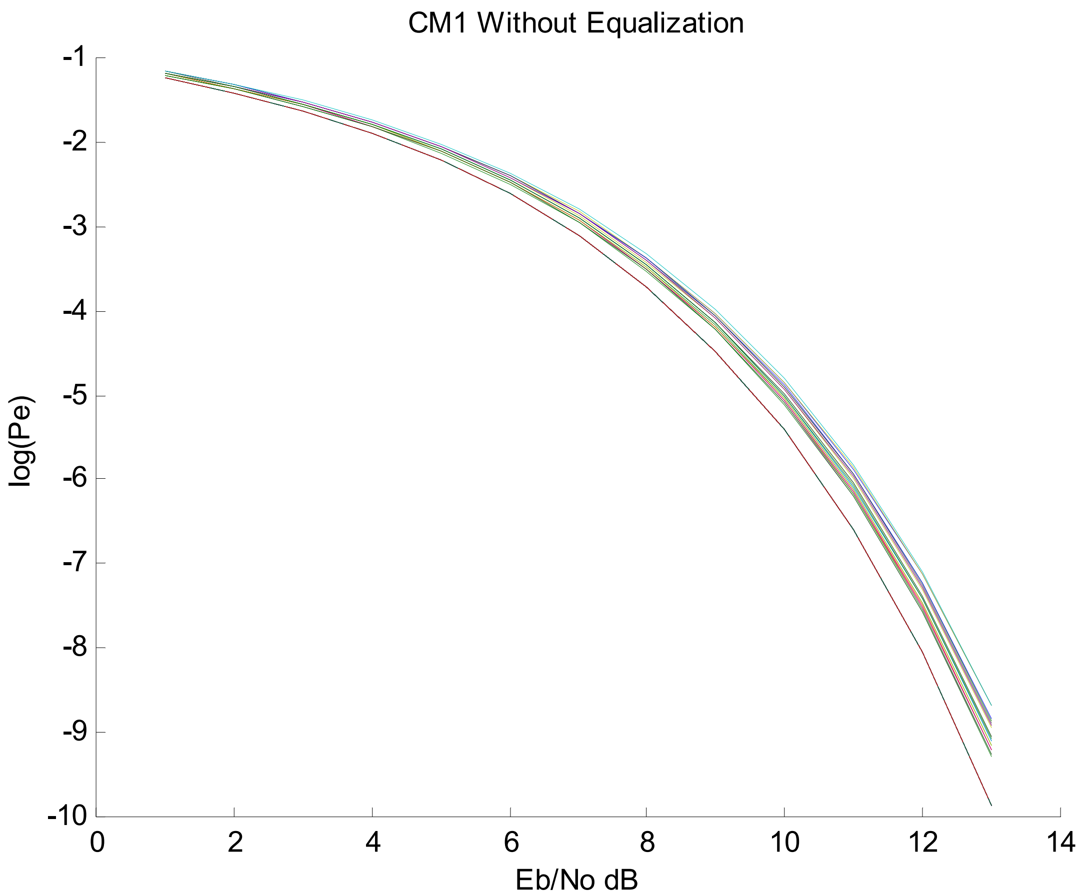
2.8.3 No Equalizer High Band (1/114e6 symbol duration)



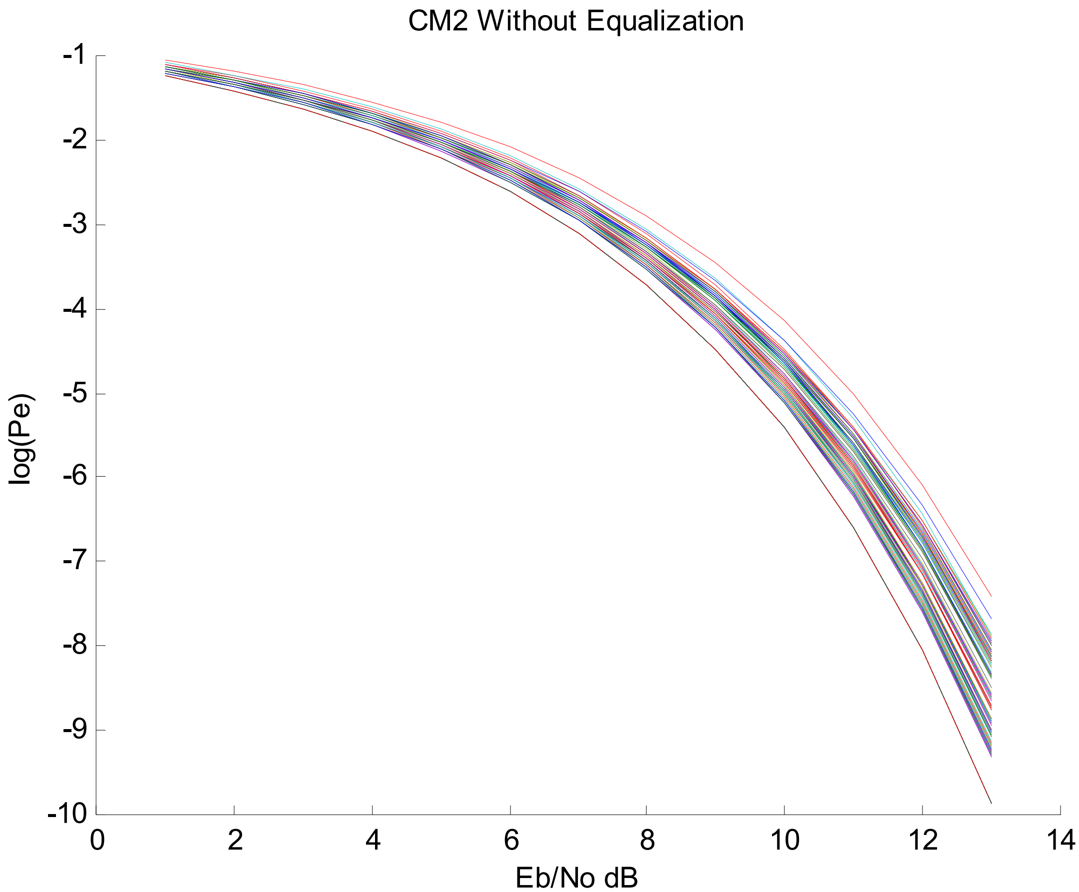
2.8.4 No Equalizer High Band (1/114e6 symbol duration)



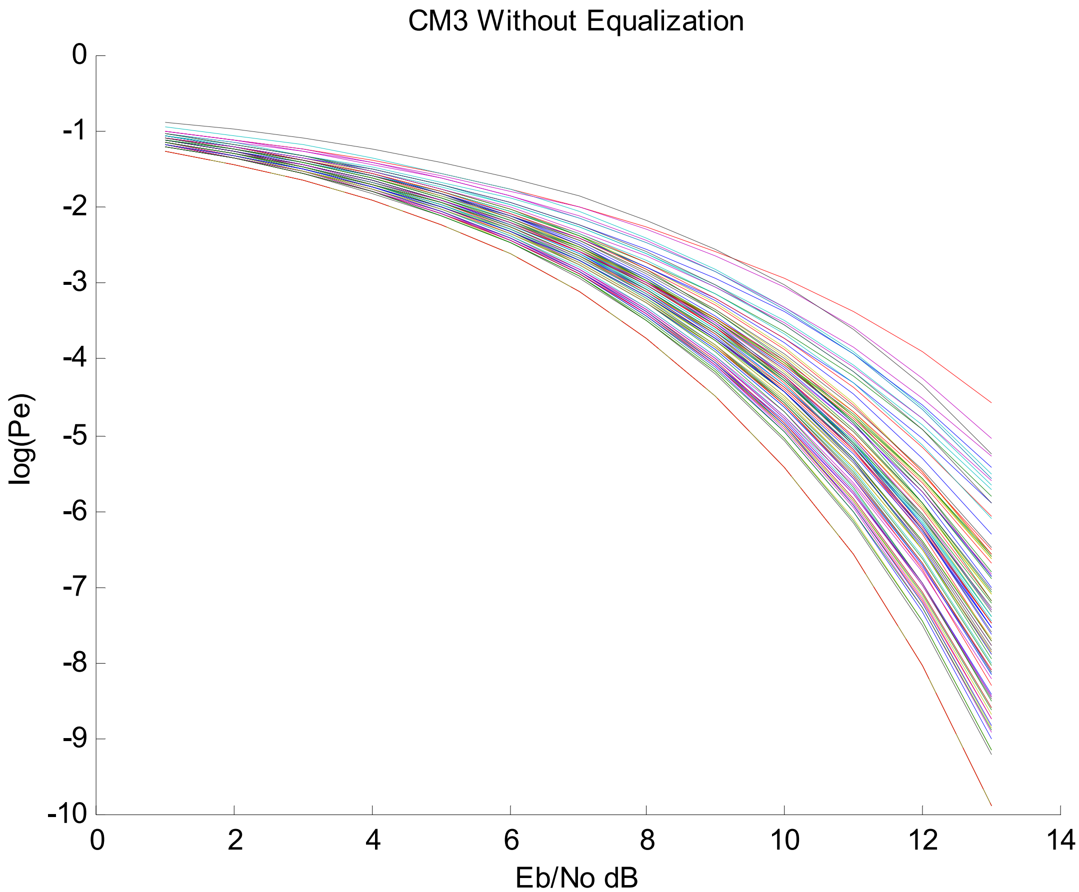
2.8.5 No Equalizer Low Band (1/57e6 symbol duration)



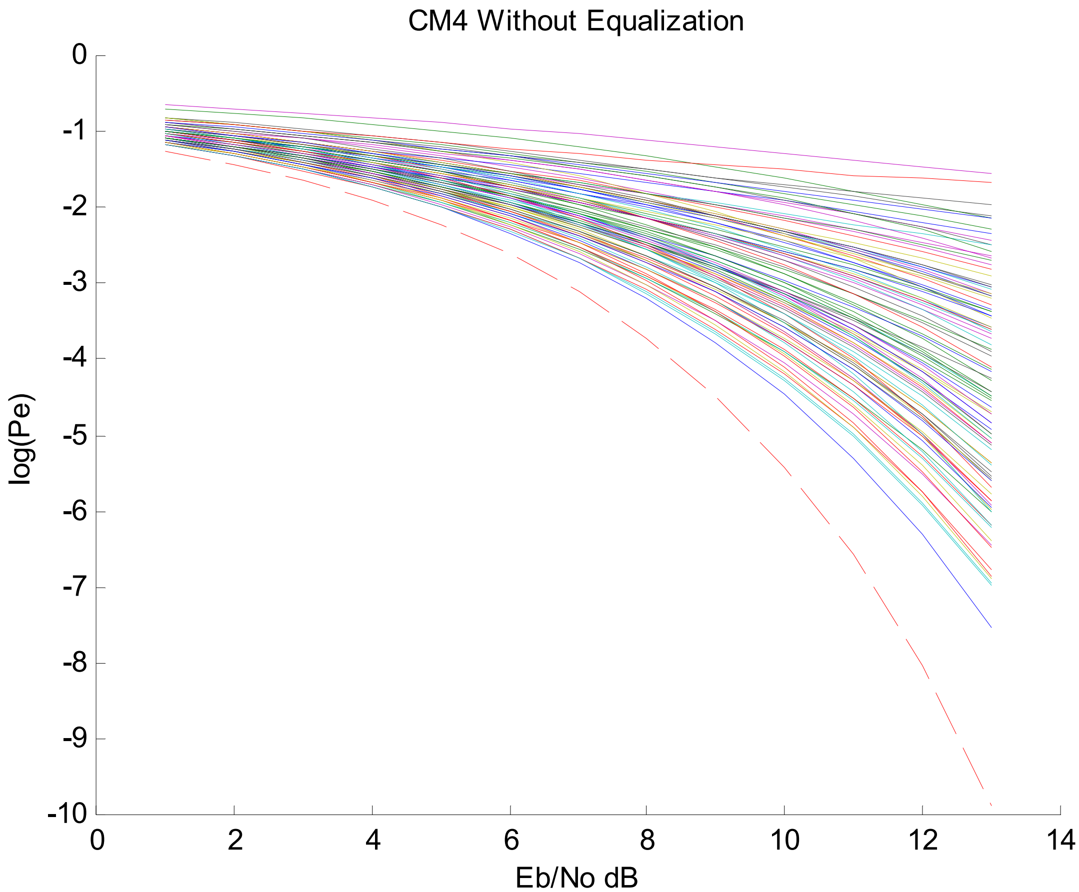
2.8.6 No Equalizer Low Band (1/57e6 symbol duration)



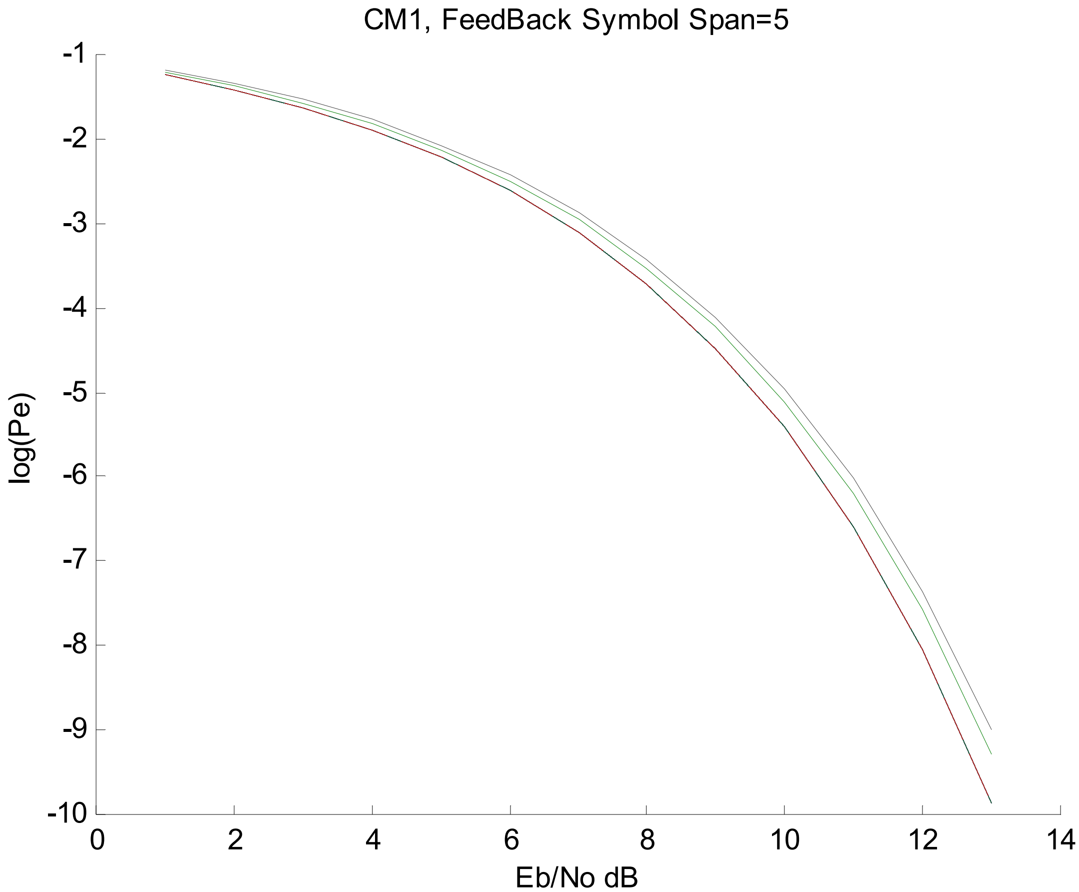
2.8.7 No Equalizer Low Band (1/57e6 symbol duration)



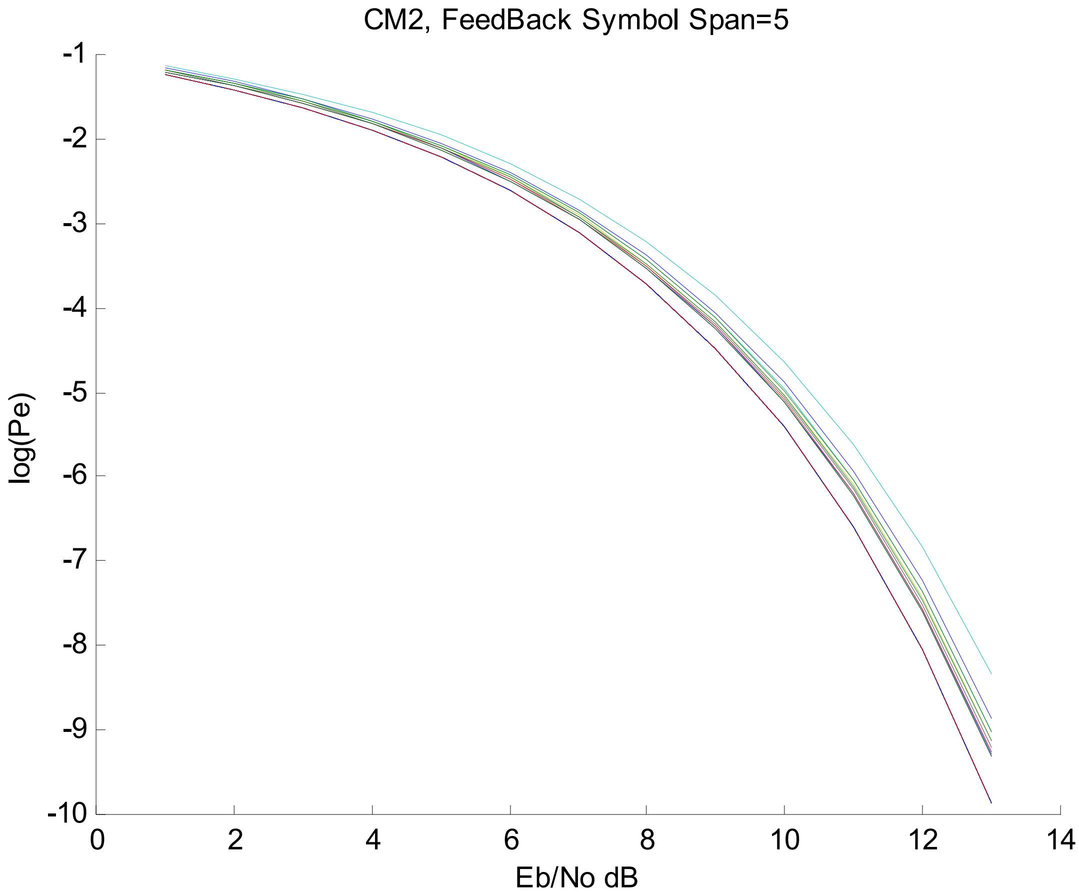
2.8.8 No Equalizer Low Band (1/57e6 symbol duration)



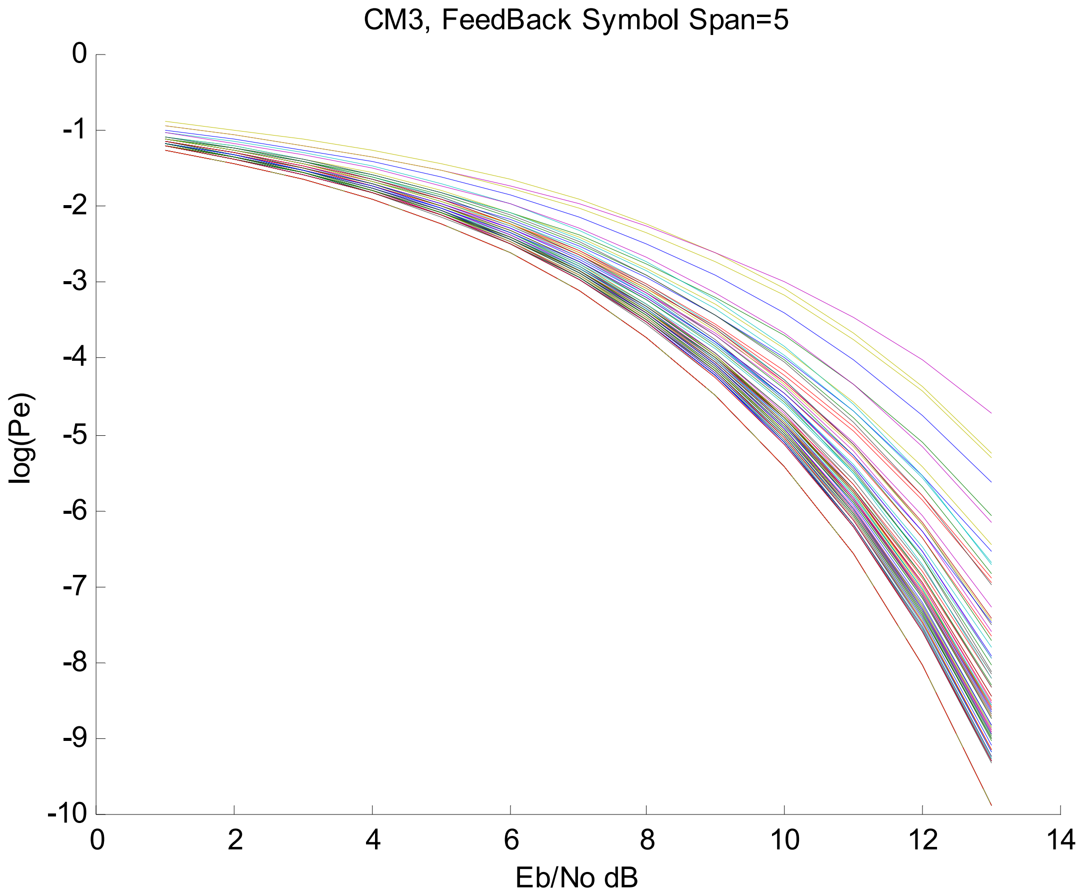
2.8.9 5 Symbol Span Equalizer High Band (1/114e6 symbol duration)



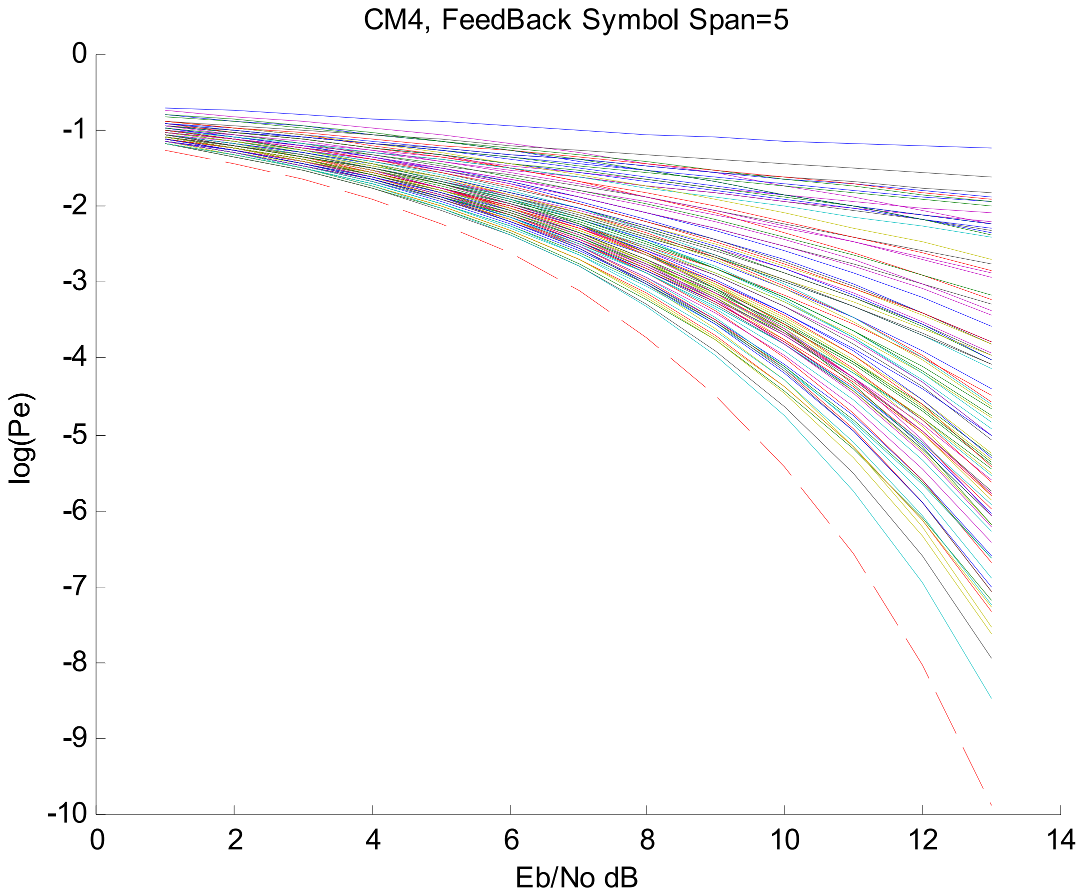
2.8.10 5 Symbol Span Equalizer High Band (1/114e6 symbol duration)



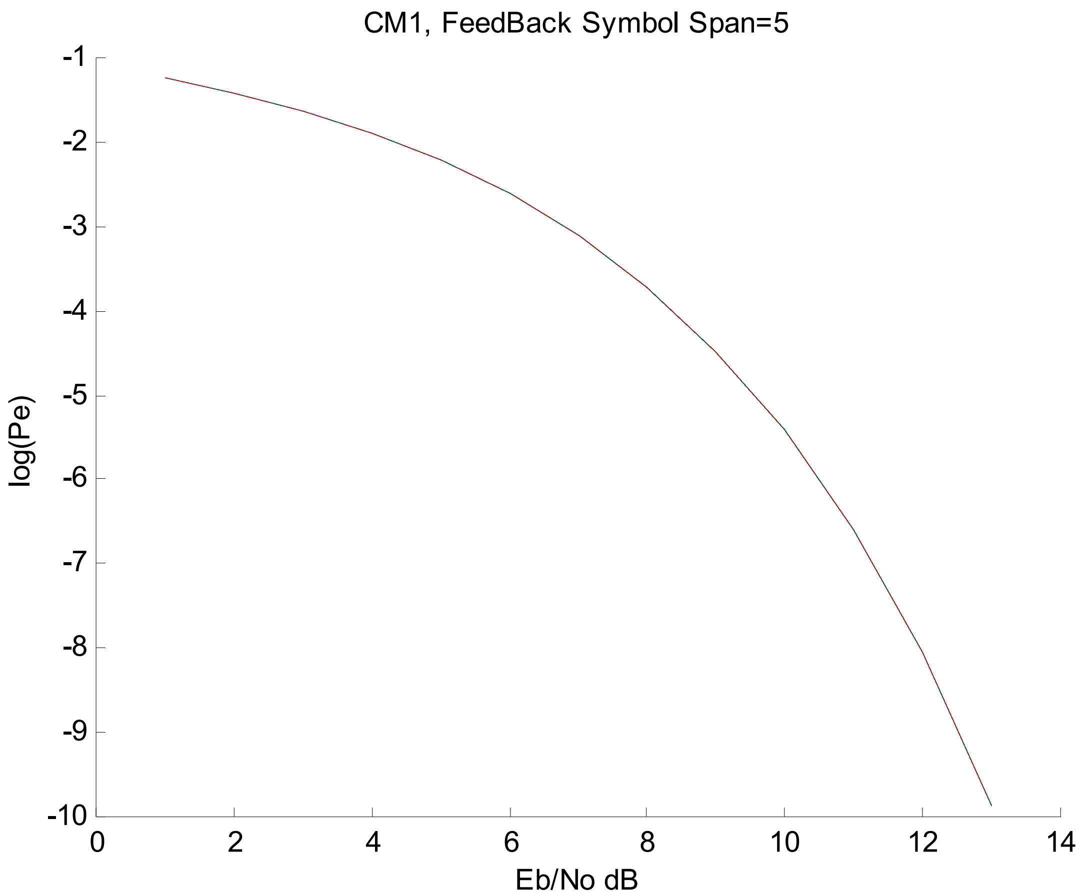
2.8.11 5 Symbol Span Equalizer High Band (1/114e6 symbol duration)



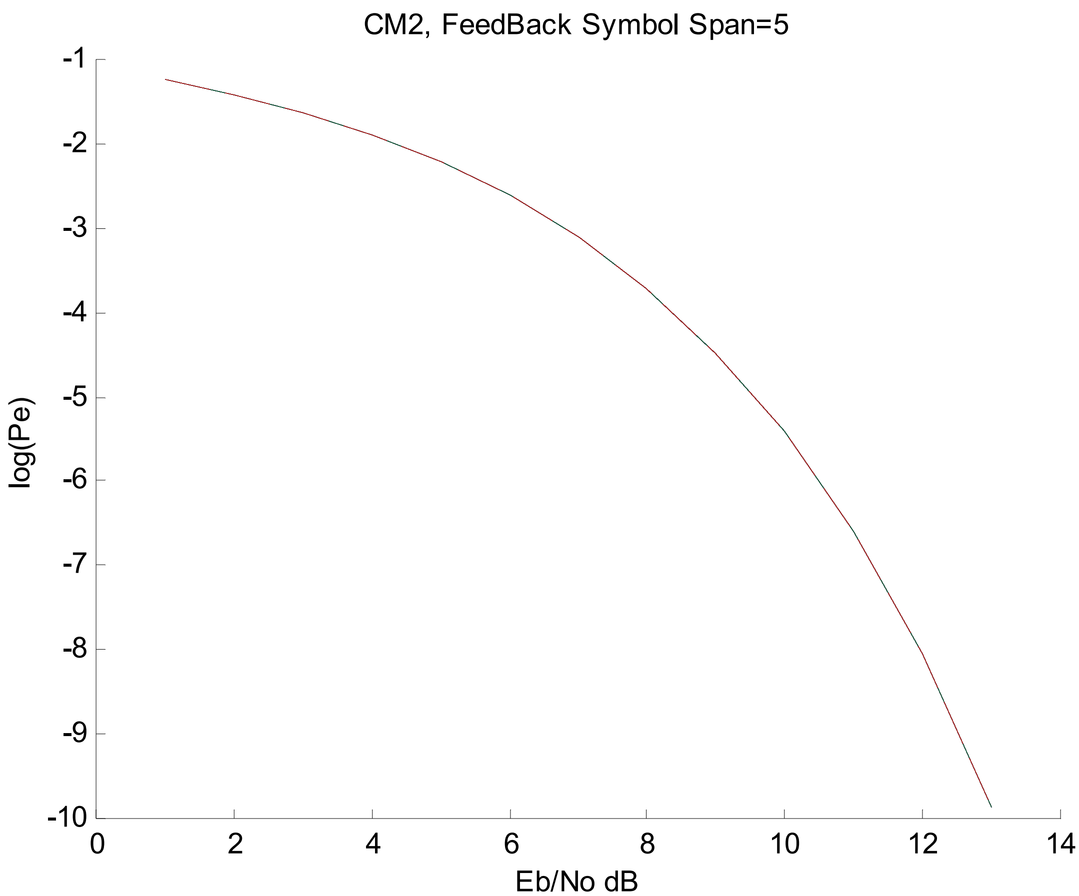
2.8.12 5 Symbol Span Equalizer High Band (1/114e6 symbol duration)



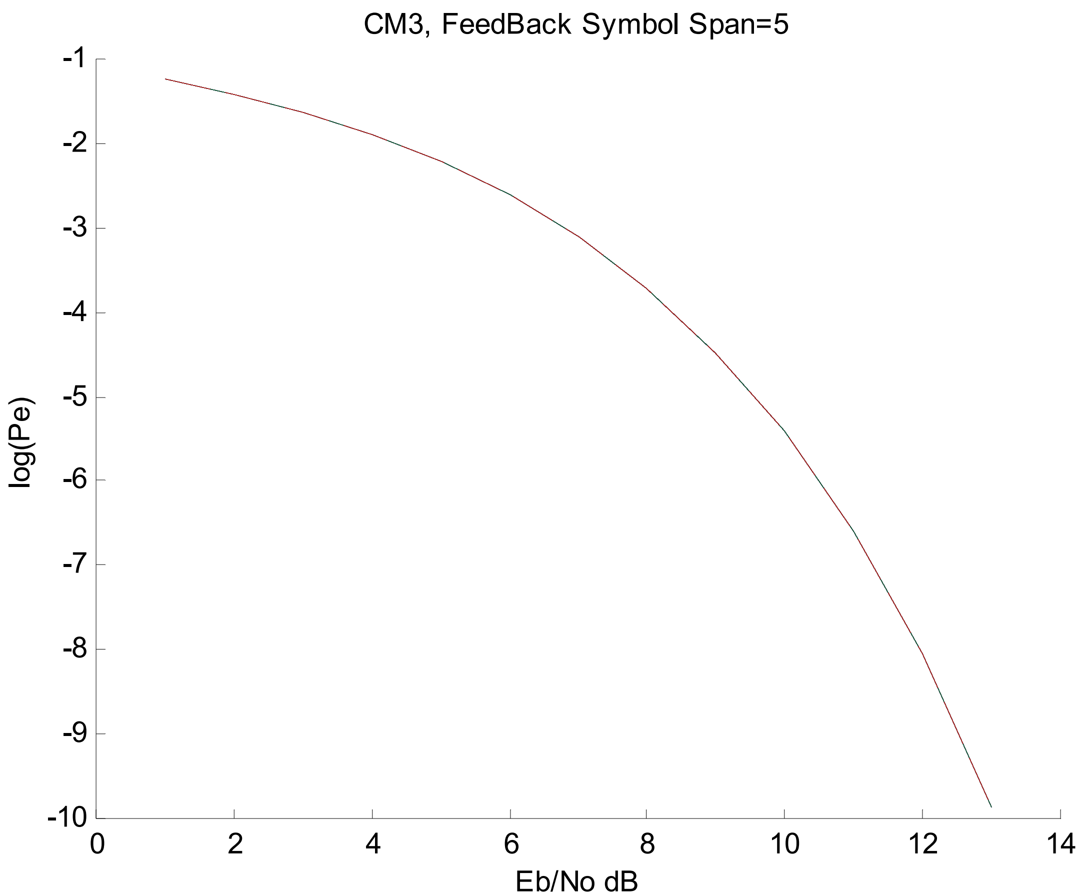
2.8.13 5 Symbol Span Equalizer Low Band (1/57e6 symbol duration)



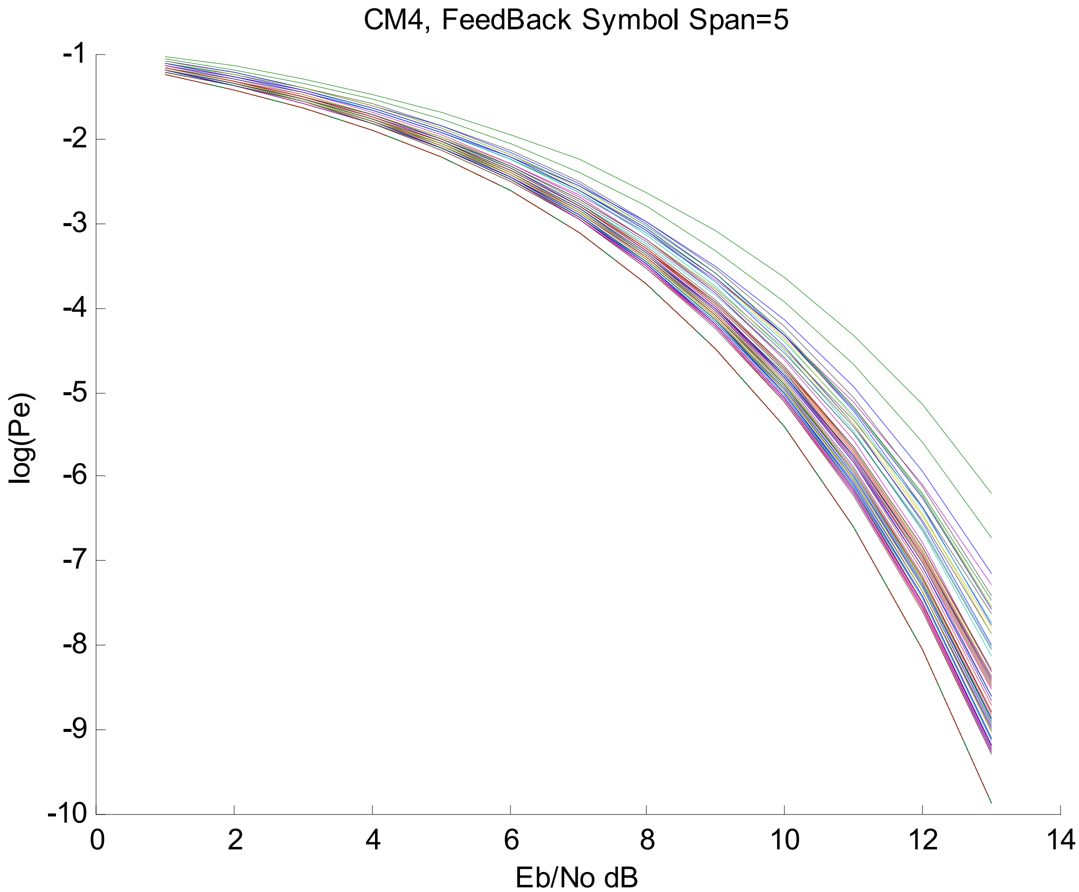
2.8.14 5 Symbol Span Equalizer Low Band (1/57e6 symbol duration)



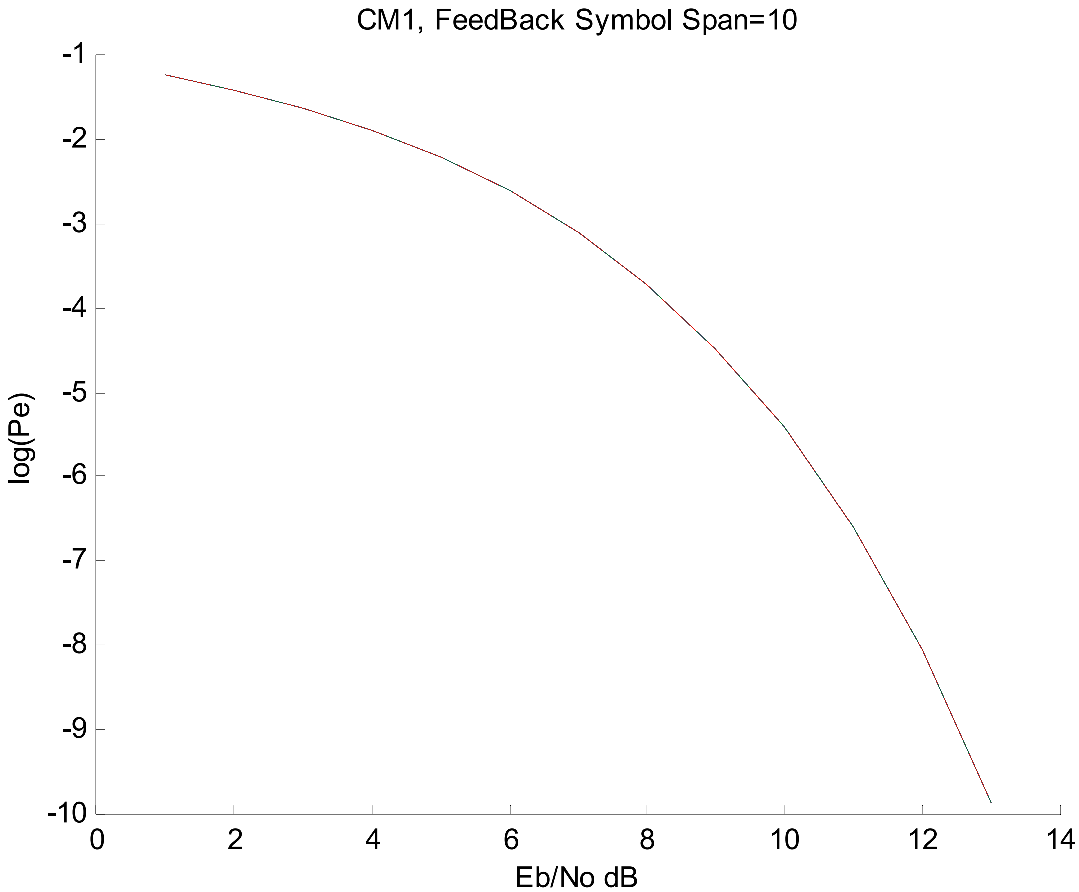
2.8.15 5 Symbol Span Equalizer Low Band (1/57e6 symbol duration)



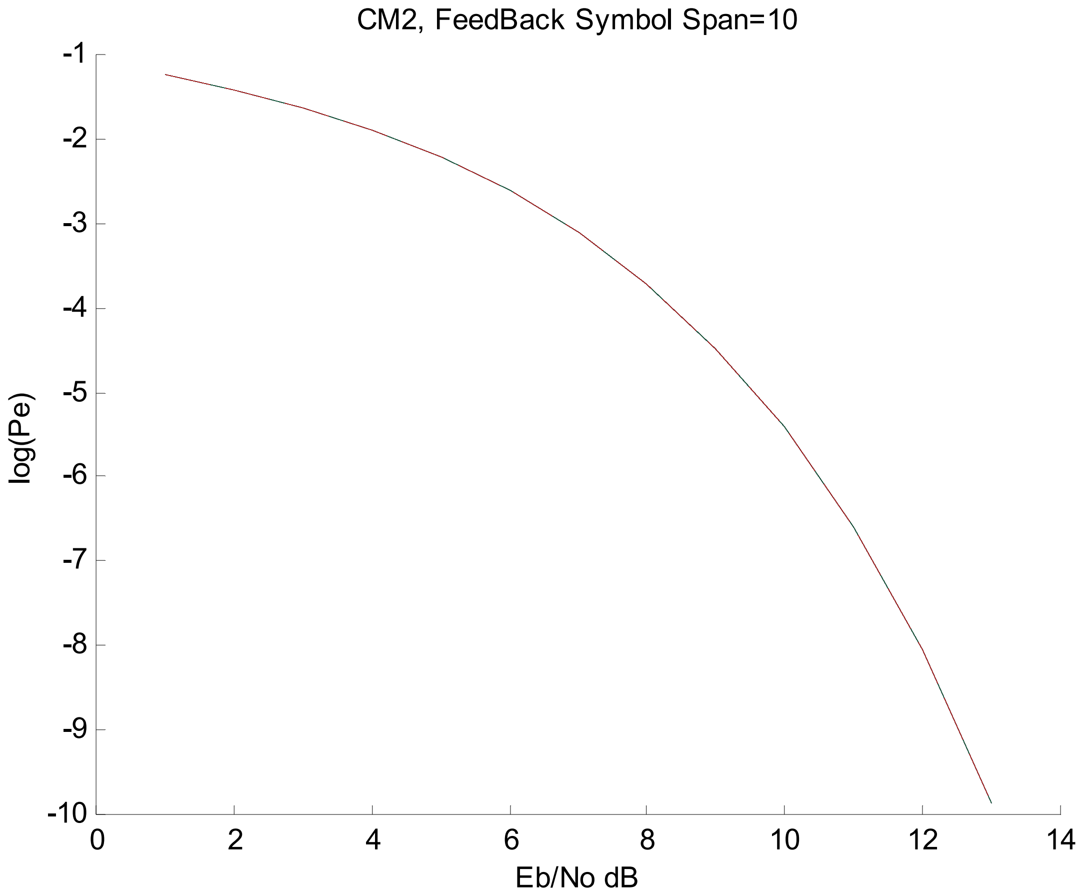
2.8.16 5 Symbol Span Equalizer Low Band (1/57e6 symbol duration)



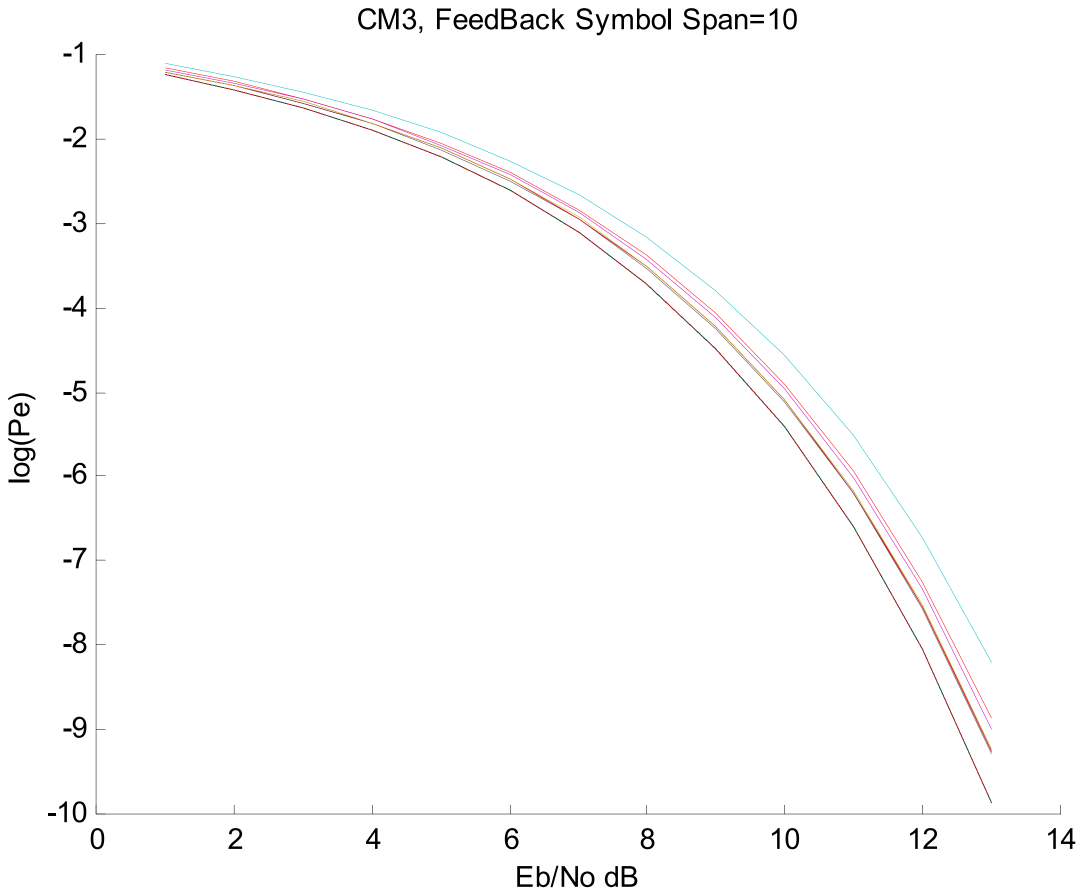
2.8.17 10 Symbol Span Equalizer High Band (1/114e6 symbol duration)



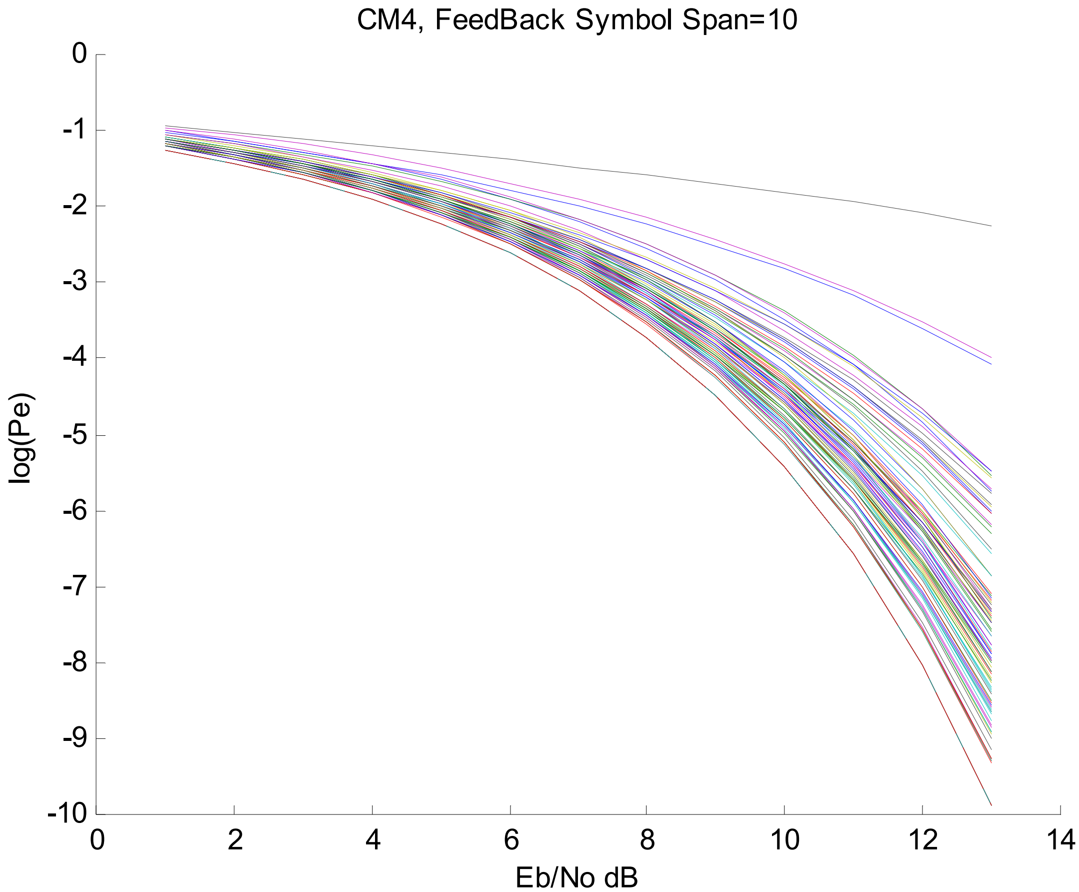
2.8.18 10 Symbol Span Equalizer High Band (1/114e6 symbol duration)



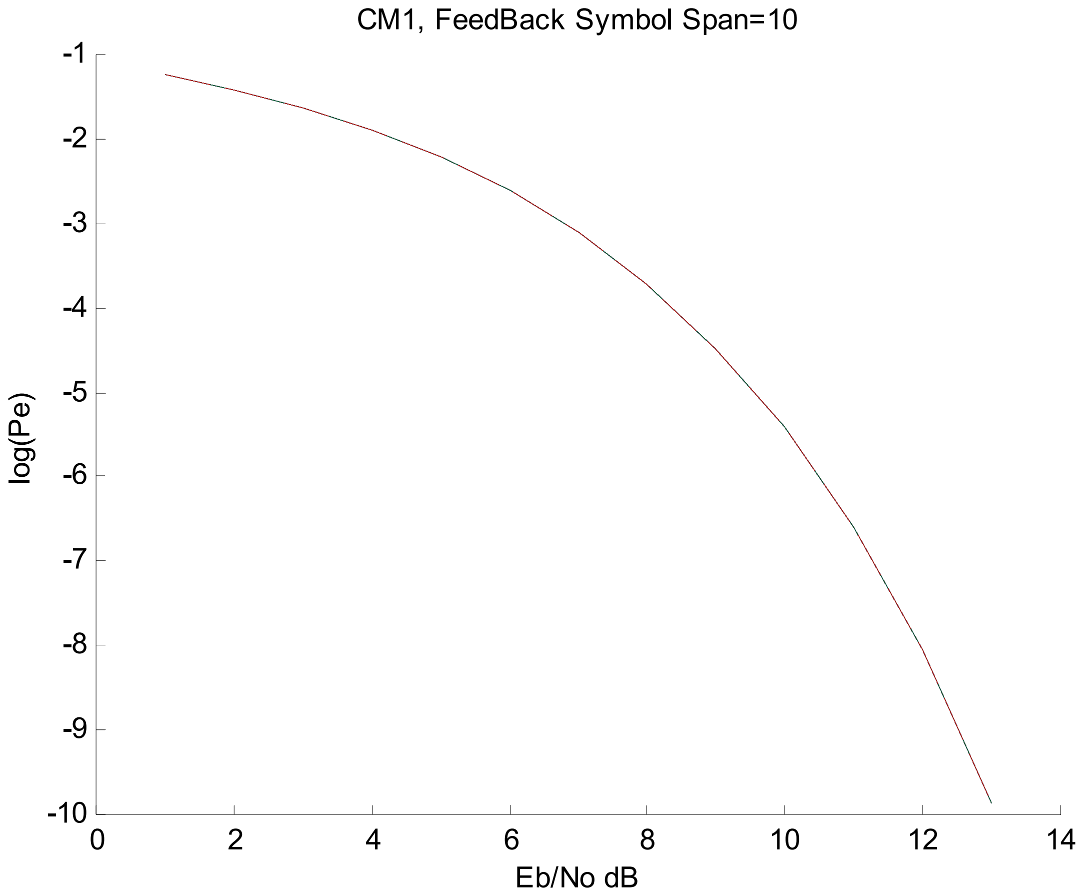
2.8.19 10 Symbol Span Equalizer High Band (1/114e6 symbol duration)



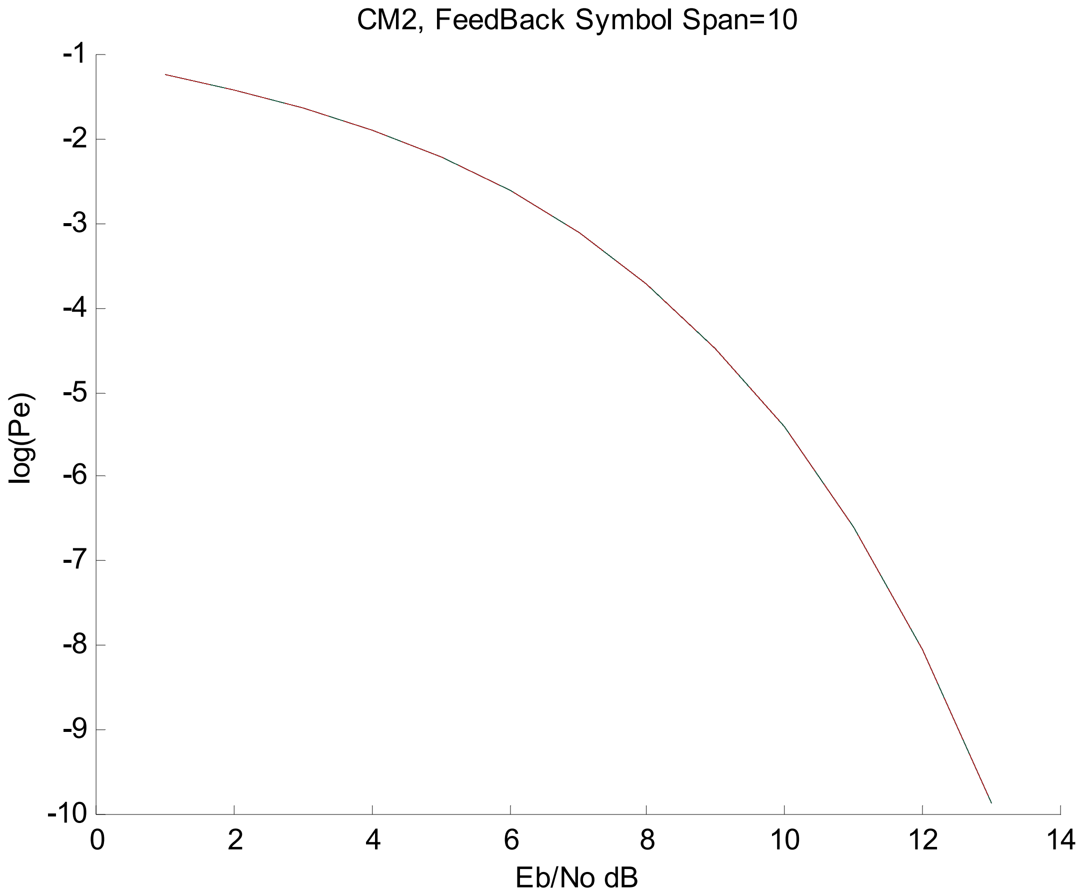
2.8.20 10 Symbol Span Equalizer High Band (1/114e6 symbol duration)



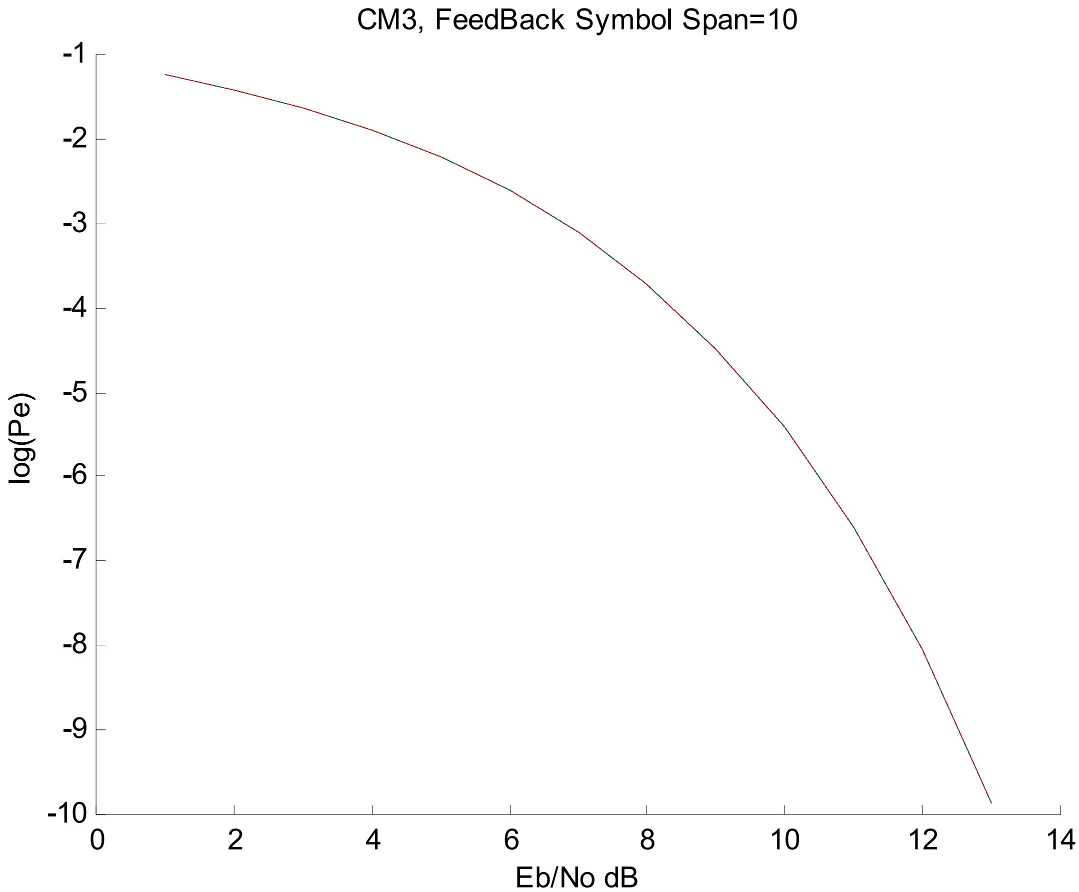
2.8.21 10 Symbol Span Equalizer Low Band (1/57e6 symbol duration)



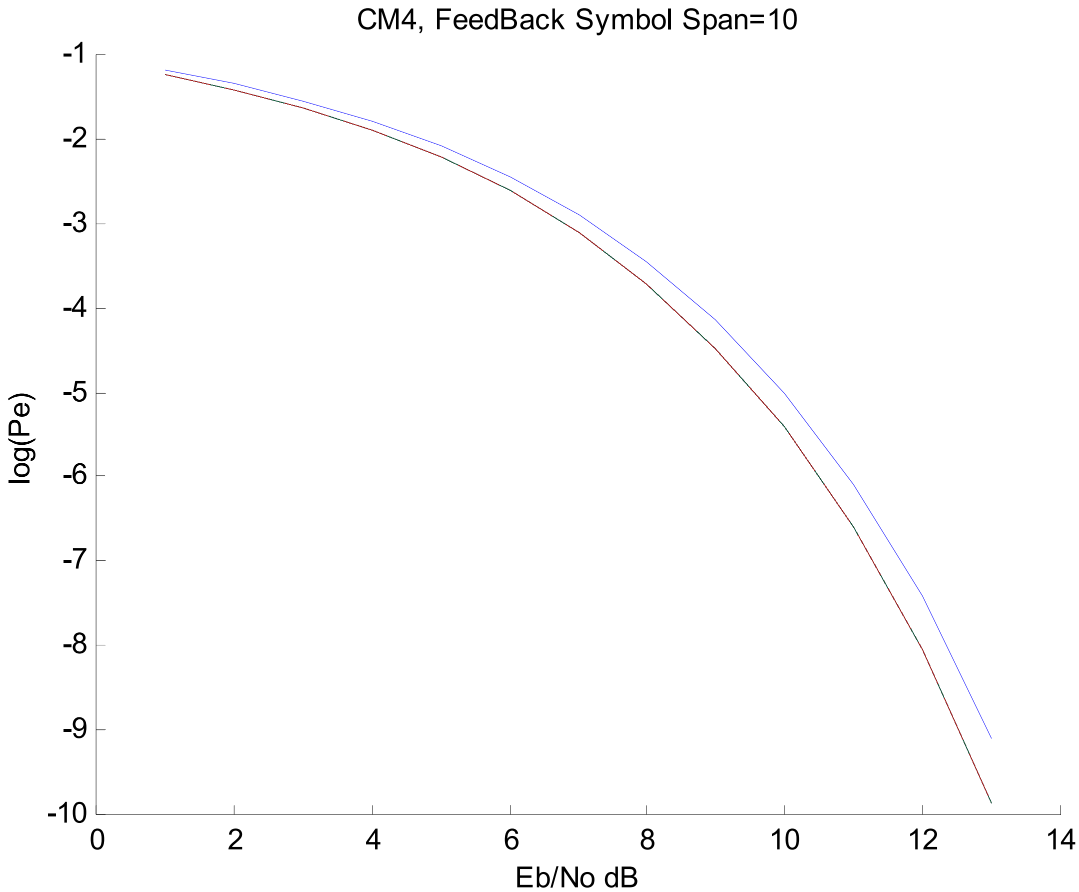
2.8.22 10 Symbol Span Equalizer Low Band (1/57e6 symbol duration)



2.8.23 10 Symbol Span Equalizer Low Band (1/57e6 symbol duration)



2.8.24 10 Symbol Span Equalizer Low Band (1/57e6 symbol duration)

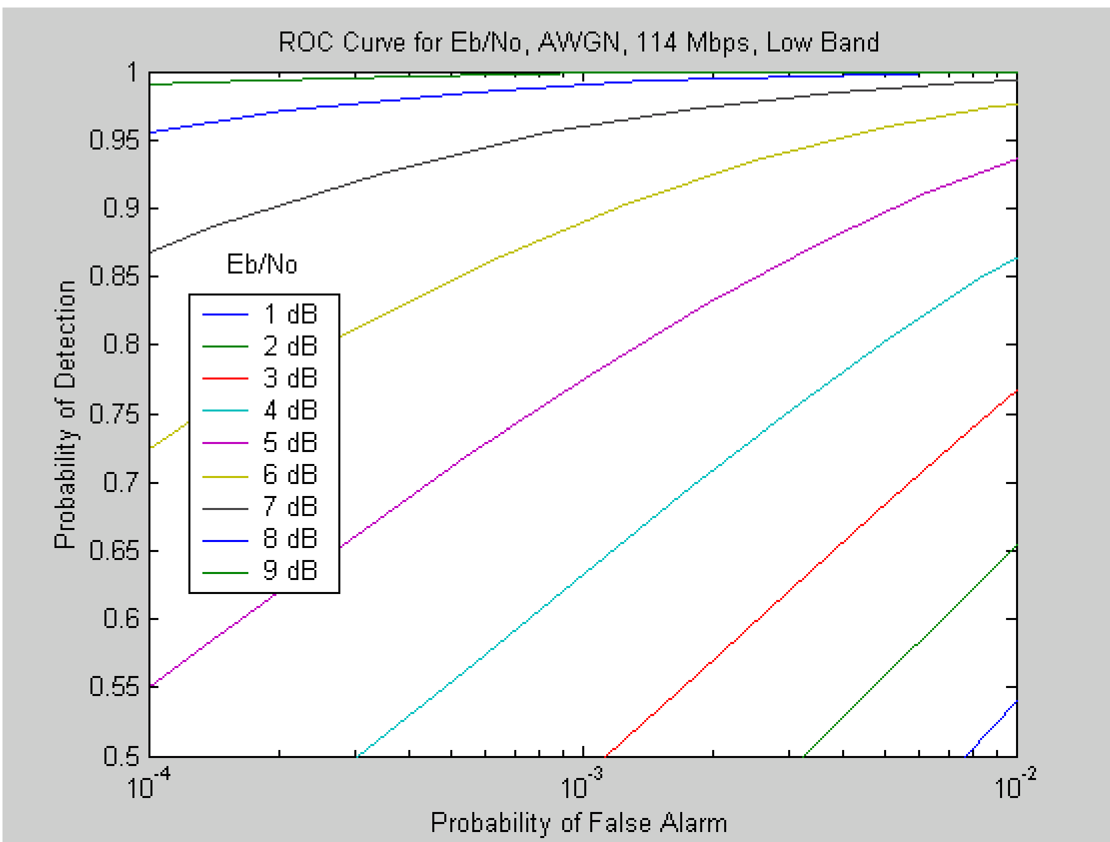


2.9 *Acquisition ROC Curvers*

Required Probability of Detection during Acquisition: >92%
Integration over preamble 48 chips for 3 dB gain relative to 24 chip codeword

2.9.1 Acquisition ROC Curve vs. Eb/No at 114 Mbps

- Constant False Alarm Rate of 10^{-2}
- Synchronization acquisition time: <15 uS



2.9.2 ROC Probability of Detection vs. Eb/No at 114 Mbps for Pf=0.01

114 Mbps Eb/No	Pd
9 dB	1.0
8 dB	0.999
7 dB	0.994
6 dB	0.976
5 dB	0.935
4 dB	0.865
3 dB	0.770
2 dB	0.655
1 dB	0.540

2.9.3 Acquisition Assumptions and Comments

In the XtremeSpectrum proposal, timing acquisition uses a sliding correlator that searches through the multi-path components looking for the best propagating ray. There are two degrees of freedom that influence the acquisition lock time, and hence the length of the PHY timing preamble:

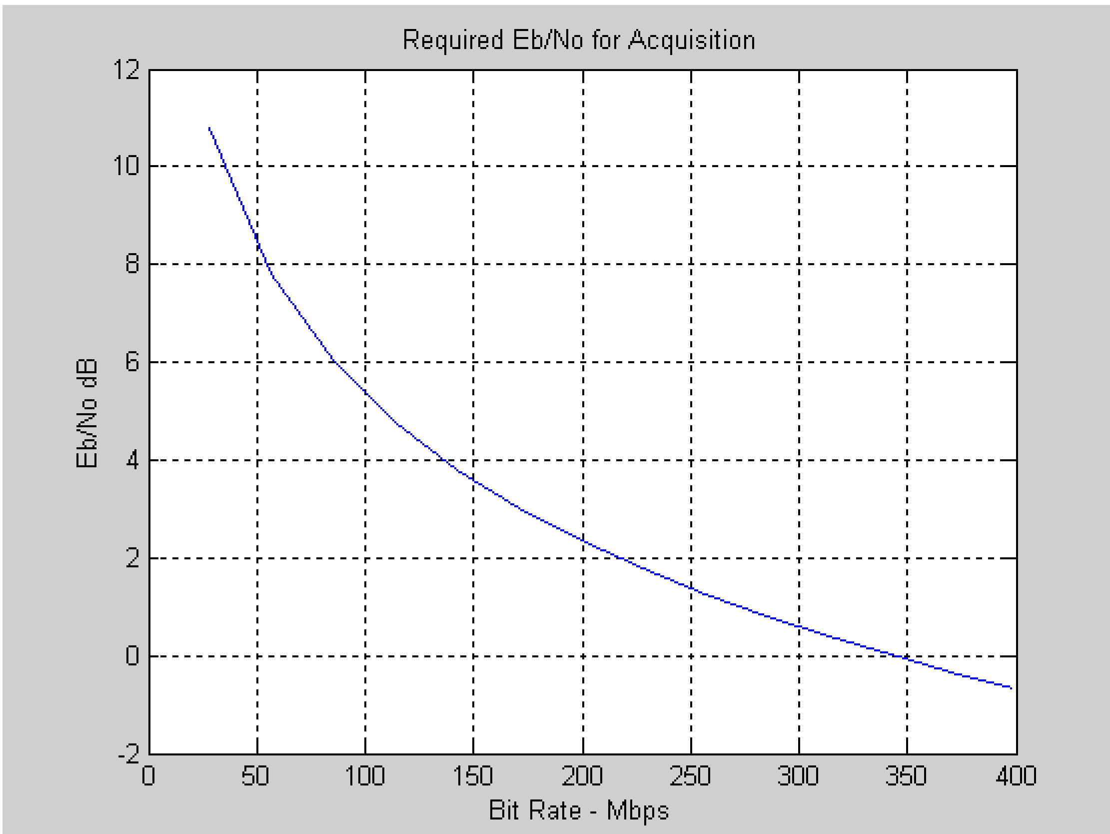
1. The time step of the search process
2. The number of sliding correlators

Both these parameters are in turn dependent upon the minimum SNR desired for acquisition.

XtremeSpectrum has tried to make a first compromise between the acquisition hardware complexity (i.e. number of correlators), the acquisition search step size, the acquisition SNR (i.e. range) and the acquisition reliability (i.e. Pd and Pf). We've limited the number of correlators during acquisition to three and we've presented results against a 15 uS nominal preamble length (we also are proposing a shorter and longer preamble to handle extremes in data rate and range respectively). Naturally we could have shortened the acquisition time by increasing the acquisition hardware complexity. The message here is that our acquisition results have a degree of flexibility and we can decrease or increase acquisition by increasing or decreasing the acquisition hardware complexity. Our acquisition performance numbers are not absolutes but arise due to our initial assumptions.

2.9.4 Acquisition Eb/No Requirements

This next plot shows the required Eb/No resulting in a Pd>0.95 when Pf=0.01. Notice that at low bit rates the range becomes acquisition limited for a fixed preamble length since we require an Eb/No<10 dB for even the uncoded 2-BOK mode.



2.10 DFE Error Propagation

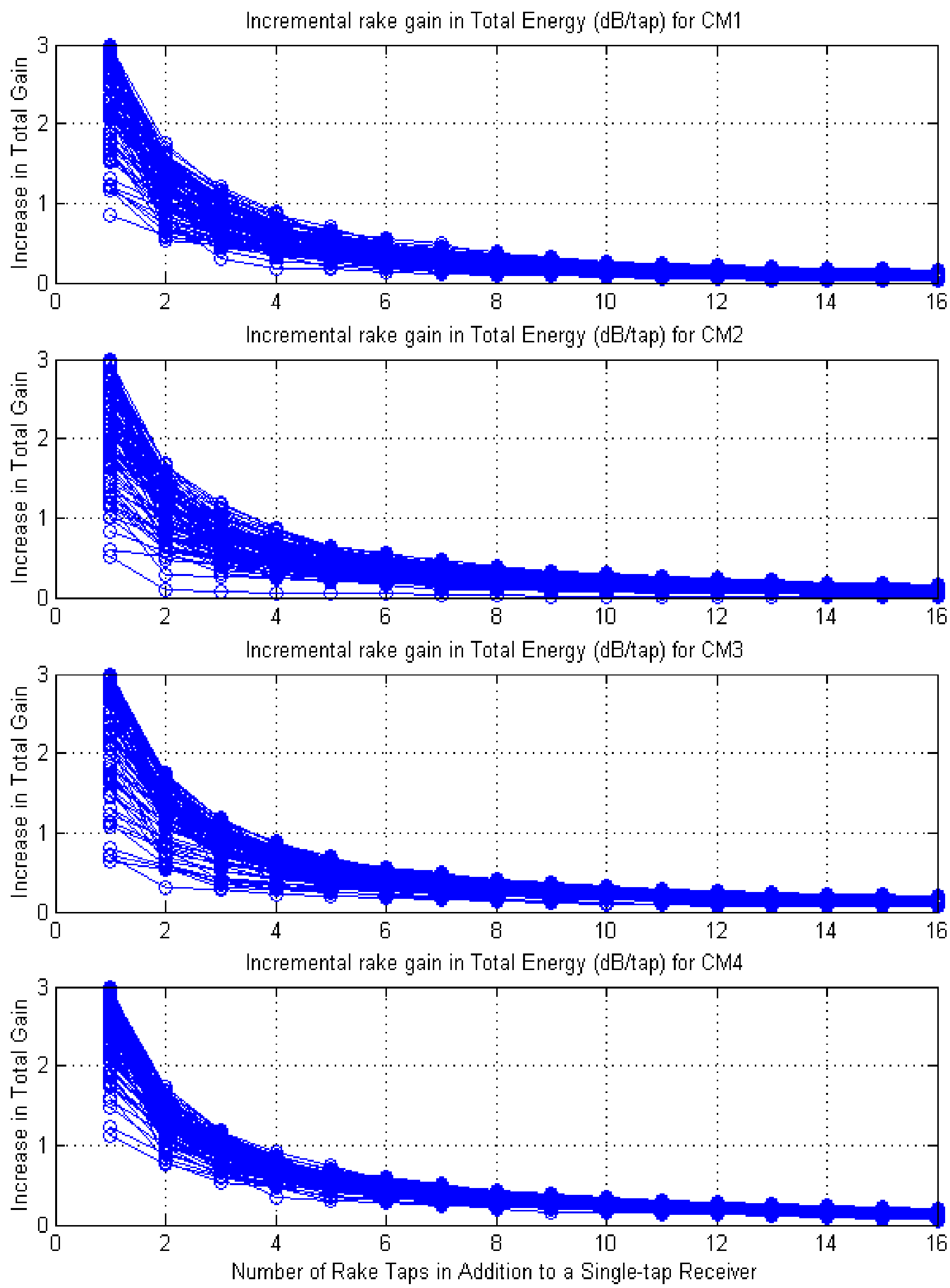
DFE burst error propagation doesn't appear to be a significant problem. A test was ran where a burst of 6 errors was introduced at two different Eb/No's, 9.6 dB and 12.6 dB. The number of resulting DFE errors was recorded after having trained the DFE against the TG3a channel. This was done for each of the 400 TG3a channels. Most of the time we just got 6 errors "out" for 6 errors "in", but occasionally we got 7 or 8 errors out given 6 input errors. The number of additional errors was proportional to the severity of the channel with CM4 giving the worst burst error expansion. On rare occasions CM4 would give more than 8 errors "out" for 6 errors "in". Typical results are shown below.

Number of output errors for an input of 6 burst errors

	Num Errors @ Eb/No=12.6 dB	**Num Errors @ Eb/No=9.6 dB**
CM1	6 on all 100 channels	6 on all 100 channels
CM2	6 on all 100 channels	7 on 26 channels, 6 on 74 channels
CM3	7 on 4 chans., 6 on 96 chans.	7 on 8, 8 on 3, 11 on 1, 6 on 88 channels
CM4	7 on 12, 8 on 1, 11 on 1, 6 on 86	7 on 16, 8 on 8, 9 on 1, 13 on 2, 6 on 73

2.11 RAKE Gain Considerations

The following figure shows the incremental benefits of additional RAKE fingers with respect to the TG3a multipath channels. Notice that regardless of the channel model, having more than 5 fingers in the RAKE yields a diminishing return of less than 1 dB as additional fingers are added. While an implementer can have as many fingers as they desire in their RAKE implementation, we generally feel that having more than 5 is unnecessary.



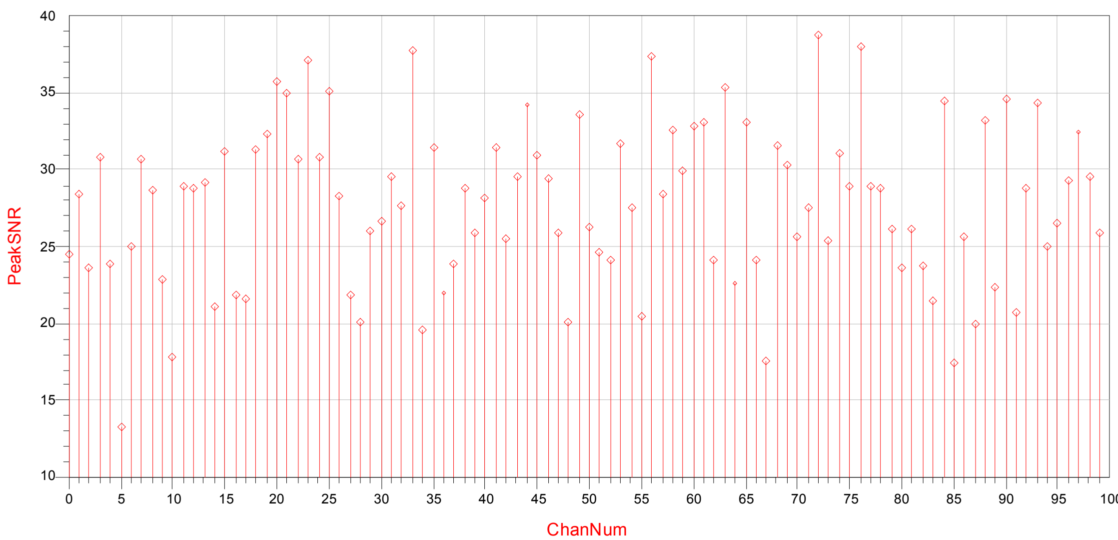
Incremental rake gain in Total Energy (dB/tap) for CM1
Increase in Total Gain
Incremental rake gain in Total Energy (dB/tap) for CM2
Increase in Total Gain
Incremental rake gain in Total Energy (dB/tap) for CM3
Increase in Total Gain
Incremental rake gain in Total Energy (dB/tap) for CM4
Increase in Total Gain
Number of Rake Taps in Addition to a Single-tap Receiver

2.12 CCA Performance with Multipath Channels

Clear Channel Assessment (CCA) is generally provided via either a sliding correlator or an energy detector. At this time the state-of-the-art makes a sliding correlator impractical at UWB data rates and bandwidths[1]. The immediate option is energy detection. Energy detection can be realized for BPSK via a squaring circuit (centered on the carrier frequency) and for QPSK via a quadrupling circuit.

2.12.1 BPSK Squaring Circuit with the CM1 channel model

The CM1 channel model was used to explore the performance of a squaring circuit working with BPSK in a multi-path environment. The same multi-path model was used for evaluation at both 4 meters and 10 meters. The range attenuation scaling is based upon 1/r^2 for the largest component of the channel impulse response. The performance metric was the SNR at the output of the squaring circuit in a 200 KHz detection bandwidth. The TX power is –41.3 dBm/MHz and the receiver noise figure is 7 dB.



Fc=4.1 GHz, D=4 meters … Average SNR=27.8 dB … Number of failures below 6 dB SNR: 0

[1] There are no fundamental limitations in our proposal that would prohibit the use of a sliding correlator for implementing CCA. As a matter of fact, future implementations of UWB will probably be DSP based.

2.12.2 BPSK Squaring Circuit with frequency offset detection

It is suggested that the frequency offsets be ±3MHz and ±9MHz and that the PNC attempts to pick a frequency offset that provides maximum distance from its' neighbors.

The following analysis was done for 7 piconets spaced at 1 MHz intervals, but the concepts are still applicable to 4 piconets spaced at 3 MHz intervals.

Multi-piconet Identification Analysis

The multi-piconet environment can be modeled as a vector of signals

$$V_s(t) = \left[S_{-3}(t) \quad S_{-2}(t) \quad S_{-1}(t) \quad S_0(t) \quad S_{+1}(t) \quad S_{+2}(t) \quad S_{+3}(t) \right]$$

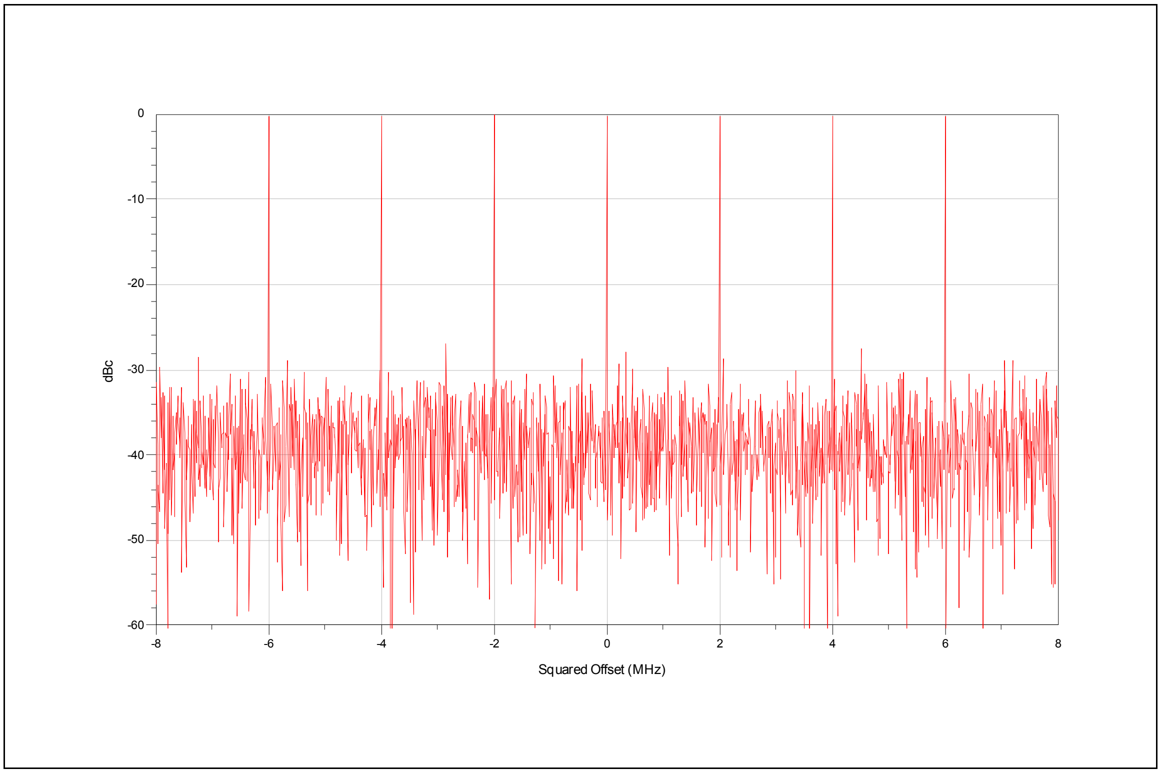
where $S_i(t) = m_i(t) * \cos\{(\omega_0 + \omega_i)t\}$ and ω_i is the frequency offset and m_i is the time dependent modulation. This vector will be processed by a square law device (squaring circuit).

The matrix product is given as

$$V_S^T(t) * V_S(t) = \begin{matrix} S_{-3}^2(t) & S_{-3}(t)S_{-2}(t) & S_{-3}(t)S_{-1}(t) & S_{-3}(t)S_0(t) & S_{-3}(t)S_{+1}(t) & S_{-3}(t)S_{+2}(t) & S_{-3}(t)S_{+3}(t) \\ S_{-2}(t)S_{-3}(t) & S_{-2}^2(t) & S_{-2}(t)S_{-1}(t) & S_{-2}(t)S_0(t) & S_{-2}(t)S_{+1}(t) & S_{-2}(t)S_{+2}(t) & S_{-2}(t)S_{+3}(t) \\ S_{-1}(t)S_{-3}(t) & S_{-1}(t)S_{-2}(t) & S_{-1}^2(t) & S_{-1}(t)S_0(t) & S_{-1}(t)S_{+1}(t) & S_{-1}(t)S_{+2}(t) & S_{-1}(t)S_{+3}(t) \\ S_0(t)S_{-3}(t) & S_0(t)S_{-2}(t) & S_0(t)S_{-1}(t) & S_0^2(t) & S_0(t)S_{+1}(t) & S_0(t)S_{+2}(t) & S_0(t)S_{+3}(t) \\ S_{+1}(t)S_{-3}(t) & S_{+1}(t)S_{-2}(t) & S_{+1}(t)S_{-1}(t) & S_{+1}(t)S_0(t) & S_{+1}^2(t) & S_{+1}(t)S_{+2}(t) & S_{+1}(t)S_{+3}(t) \\ S_{+2}(t)S_{-3}(t) & S_{+2}(t)S_{-2}(t) & S_{+2}(t)S_{-1}(t) & S_{+2}(t)S_0(t) & S_{+2}(t)S_{+1}(t) & S_{+2}^2(t) & S_{+2}(t)S_{+3}(t) \\ S_{+3}(t)S_{-3}(t) & S_{+3}(t)S_{-2}(t) & S_{+3}(t)S_{-1}(t) & S_{+3}(t)S_0(t) & S_{+3}(t)S_{+1}(t) & S_{+3}(t)S_{+2}(t) & S_{+3}^2(t) \end{matrix}$$

All the signals off the main diagonal represent the product of two uncorrelated spread spectrum signals which yields just another spread spectrum signal (represents an increase in the noise floor). However, the trace represents the square-law product sum of the signals $S_i^2(t) = m_i^2(t) * \cos^2\{(\omega_0 + \omega_i)t\}$. The expectation of each double frequency term is given by $\overline{S_i^2(t)} = \frac{1}{2} * \overline{m_i^2(t)} * \cos\{2(\omega_0 + \omega_i)t\}$ where we can assume that $\overline{m_i^2(t)} \approx 1$. Thus we see that the trace terms collapse to a double frequency component and the cross-product terms (off main diagonal terms) simply raise the noise floor. Assuming each piconet uses a unique chipping rate offset, the output of the squaring loop can be used for piconet identification.

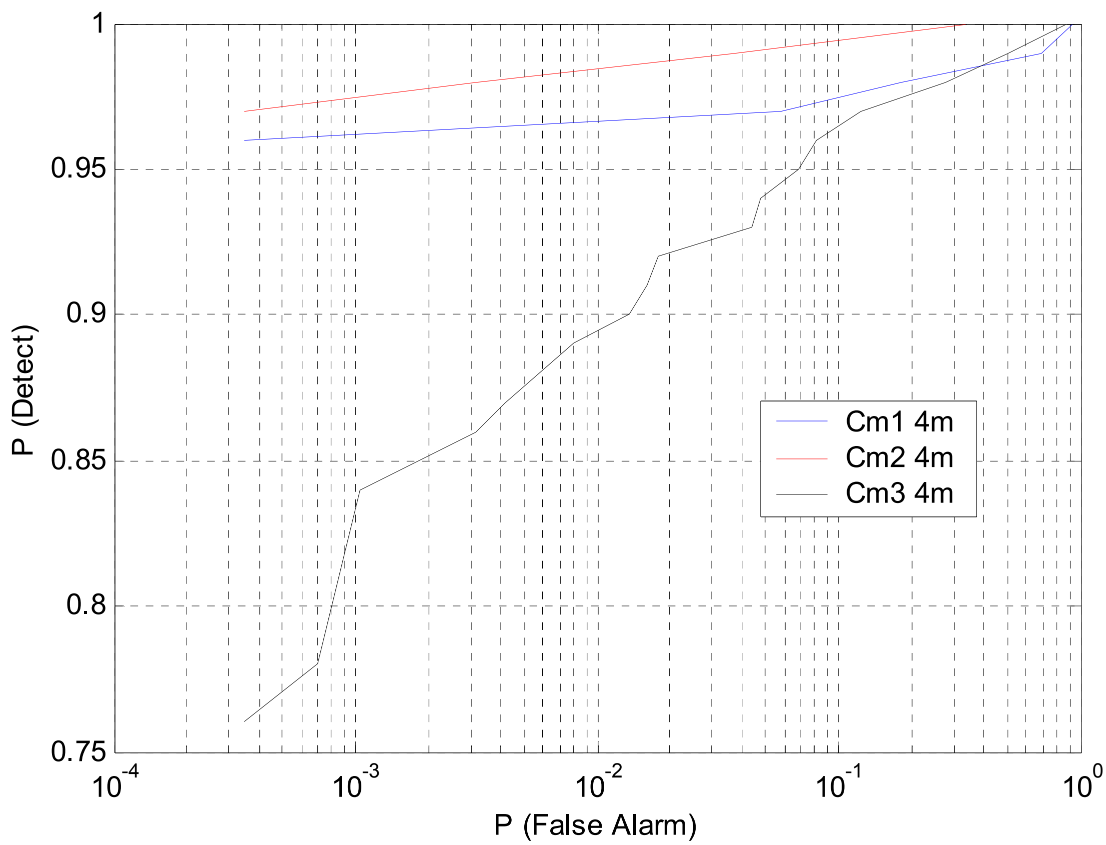
An example output of the squaring circuit for an input of 7 piconets is shown below. These results readily scale to operation with less than 7 piconets, such as with 4 piconets.



Seven Term Squared Output

2.12.3 BPSK Squaring Circuit ROC Curves – 4.1 GHz

The following figure represents the CCA ROC curves for CM1, CM2 and CM3 at 4.1 GHz. This curve shows good performance on CM1 and CM2 with high probability of detection and low probability of false alarm (e.g. usage of a CAP CSMA based algorithm is feasible); however, on CM3 use of the management slots (slotted aloha) is probably more appropriate.



<u>Low Band</u>
TX BW=1.368 GHz
RX NF=4.2 dB
CCA Detection BW: 200 KHz

<u>Path Loss Exponent</u>
CM1: r^2.0 mean path
CM2: r^2.5 mean path
CM3: r^3.0 mean path

2.13 Simultaneously Operating Piconet (SOP) Ratio Tables

2.13.1 SOP Testing

These tables are in response to the requested testing of document 03/031r11, clause 5.3, "Simultaneously Operating Piconets". Our testing was done over all 100 channel realizations for each channel model with the exclusion of the worst case 10%. The coexistence tables contain range ratio entries which are defined as ratio=Dint/Dref. The value of Dint (interference distance) can be calculated as the product of the ratio times the appropriate averaged outage range distance as given in the Averaged Outage Range tables.

2.13.1.1 SOP Ratios

Initial Conditions:

- *ACQ Symbol Duration=140.35 nS*
- *5 Finger RAKE*

114 Mbps, 8-BOK, 2/3 Rate FEC

Averaged Outage Range

	CM1	CM2	CM3	CM4
Meters Distance	15.0	13.5	11.5	10.0

Coexistence Ratios – 1 MUI

Ref \ Int	CM1	CM2	CM3	CM4
CM1	0.60	0.58	0.53	0.50
CM2	0.67	0.65	0.59	0.55
CM3	0.71	0.69	0.62	0.59
CM4	0.83	0.80	0.73	0.69

200 Mbps, 16-BOK, R-S FEC

Averaged Outage Range

	CM1	CM2	CM3	CM4
Meters Distance	11.1	10.0	8.8	7.5

Coexistence Ratios – 1 MUI

Ref \ Int	CM1	CM2	CM3	CM4
CM1	0.55	0.53	0.48	0.46
CM2	0.61	0.59	0.54	0.51
CM3	0.67	0.65	0.59	0.56
CM4	0.77	0.74	0.67	0.64

Continuing

Coexistence Ratios – 2 MUI

Ref \ Int	CM1	CM2	CM3	CM4
CM1	0.85	0.82	0.74	0.70
CM2	0.94	0.91	0.83	0.78
CM3	1.01	0.97	0.88	0.84
CM4	1.17	1.13	1.03	0.97

Coexistence Ratios – 3 MUI

Ref \ Int	CM1	CM2	CM3	CM4
CM1	1.04	1.00	0.91	0.86
CM2	1.16	1.12	1.02	0.96
CM3	1.24	1.19	1.08	1.03
CM4	1.43	1.38	1.26	1.19

Coexistence Ratios – 2 MUI

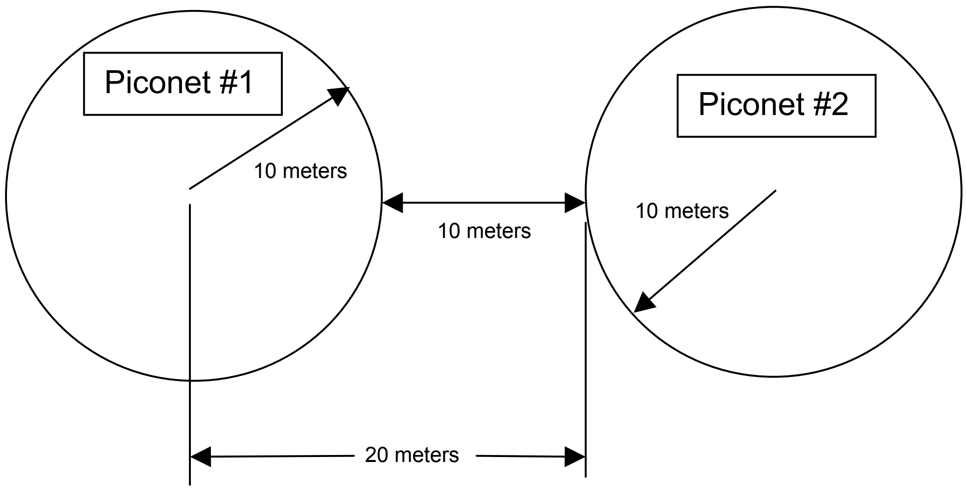
Ref \ Int	CM1	CM2	CM3	CM4
CM1	0.78	0.75	0.68	0.65
CM2	0.87	0.84	0.77	0.72
CM3	0.95	0.91	0.83	0.79
CM4	1.09	1.05	0.96	0.90

Coexistence Ratios – 3 MUI

Ref \ Int	CM1	CM2	CM3	CM4
CM1	0.96	0.92	0.84	0.79
CM2	1.06	1.03	0.94	0.88
CM3	1.16	1.12	1.02	0.96
CM4	1.33	1.28	1.17	1.11

2.13.2 Single Co-channel separation distance test

(For CDMA, this test measures the recommended distance between piconets when reusing the CDMA code set)



2.13.2.1 CM1 Testing

~20 meters

2.13.2.2 CM2 Testing

~20 meters

2.13.2.3 CM3 Testing

~20 meters

2.13.2.4 CM4 Testing

~20 meters

3 MAC Enhancements Estimates

3.1 Channel Selection

Our proposed PHY offers 4 logical channels per frequency band with 2 frequency bands for a total of 8 logical channels. These channels are independent and are selected by the DME via the existing channel list (ChannelList) and the channel index (CHNL_ID).

3.2 Preamble Selection

The default preamble is used to communicate with the PNC. The preamble type is specified during the Channel Time Allocation by adding a Preamble Type octet to the CTA block. Likewise, a Preamble Type octet would be added to the CTR control field. These are relatively minor MAC additions.

3.3 DEV Capability field

The DEV capabilities field in 802.15.3 clause 7.4.11 has a 5 bit supported rates field. In order to support asymmetric devices, ones with high transmit capabilities but low receive capabilities in particular, this proposal includes a separate supported rate field for transmit and for receive. Additionally "Number supported bands" field indicates if the DEV supports one or 2 bands. In order to have enough bits, the DEV capability field (figure 42 in D17) should be modified as follows:

b23-b18	b17-b16	b15-b11	b10	b9	b8	b7-b5	b4-b0
Reserved	Number of Bands Supported	Supported Tx Data Rates	Listen to Multicast	Listen to Source	Always Awake	Preferred Fragment Size	Supported Rx Data Rates

3.4 PHY Supported Rate Fields

The PHY PIB comprises the managed objects, attributes and notifications required to manage the PHY layer of a DEV.

There are 3 fields related to supported PHY data rates in the Capability IE, 7.4.11: the Supported RX Data Rates field, the Supported TX Data Rates field, and the Number of Bands Supported field. The RX and TX supported rates fields are described in Table 22.

Table 22—UWB PHY Supported Data Modes

bits	Content	Description
b0-b1	FEC Type	2 bit field that indicates supported FEC types 00 = no FEC 01 = Convolutional FEC 10 = Reed-Solomon(223, 255) 11 = Concatenated
b2-b3	M-BOK	2 bit field that indicates supported M-BOK types 00 = 2-BOK 01 = 4-BOK 10 = 8-BOK 11 = 16-BOK
b4	PSK	1 bit field that indicates supported PSK types 0 = BPSK 1 = QPSK

The Number of Supported Bands field is described in Table 23.

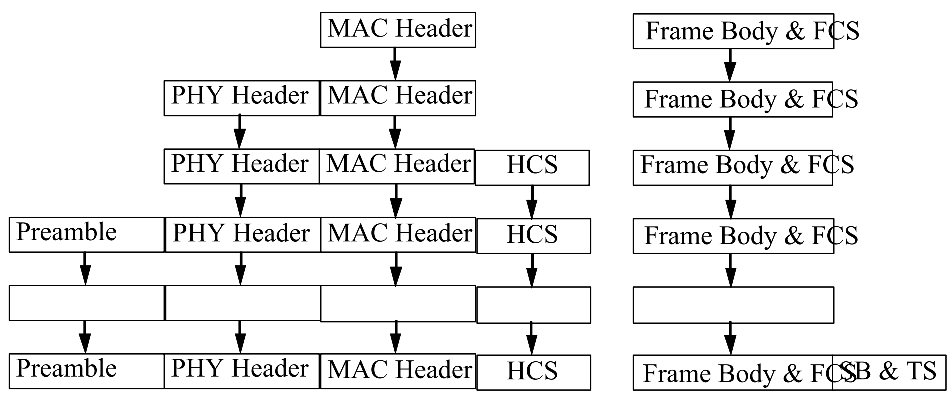
Table 23—Number of Supported Bands

Supported Bands	b0
Only Current Band	0
Both Bands	1

4 PHY Technical Detail

4.1 Frame Format

The PHY frame format for all data rate modes is illustrated below. The UWB PHY prepends the PHY header to the MAC header, calculates the HCS, and appends this to the MAC header. If the size of the frame body plus FCS, in bits, is not an integer multiple of the bits/symbol, then stuff bits are added following the FCS. The PHY preamble is sent first in the packet, followed by the PHY and MAC header, followed by the MPDU and finally the tail symbols.



PHY frame formatting

4.2 Randomization

Randomization shall be employed to ensure an adequate number of bit transitions to support clock recovery. The stream of downlink packets shall be randomized by modulo-2 addition of the data with the output of the pseudo-random binary sequence (PRBS) generator. The randomizer shall be used for the MAC header and frame body. The PHY preamble and PHY header shall not be scrambled. The polynomial for the pseudo random binary sequence (PRBS) generator shall be

$g(D)=1+D^{14}+D^{15}$ (4).

The polynomial forms not only a maximal length sequence, but also is a primitive polynomial. By the given generator polynomial, the corresponding PRBS is generated as

$$Xn = Xn - 14 \oplus Xn - 15 \; .$$

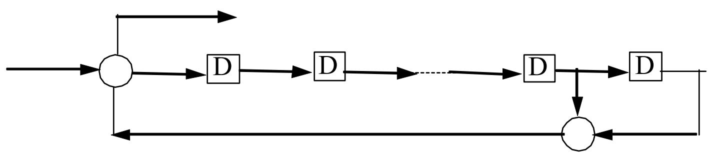


Figure 3 - Realization of the randomizer linear feedback shift registers

The following sequence defines the initialization sequence,

x_{init}=[x^in-1 x^in-2 x^in-3 x^in-4 x^in-5 x^in-6 x^in-7 x^in-8 x^in-9 x^in-10 x^in-11 x^in-12 x^in-13 x^in-14 x^in-15] (6)

where x^in-k represents the binary initial value at the output of the k^{th} delay element.

The scrambled data bits, s_n, are obtained as follows

$$s_n = b_n \oplus x_n$$

where b_n represents the unscrambled data bits. The side-stream de-scrambler at the receiver shall be initialized with the same initialization vector, x_{init}, used in the transmitter scrambler. The initialization vector is determined from the seed identifier contained in the PHY header of the received packet.

Randomizer Seed Selection

Seed Identifier	Seed Value
0,0	0011 1111 1111 111
0,1	0111 1111 1111 111
1,0	1011 1111 1111 111
1,1	1111 1111 1111 111

The 15 bit seed value chosen shall correspond to the seed identifier. The seed identifier value is set to 00 when the PHY is initialized and is incremented in a 2-bit rollover counter for each packet that is sent by the PHY. The value of the seed identifier that is used for the packet is sent in the PHY header. The 15-bit seed value is configured as follows. At the beginning of each PHY frame, the register is cleared, the seed value is loaded, and the first scrambler bit is calculated. The first bit of data of the MAC header is modulo-2 added with the first scrambler bit, followed by the rest of the bits in the MAC header and frame body.

4.3 FEC coding

The forward error correction (FEC) schemes are selectable from the types in Table 5. All FEC schemes shall be mandatory and supported by all DEVs.

FEC Code Types

Code Type	Outer Code	Inner Code
1 - Reed-Solomon	RS GF(255,223)	None
2 – Convolutional	None	Rate ½ or ¾, K=7, (171, 133) Convolutional Code
3 – Concatenated	RS GF(255,223)	Rate ½ or ¾, K=7, (171, 133) Convolutional Code

The following is a summary of the three Code Types:

a)***Code Type 1:*** *Reed-Solomon only:* Reed-Solomon decoders offer implementation advantages that extend practical bit rate limits far beyond what is possible with convolutional decoders (specifically the Viterbi algorithm decoder). Reed-Solomon codes offer high coding rate at high bit rates with moderate latency. The protection offered by the GF(255, 223) code is t =16. The code works on octets and not individual bits.

b)***Code Type 2:*** *Convolutional code:* This code is useful for low to moderate coding rates providing good coding gain with low latency. Implementation issues often limit the practical bit rate to less than 200 Mbps. The basic code is a ½ rate code that can be punctured to achieve a code rate of ¾ at slightly less coding gain. Typically an interleaver is used prior to the convolutional decoder to randomize burst errors.

b)***Code Type 3:****Reed-Solomon + Convolutional code:* A Reed-Solomon code concatenated with a Convolution code offers excellent coding gain for those applications that can tolerate the low to moderate code rate and longer latency. The bit rate is generally limited by the convolutional decoder. A symbol block interleaver is required between the convolutional decoder and the Reed-Solomon decoder to random burst errors caused by the convolutional decoder.

4.3.1 Reed-Solomon GF(255,223) Code

RS(255, 223) codes are a class of block codes that operate on non-binary symbols. The symbols are formed from 8 bits of a binary data stream and a code block is formed with 255 symbols. In each block 223 symbols are formed from the encoder input and $2t$ parity symbols are added where t=16 in this case. The code is thus a systematic code, with a code rate of 223/255, and the code is able to correct up to 16 symbol errors in a block. The RS generator polynomial can be reduced to a $2t$ order polynomial as shown below.

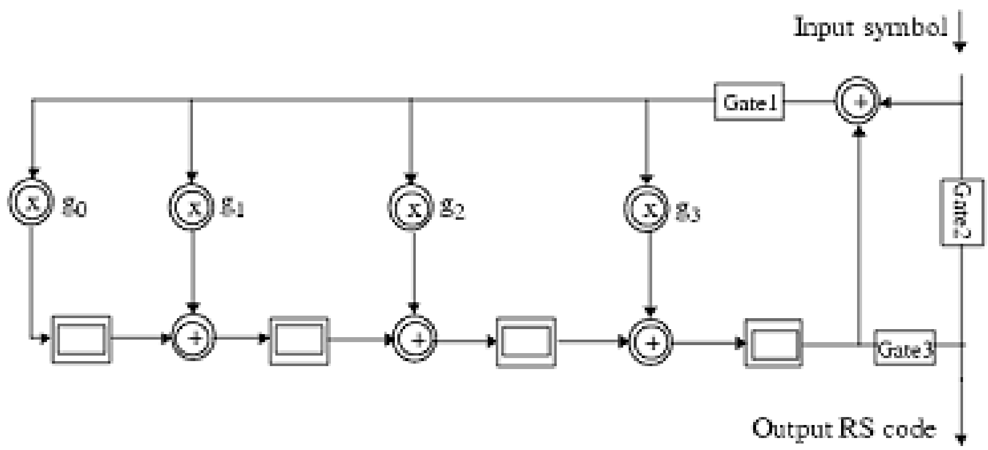
$g(x)=x^{2t} + g_{2t-1}x^{2t-1} + ... + g_0$.

The RS field generation polynomial is specified as below.

P(x) = 1 + x2 + x3 + x4 + x8

For last codeword or the MAC message less than K, shortened operation is performed. Let k' as the message length, and the shortened operation is described as:

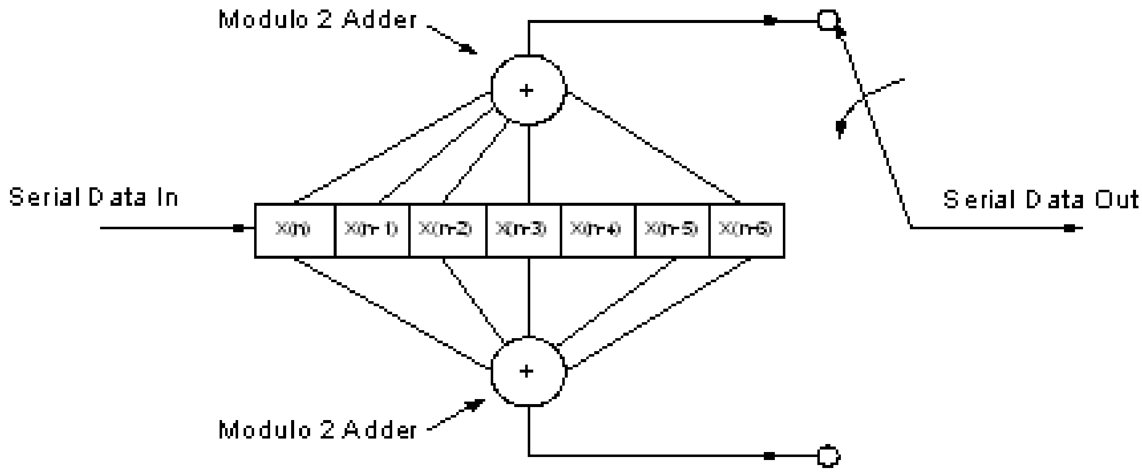
A1) Add (K-k') zero bytes to the block as a prefix.
A2) Encode the K bytes and append the R parity bytes.
A3) Discard all of the (K-k') zero symbols.
A4) Serialize the bytes and transmit them to the inner coder or the modulator MSB first.



Reed-Solomon Encoder

4.3.2 Convolutional Code

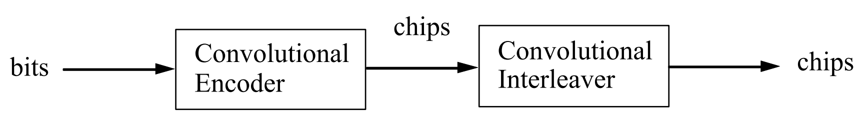
The convolutional encoder is used to encode data so that errors introduced due to noise in the channel can be corrected by the decoder. Two important characteristics of a convolutional encoder are its rate and constraint length. If k data bits are shifted in for every n encoded bits shifted out, the rate of the code equals k/n. If the maximum degree of the generator polynomials are m, then the constraint length of the code equals k(m+1). The half-rate convolutional encoder is a linear feed-forward shift register network in which, for every data bit that is shifted in, 2 encoded bits are shifted out. The structure of the encoder is specified by a set of generator polynomials go=171 and g1=133. The error correcting capabilities of a code are determined by these generator polynomials.



Rate ½ Encoder

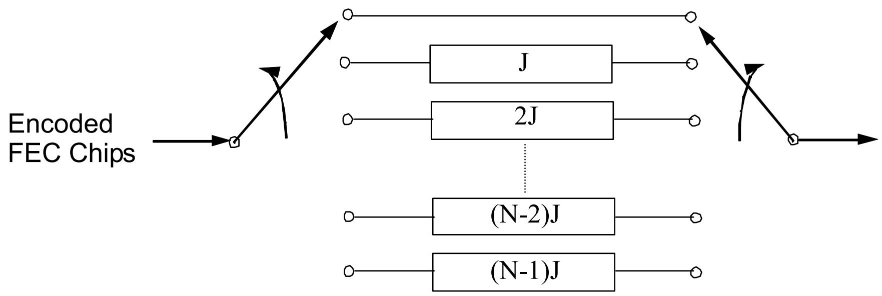
4.3.3 Chip Wise Convolutional Interleaver

The convolutional decoder is sensitive to burst errors; hence, interleaving is used to disperse burst errors as shown below.



Convolutional Encoder with Interleaving

Convolutional interleaving is used over block interleaving because of it has lower latency and memory requirements. The structure for a convolutional interleaver is shown below. The encoded chips are sequentially shifted in to the bank of N registers; each successive register provides J chips more storage than did the preceding. The zeroth register provides no storage. With each new code chip the commutator switches to a new register, and the new code chip is shifted in while the oldest code chip in that register is shifted out. After the (N-1)th register, the commutator returns to the zeroth register and starts again. The deinterleaver performs the inverse operation, and the input and output commutators for both interleaving and deinterleaving must be synchronized.

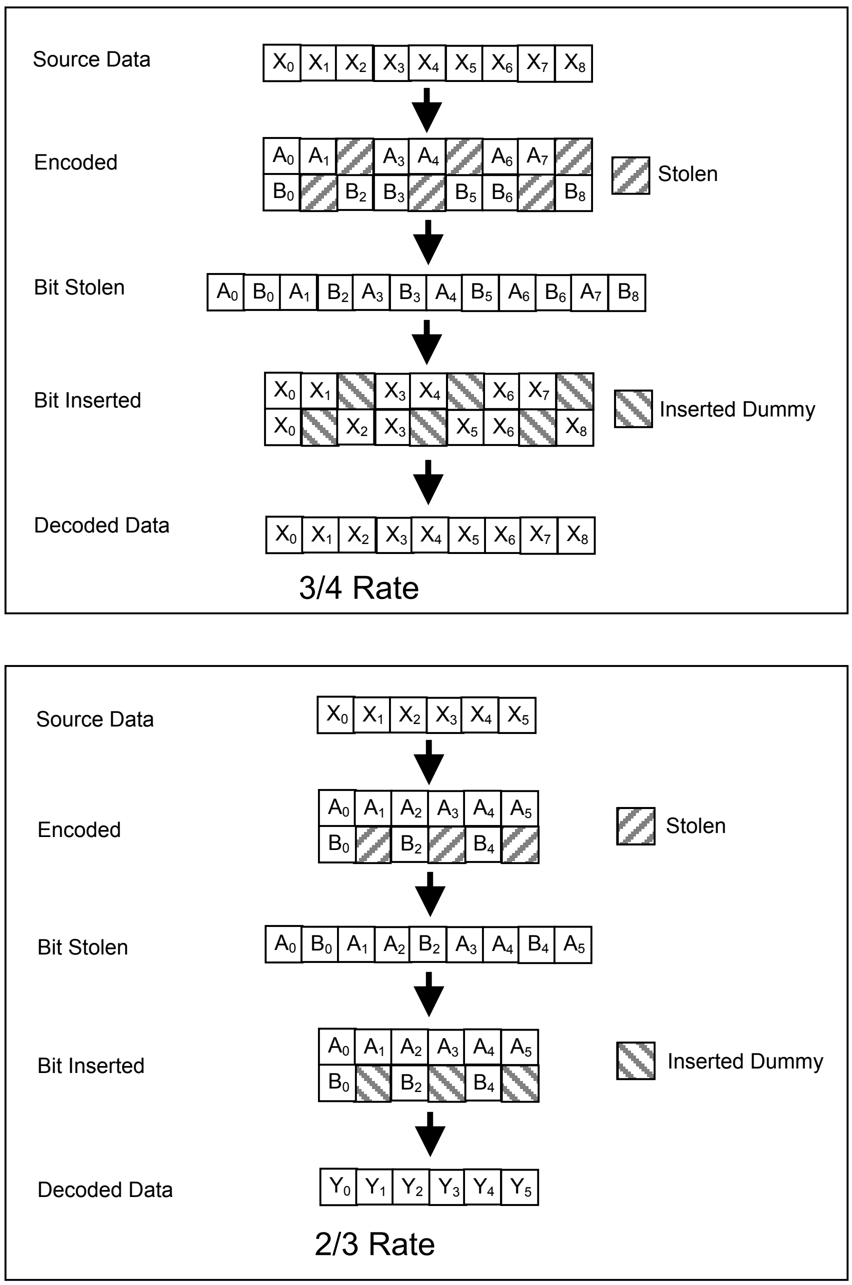


Convolutional Chip-wise Interleaver

The chip interleaver shall have the values of J=7 and N=10.

4.3.4 Puncturing

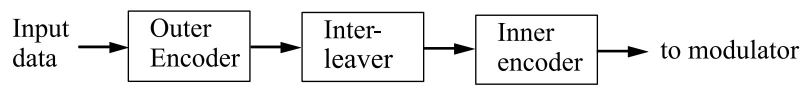
Higher data rates are derived from convolutional encoders by employing "puncturing." Puncturing is a procedure for omitting some of the encoded bits in the transmitter (thus reducing the number of transmitted bits and increasing the coding rate) and inserting a dummy "zero" metric into the convolutional decoder on the receive side in place of the omitted bits. This allows a 1/2 rate code to be transformed into a 2/3 rate code or a 3/4 rate code. The puncturing patterns are illustrated in Figure X. Decoding by the Viterbi algorithm is recommended.



Puncturing Patterns

4.3.5 Concatenated Code

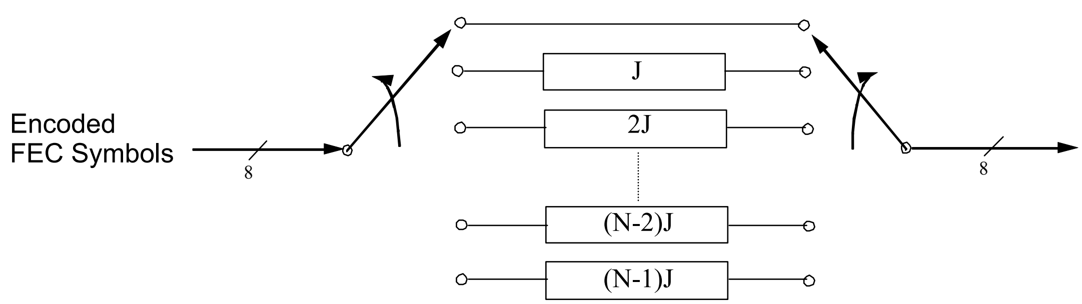
A concatenated code is one that uses two levels of coding, an inner code and an outer. Figure X shows a concatenated encoding scheme with an interleaver between the outer encode and the inner encoder. The concatenated code shall consist of a Reed-Solomon outer code (ref. 11.4.1) and a convolutional inner code (ref. 11.4.2). A bytewise interleaver shall be used between the outer encoder and the inner encoder.



Concatenated Coding Scheme

4.3.6 Convolutional Symbol Interleaver

Convolutional interleaving is used over block interleaving because of it has lower latency and memory requirements. The structure for a convolutional interleaver is shown below in Figure X. The code symbols are sequentially shifted into the bank of N registers; each successive register provides J symbols more storage than did the preceding. The zeroth register provides no storage. With each new code symbol the commutator switches to a new register, and the new code symbol is shifted in while the oldest code symbol in that register is shifted out. After the (N-1)th register, the commutator returns to the zeroth register and starts again. The deinterleaver performs the inverse operation, and the input and output commutators for both interleaving and deinterleaving must be synchronized.



Convolutional Symbol-wise Interleaver

The symbol interleaver shall have the values of J=21 and N=15.

4.4 Code Set Modulation

4.4.1 Base Symbol Rate

The IEEE 802.15.3a UWB physical layer standard specifies bi-phase modulated CDMA coded BPSK wavelet signalling. The base symbol rate for all modulations shall be 114 Msps (Mega Symbols per Second) for the high band and 57 Msps for the low band**.**

4.4.2 Code Sets and Code Set Modulation

This proposal enables higher data rates primarily through the use of bi-orthogonal keying (BOK). This modulation format uses a set of orthogonal codes and their inverses to send multiple bits of information in each symbol interval. This modulation allows higher data rates without the need to increase ADC clock rates and also provides more robust BER performance through lower Eb/No requirements.

There are 4 piconets with up to 8 code words per piconet. The code words are 24 chips long with each chip selected from the set {-1, 0, -1}. The following tables show half of the code space. The other half of the code space is just the inverse. The codes are used for 2-BOK (first row), 4-BOK (first and second rows), 8-BOK (first, second, third and forth rows) and 16-BOK (all rows).

4.4.2.1 Piconet 1 BOK Codes

Table 6—Piconet 1 BOK Codes

symbol bit mapping	codeword
0000	-1 1 -1 -1 1 -1 -1 1 -1 0 -1 0 -1 -1 1 1 1 -1 1 1 1 -1 -1 -1
0001	0 -1 -1 0 1 -1 -1 1 -1 -1 1 1 1 1 -1 -1 1 -1 1 -1 1 1 1 1
0010	-1 -1 -1 -1 1 -1 1 -1 1 -1 -1 1 -1 -1 1 -1 -1 1 1 0 -1 0 1 1
0011	0 -1 1 1 1 -1 -1 -1 -1 -1 -1 -1 1 -1 1 -1 0 1 -1 1 1 -1 -1 1
0100	-1 0 1 -1 -1 -1 1 1 0 1 1 1 1 -1 1 -1 1 1 1 -1 1 -1 -1 1
0101	-1 0 -1 1 -1 1 -1 -1 0 1 1 1 1 -1 1 1 -1 -1 -1 1 1 -1 1 1
0110	-1 -1 -1 -1 -1 -1 1 1 1 0 -1 -1 1 1 -1 1 -1 1 -1 1 1 -1 0 1
0111	-1 1 -1 -1 -1 1 -1 -1 0 -1 1 -1 -1 1 -1 0 1 1 1 1 -1 -1 -1 1 1

4.4.2.2 Piconet 2 BOK Codes

Table 7—Piconet 2 BOK Codes

symbol bit mapping	codeword
0000	-1 -1 1 0 1 1 1 -1 -1 1 -1 1 1 -1 1 0 1 -1 -1 -1 1 -1 -1 -1
0001	-1 -1 -1 1 -1 -1 -1 1 0 1 -1 1 1 -1 1 -1 -1 1 1 1 0 1 -1 -1
0010	-1 1 -1 1 1 -1 1 0 1 1 1 -1 -1 1 1 -1 1 1 1 -1 -1 -1 0 -1
0011	0 -1 1 1 1 1 -1 -1 1 1 1 -1 1 1 -1 1 1 1 -1 1 -1 0 -1 -1
0100	-1 1 -1 1 -1 -1 -1 -1 -1 -1 -1 1 1 1 -1 -1 1 1 -1 0 1 -1 0 1
0101	-1 1 -1 -1 1 0 -1 -1 1 1 -1 -1 0 1 1 1 -1 -1 -1 -1 -1 1 -1 1
0110	-1 0 1 -1 -1 -1 1 -1 1 -1 1 1 1 1 -1 -1 -1 -1 1 -1 0 1 -1 -1
0111	-1 -1 -1 -1 -1 -1 1 1 1 0 -1 1 -1 1 -1 1 1 -1 -1 1 -1 0 1 -1

4.4.2.3 Piconet 3 BOK Codes

Table 8—Piconet 3 BOK Codes

symbol bit mapping	codeword
0000	-1 1 -1 1 -1 -1 0 1 -1 -1 -1 1 -1 -1 1 0 -1 -1 -1 -1 1 1 1 1
0001	-1 -1 1 1 -1 -1 -1 -1 -1 -1 1 1 0 1 -1 1 1 -1 1 -1 0 -1 1 -1
0010	-1 -1 -1 1 1 1 -1 -1 -1 1 -1 -1 -1 1 -1 -1 1 -1 1 0 1 1 0 1
0011	-1 -1 1 -1 -1 1 1 1 -1 -1 1 -1 -1 -1 -1 0 1 1 -1 1 -1 1 0 1
0100	-1 -1 -1 1 -1 1 -1 1 0 -1 -1 -1 1 1 1 1 -1 1 1 -1 0 1 -1 -1
0101	-1 -1 -1 0 -1 -1 -1 -1 1 1 1 0 1 -1 -1 1 -1 1 -1 1 1 -1 -1 1
0110	-1 1 -1 1 -1 1 1 0 1 1 1 0 -1 1 1 -1 1 1 -1 -1 -1 -1 1 1
0111	-1 1 0 -1 1 -1 1 -1 -1 -1 1 -1 -1 0 1 -1 -1 1 1 1 1 -1 -1 -1

4.4.2.4 Piconet 4 BOK Codes

Table 9—Piconet 4 BOK Codes

symbol bit mapping	codeword
0000	-1 -1 1 1 1 -1 -1 -1 -1 -1 -1 0 -1 1 -1 1 -1 1 1 -1 1 1 -1 0
0001	-1 -1 -1 1 -1 1 1 1 1 -1 1 1 -1 1 1 -1 -1 1 1 1 0 0 -1 1
0010	-1 1 -1 1 1 1 1 0 -1 -1 -1 -1 1 -1 0 -1 -1 1 1 -1 -1 1 1 -1
0011	0 -1 -1 -1 -1 -1 -1 1 1 0 -1 1 1 -1 1 -1 -1 1 1 -1 1 -1 1 -1
0100	-1 -1 1 1 -1 -1 1 0 -1 1 1 1 1 -1 1 -1 1 -1 0 -1 1 1 1 1
0101	-1 -1 1 -1 -1 1 -1 -1 0 -1 1 -1 1 1 -1 -1 -1 1 -1 0 -1 1 1 1
0110	-1 1 0 1 -1 -1 -1 1 1 -1 0 -1 1 -1 -1 1 -1 -1 1 1 1 1 1 1
0111	-1 -1 -1 -1 1 -1 1 0 -1 1 -1 1 1 1 0 1 -1 -1 1 1 -1 -1 1 1

4.4.2.5 Code Set Statistics

Group 1	Spectral Peak	Worst Corr Coeff
2-BOK	1.9496 dB	
4-BOK	1.8332 dB	0
8-BOK	1.2047 dB	2 over 22
16-BOK	1.1707 dB	2 over 22
Group 2		
2-BOK	2.1388 dB	
4-BOK	2.1388 dB	0
8-BOK	1.6535 dB	2 over 22
16-BOK	1.0527 dB	2 over 22
Group 3		
2-BOK	2.1963 dB	
4-BOK	1.7794 dB	0
8-BOK	1.3501 dB	2 over 22
16-BOK	1.1055 dB	2 over 22
Group 4		
2-BOK	2.1540 dB	
4-BOK	1.5966 dB	0
8-BOK	1.4135 dB	2 over 22
16-BOK	1.3223 dB	2 over 22

4.4.3 Preamble and Header Modulation Rate

The PHY header and MAC header shall be modulated at the base rate using one of the 2-BOK PNC selected formats as shown in the tables with no FEC.

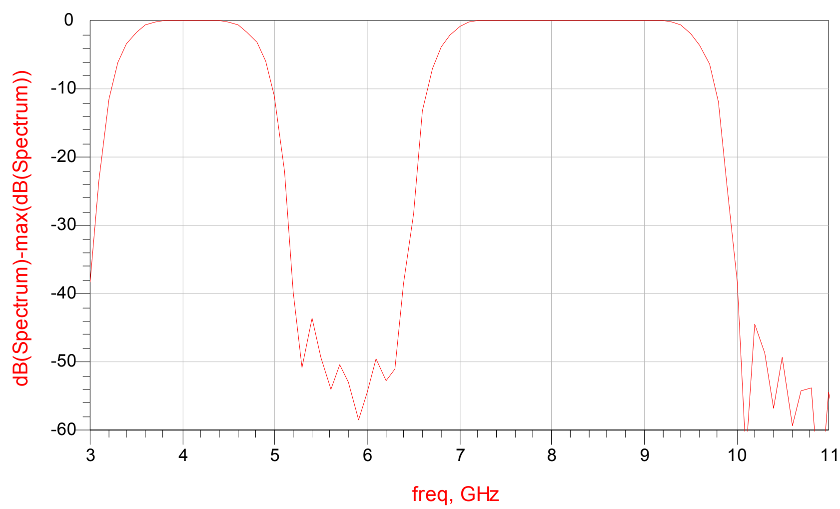
4.5. Pulse Shaping and Modulation

4.5.1 Impulse Response

The reference pulse is a root raised cosine low pass filter. For the low frequency band the filter cutoff frequency (-3 dB point) is 684 MHz and for the high frequency band the filter cutoff frequency (-3 dB point) is 1368 MHz. The implemented baseband impulse response must have a peak cross-correlation within 3 dB of the reference pulse. The excess bandwidth is 50%.

4.5.2 Reference Spectral Mask

The reference spectral mask is shown in figure below. Out-of-band emissions must meet regulatory domain requirements.



Super-impose Lower and Upper Band Reference Pulse Spectral Mask

4.5.3 Chip Rate Clock and Chip Carrier Alignment

The chip rate clock and the chip carrier shall be provided from the same source with the frequencies shown below. The accuracy is 25 ppm.

Chip Rate Clock and Chip Carrier Frequencies

Chip Rate	1.368 Gcps	2.736 Gcps
Carrier Frequency	4.104 GHz	8.208 GHz
RRC Excess BW	50%	50%

4.6. Power Management Modes

Our proposal supports all the IEEE802.15.3 Power Management Modes.

4.7. General Requirements

4.7.1 Channel Assignements

A total of 8 logical channels are assigned for operation, 4 CDMA channels per band with two bands. A compliant 802.15.3 implementation shall support at least one band of operation and optionally both bands of operation. The assigned channels are shown in table 19 along with the associated carrier frequency offsets.

UWB PHY Channel Plan

CHNL_ID	Center Frequency	Piconet Code Set	Frequency Offset
1	4.104 GHz	1	-9 MHz
2	4.104 GHz	2	-3 MHz
3	4.104 GHz	3	+3 MHz
4	4.104 GHz	4	+9 MHz
5	8.108 GHz	1	-9 MHz
6	8.108 GHz	2	-3 MHz
7	8.108 GHz	3	+3 MHz
8	8.108 GHz	4	+9 MHz

PHYPIB_CurrentChannel is the CHNL_ID of the current channel. For the purpose of the remote scan commands, 7.5.6.3 and 7.5.6.4, the channel index is the CHNL_ID in Table 19.

4.7.2 Transmit Power Control

A compliant transmitter is allocated power on a power density basis. It shall be capable of transmitting no more than -2.5 dBm (TBR) and shall be capable of reducing its power to less than -10 dBm in monotonic steps no smaller than 3 dB and no larger than 5 dB. The steps shall form a monotonically decreasing sequence of transmit power levels. A compliant device shall have its supported power levels indicated in its PHY PIB based on its maximum transmit power and power level step size.

The minimum TX power level required to support TPC, aMinTPCLevel, shall be -10 dBm.

5 Overhead and Data Throughput

5.1 Preamble and Acquisition Details

5.1.1 General Preamble Structure

There are 3 preamble options that are structurally the same except for field durations:

1. A nominal preamble used for nominal data rates and channels
2. A long preamble used for low data rates and difficult channels
3. A short preamble used for high data rates and benign channels

Acq Seq 8 uS	TBD TBD uS	Training 4 uS	SFD 1 uS	PHY Header	MAC Header	data

Preamble Structure

The preamble structure is summarized below.

1. The TX MAC selects one of 4 piconet acquisition codes (PAC) and sets the corresponding carrier offset frequency.

2. The TX modulates the PAC code (one bit per PAC symbol) with random data to generate the acquisition sequence which is used by the receiver for initial acquisition (AGC and clock frequency lock)

3. Next is sent the training frame. The receiver uses this training frame to adjust the receiver.

4. The TX next sends the SFD (start frame delimiter) that indicates to the RX the next frame will be the PHY header, which contains rate information.

5. After the PHY header comes the MAC header.

6. Following the MAC header the TX starts sending data frames.

5.1.2 Acquisition Sequence

There are four PAC codewords with are given by the first row of tables 6 through 12, and the correpsonding frequency offsets are given in table 14. Each piconet uniquely uses one of these codes. The selection of the code is determined by the PNC during the initial scan prior to initiating the piconet (the PNC selects a PAC codeword that is not in use). Use of the PAC codewords provides a degree of "channel separation" between overlapping piconets during preamble acquisition, limited only by the rms cross-correlation properties of the PAC codeword set. The PAC codewords increases the probability that a DEV will train on the preamble associated with the "desired" piconet.

Piconet number to carrier offset mapping

PNC Number	Chipping Offset (MHz)	Carrier Offset (MHz)
1	-3	-9
2	-1	-3
3	+1	+3
4	+3	+9

The preamble starts with the acquisition sequence, which is used primarily by the receiver to set gains and achieve clock synchronization. The acquisition sequence is random bits, one bit per codeword.

5.1.3 Training Frame

The length of the training frame varies depending upon the preamble length. Table XYZ indicates the bits that shall be sent during the preamble. The high band bit time duration is 1/114e6 and the low band bit time duration is 1/57e6.

Training Frame Bit Sequence

Preamble Type	High Band Preamble Sequence (base 32)	Low Band Preamble Sequence (base 32)
Short	TBD	TBD
Medium	JNJNB5ANB6APAPCPANASASCNJNAS K9B5K6B5K5D5D5B9ANASJPJNK5MNC PATB5CSJPMTK9MSJTCTASD9ASCTA TASCSANCSASJSJSB5ANB6JPAPD6B5 ATASCPMNCSN5D5K6K5B9CND5JTJP BAMNK6KAMTCNJTB5N9N6N9JNMN MTJSANMSD5K9K6K9JNMNMPJSANC SN5JSK6JTJPMPJNJSASCNN5DAASB9K 5MSD5B7291AT2W67PGC9Q1FNKPHH9 R64FGJZRK9TYMS2KEWFCMRY31Q8N QZ8J5YNYTTS00Y87NKWHKV8J4YNPJ RS2GEWQMJRSJGARPMKGHRRA84GK T1Z3J50	JNJNB5ANB6APAPCPANASASCNJNAS K9B5K6B5K5D5D5B9ANASJPJNK5MNC PATB5CSJPMTK9MSJTCTASD9ASCTA TASCSANCSASJSJSB5ANB6JPN5DAAS B9K5MSCNDE6AT3469RKWAVXM9JFE Z8CDS0D6BAV8CCS05E9ASRWR914A1 BR
Long	TBD	TBD

The notation for Base32 is: 0123456789ABCDEFGHJKMNPQRSTVWXYZ

5.1.4 SFD

The SFD consists of the 16-bit binary pattern 0000 1100 1011 1101 (transmitted leftmost bit first) as modulation on the selected 2-BOK code. The first bit of the SFD follows the last bit of the sync pattern. The SFD defines the frame timing in anticipation of the PHY header.

5.1.5 PHY Header

The PHY header consists of two octets that contain the number of octets in the frame body (including the FCS), the data rate of the frame body and seed identifier for the data scrambler. The fields for the PHY service field are shown in Table 13. Bit b0 is sent over the air first and the other bits follow sequentially.

PHY service field

Bits	Content	Description
b0-b1	Seed Identifier	2 bit field that selects the seed for the data scrambler, defined in Table 82
b2-b4	FEC Type	3 bit field that selects the FEC type 000 = no FEC 001 = 1/2 rate Convolutional 010 = 2/3 rate Convolutional 011 = 3/4 rate Convolutional 100 = Reed-Solomon(223, 255) 101 = Concatenated R-S, 1/2 rate 110 = Concatenated R-S, 2/3 rate 111 = Concatenated R-S, 3/4 rate
b5-b6	M-BOK	2 bit field that selects the M-BOK type 00 = 2-BOK 01 = 4-BOK 10 = 8-BOK 11 = 16-BOK
b7	PSK	1 bit field that selects the PSK type 0 = BPSK 1 = QPSK
b8-b9	Interleaver Type	2 bit field that selects the interleaver type 00 = no interleaver 01 = bit interleaver 10 = byte interleaver
b10-b23	Frame Body Length	A 14 bit field that contains the length of the frame body, in octets, MSB is b5, LSB is b15, e.g. 4 octets of data, is encoded as 0b00000000100. A zero length frame body is encoded as 0b000000000000 and there is no FCS for this packet.

5.1.6 MAC Header

The MAC header is unchanged from the 802.15.3 draft standard.

5.1.7 HCS

The header check sequence is calculated on the combined PHY and MAC Headers. The header check sequence is appended after the MAC header and contains the 16 bit CRC for the combined PHY and MAC headers. The polynomial used is:

$x^{16}+x^{12}+x^{5}+1$

This CRC is the same one used in IEEE Std 802.11b-1999.

6 Overhead and Throughput Summary

Section frame overhead values described.

6.1 Low Band

All rates in Mbps, times in µs							
PHY Header bits	24						
MAC Header Bits	80						
HCS bits	16						
Header Bits	120						
Payload Bytes	1024						
Payload Bits	8192						
FCS Bits	32						
FEC Overhead symbols (conv)	730						
FEC Overhead symbols (RS)	3112						
Symbol Rate	57						
Header equivalent "FEC" rate	0.333333						
Header BOK bits per symbol	1						
Initial PHY Header rate	19						
FEC		conv	conv	concat.	conv	R/S	R/S
Bit Rate		28.5	57	75	114	200	400
FEC symbol rate		57	114	171.5247	228	228.6996	457.3991
BOK		2	3	8	16	16	16
BPSK/QPSK		BPSK	BPSK	BPSK	BPSK	BPSK	QPSK
Bits per symbol		1	2	3	4	4	8
Payload FEC rate		0.5	0.5	0.437255	0.5	0.87451	0.87451
T_PA_INITIAL	15						
T_PA_CONT	0						
T_PHYHDR_INITIAL	1.263158						
T_MACHDR_INITIAL	4.210526						
T_HCS_INITIAL	0.842105						
T_PHYHDR_CONT		0.842105	0.421053	0.32	0.210526	0.12	0.06
T_MACHDR_CONT		2.807018	1.403509	1.066667	0.701754	0.4	0.2
T_HCS_CONT		0.561404	0.280702	0.213333	0.140351	0.08	0.04
T_MPDU		287.4386	143.7193	109.2267	71.85965	40.96	20.48
T_FCS		1.122807	0.561404	0.426667	0.280702	0.16	0.08
T_SIFS	5	5	5	5	5	5	5
T_FEC_OH		12.80702	6.403509	22.39911	3.201754	13.60737	6.803686
T_MIFS	0	0	0	0	0	0	0
T_ONE_FRAME		327.6842	177	158.3682	101.6579	81.04316	53.67948
Throughput_1		24.99968	46.28249	51.72755	80.584	101.0819	152.6095
T_FIVE_FRAMES		1498.772	762.5439	603.3816	394.4298	247.9232	137.1195
Throughput_5		27.32904	53.71494	67.88408	103.8461	165.2125	298.7176

6.2 High Band

All rates in Mbps, times in µs								
PHY Header bits	24							
MAC Header Bits	80							
HCS bits	16							
Header Bits	120							
Payload Bytes	1024							
Payload Bits	8192							
FCS Bits	32							
FEC Overhead symbols (conv)	730							
FEC Overhead symbols (RS)	3112							
Symbol Rate	57							
Header equivalent "FEC" rate	0.333333							
Header BOK bits per symbol	1							
Initial PHY Header rate	19							
FEC		concat.	conv	R/S	R/S	R/S	R/S	R/S
Bit Rate	Common	100	114	200	300	400	600	800
FEC symbol rate		228.6996	228	228.6996	343.0493	457.3991	686.0987	914.7982
BOK		4	4	4	8	16	8	16
BPSK/QPSK		BPSK	BPSK	BPSK	BPSK	BPSK	QPSK	QPSK
Bits per symbol		2	2	2	3	4	4	8
Payload FEC rate		0.437255	0.5	0.87451	0.87451	0.87451	0.87451	0.87451
T_PA_INITIAL	15							
T_PA_CONT	0							
T_PHYHDR_INITIAL	1.263158							
T_MACHDR_INITIAL	4.210526							
T_HCS_INITIAL	0.842105							
T_PHYHDR_CONT		0.24	0.210526	0.12	0.08	0.06	0.04	0.03
T_MACHDR_CONT		0.8	0.701754	0.4	0.266667	0.2	0.133333	0.1
T_HCS_CONT		0.16	0.140351	0.08	0.053333	0.04	0.026667	0.02
T_MPDU		81.92	71.85965	40.96	27.30667	20.48	13.65333	10.24
T_FCS		0.32	0.280702	0.16	0.106667	0.08	0.053333	0.04
T_SIFS	5	5	5	5	5	5	5	5
T_FEC_OH		16.79933	3.201754	13.60737	9.071582	6.803686	4.535791	3.401843
T_MIFS	0	0	0	0	0	0	0	0
T_ONE_FRAME		125.3551	101.6579	81.04316	62.8007	53.67948	44.55825	39.99763
Throughput_1		65.35034	80.584	101.0819	130.4444	152.6095	183.8492	204.8121
T_FIVE_FRAMES		459.1151	394.4298	247.9232	174.054	137.1195	100.1849	81.71763
Throughput_5		89.2151	103.8461	165.2125	235.3292	298.7176	408.844	501.2382

7 Ranging Support

7.1 MLME Enhancements

Our proposal adds the appropriate MLME primitives to support ranging. Specifically it adds the following:

- MLME-RANGE.request
- MLME-RANGE.indication
- MLME-RANGE.response
- MLME-RANGE.comfirm

Complete detail can be found in the PDF text accessible on page 4 of this document.

7.2 MAC Frame Format Enhancements

A ranging command sub-clause will be added. This ranging command is used to initiate a ranging token exchange between two devices.

7.3 MAC Functional Description Enhancements

A ranging functional description sub-clause will be included in our proposal that includes the approach MSC for the ranging token exchange. Complete details can be found in our PDF text accessible on page 4 of this document.

8 Comments on Receiver Performance

8.1 Maximum Input Level

The receiver maximum input level is the maximum power level of the incoming signal, in dBm, present at the input of the receiver for which the error rate criterion met. A compliant receiver shall have a receiver maximum input level of at least -20 dBm.

8.2 Coexistence

8.2.1 IEEE802.15.1

Our proposed UWB waveform does not intentionally emit power into the 2.4 GHz ISM band.

8.2.2 IEEE802.11b

Our proposed UWB waveform does not intentionally emit power into the 2.4 GHz ISM band.

8.2.3 IEEE802.15.3

Our proposed UWB waveform does not intentionally emit power into the 2.4 GHz ISM band.

8.2.4 IEEE802.11a

Our proposed UWB waveform does not intentionally emit power into the 5 GHz UNII band.

8.2.5 IEEE802.15.4

Our proposed UWB waveform does not intentionally emit power into neither the 2.4 GHz ISM band nor the 900 MHz ISM band.

8.3 Receiver Jamming Resistance

A general comment on receiver jamming resistance is the fact that the RX RF front end needs to have enough dynamic range to handle any signal overload condition until the detection bandwidth is set by the cascaded signal filtering, whether this be band pass filtering or low pass filtering.

8.3.1 Microwave Ovens

Our proposal does not require a receiver that is responsive to energy in the 2.4 GHz ISM band.

8.3.2 IEEE802.15.1

Our proposal does not require a receiver that is responsive to energy in the 2.4 GHz ISM band.

8.3.3 IEEE802.11b

Our proposal does not require a receiver that is responsive to energy in the 2.4 GHz ISM band.

8.3.4 IEEE802.15.3

Our proposal does not require a receiver that is responsive to energy in the 2.4 GHz ISM band.

8.3.5 IEEE802.11a

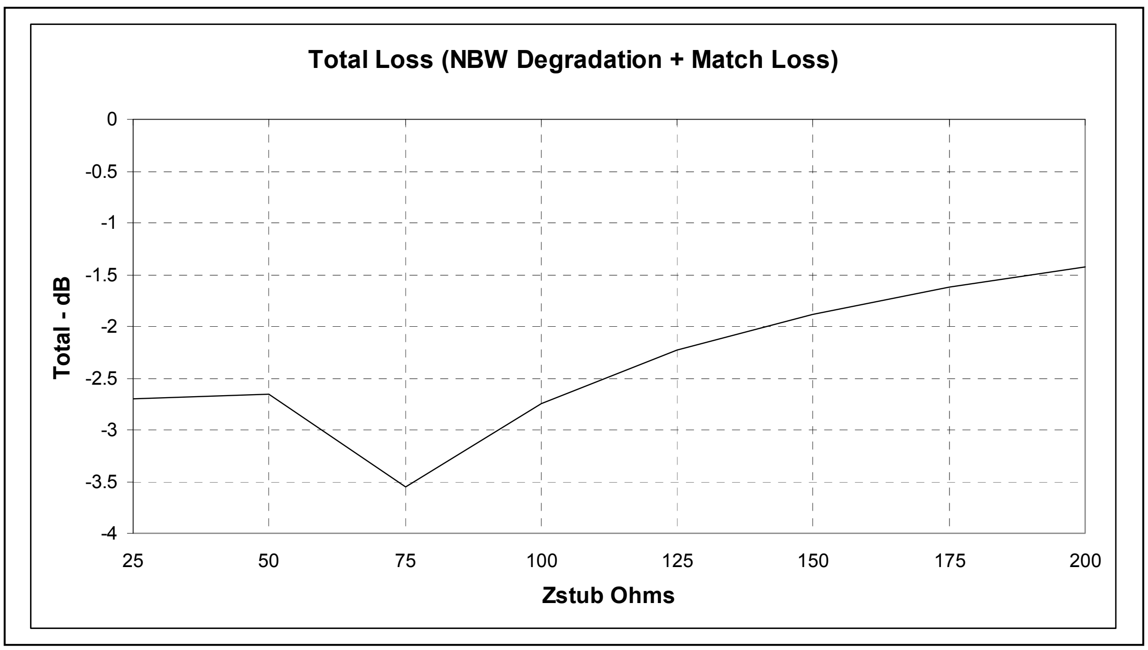
Our proposal does not require a receiver that is responsive to energy in the 5 GHz UNII band.

8.3.6 IEEE802.15.4

Our proposal does not require a receiver that is responsive to energy in neither the 2.4 GHz ISM band nor the 900 MHz ISM band.

8.3.7 In-Band Modulated and Unmodulated Interference

The minimum bandwidth of our proposal is ~1.5 GHz and narrowband modulated interference is not distinguishable from unmodulated interference and the same methods is used to deal with both forms of interference. Interference rejection can be either in front of the analog-to-digital converter (in the analog domain) or after the analog-to-digital converter (in the digital domain via DSP). An example of an analog domain NBI filtering circuit is a notch filter that is tuned to the interference frequency and cascaded with the receiver front end to reject the interference[2]. The depth of the notch can easily exceed 40 dB, which in conjunction with the processing gain of 13.8 dB allows an interference rejection in excess of 50 dB. The notch filter slightly increases the implementation loss. Typical implementation loss for a 50 ohm system with a simple quarter wave stub notch filter is shown below. The additional implementation loss varies between <1.5 dB to 3.5 dB depending upon the stub line impedance. This embodiment is just but one of several notch filter implementations.



8.3.8 Out-of-Band Modulated and Unmodulated Interference

Our proposal does not require a receiver that is responsive to energy outside the specified low UWB band and the high UWB band. Receiver filtering can be of the root raised cosine type exhibiting very sharp cutoff frequency response while not causing inter-chip interference problems. The receiver front-end needs to be designed against anticipated

2 A similar technique can be used in the transmitter to prevent interference to a fixed service occupying a frequency within the UWB band.

out-of-band overload conditions, of which the exact specification is out-of-scope of the standard.

8.4 Link Quality Indication

The link quality indication (LQI) shall be reported using an SNR estimation. The SNR shall be measured at the decision point in the receiver. The SNR includes the thermal noise, distortion, uncorrected interference and other signal impairments at the decision point in the receiver. The receiver shall report the SNR as a 5 bit number that covers a range of TBD dB to TBD dB of SNR. The value 0x00000 shall correspond to less than or equal to TBD (lower limit) dB SNR and 0x11111 shall correspond to more than or equal to TBD dB (upper limit) SNR with equal steps in between.

9 APPENDIX- XSI Draft Text for the IEEE802.15.3a Standard

XSI Proposal 802.15.3a-2003

Proposed Supplement to IEEE Standard for Information technology—

Telecommunications and information exchange between systems—

Local and metropolitan area networks— Specific requirements—

Part 15.3: Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications for High Rate Wireless Personal Area Networks (WPAN™)

UWB High-speed Alternate Physical Layer

6 Layer Management

6.3.20 Ranging

This mechanism supports range determination between two DEVs. The primitive's parameters are defined in Table 1.

Table 1—MLME-RANGE primitive parameters

Name	Type	Valid Range	Description
Source DEVID	Octet	2	The device ID of the source
Destination DEVID	Octet	2	The device ID of the destination
Timeout	Octet	As defined in 6.3.20.4.2	The time limit for the reception of the returned range token #2 as shown in clause TBD.
ReasonCode	Octet	As defined in 6.3.20.4.2	Indicates the result of the command.

6.3.20.1 MLME-RANGE.request

This primitive is used to request that the range between two devices be measured. The semantics of the primitive are as follows:

MLME-RANGE.request (Source PNID, Destination PNID, Timeout)

The parameters are defined in Table 1.

6.3.20.1.1 When generated

This primitive is generated by the source DME to request a range measurement.

6.3.20.1.2 Effect of receipt

When a DEV MLME receives this primitive from its DME, it will generate a RANGE command, which it will send to the Destination PNID. The Destination PNID, upon receiving the RANGE command, will generate an MLME-RANGE.indication.

6.3.20.2 MLME-RANGE.indication

This primitive is used to indicate a received RANGE command. The semantics of the primitive are as follows:

MLME-RANGE.indication (Source PNID, Destination PNID, Timeout)

The parameters are defined in Table 1.

6.3.20.2.1 When generated

This primitive is sent by the non-initiating MLME to its DME upon receiving a RANGE command.

6.3.20.2.2 Effect upon receipt

When the Destination DME receives this primitive, it will determine whether to accept or reject the source DEV request for a range measurement. The Destination DME will then send a MLME-RANGE.response with appropriate parameter values to its MLME via the MLME-SAP.

6.3.20.3 MLME-RANGE.response

This primitive is used to initiate a response to an MLME-RANGE.indication. The semantics of the primitive are as follows:

MLME-RANGE.response (Source PNID, Destination PNID, ReasonCode)

The parameters are defined in Table 1.

6.3.20.3.1 When generated

This primitive is generated by the Destination DME upon receiving an MLME-RANGE.indication.

6.3.20.3.2 Effect upon receipt

When the destination MLME receives this primitive from its DME, it will either initialize the ranging state machine in anticipation of exchanging ranging tokens or it will reject the ranging request with a ReasonCode indicating the reason for the request being denied.

6.3.20.4 MLME-RANGE.confirm

This primitive is used to inform the initiating source DME whether the requested ranging token exchange will commence or was the ranging request rejected. The semantics of the primitive are as follows:

MLME-RANGE.confirm (Source PNID, Destination PNID, ReasonCode)

The parameters are defined in Table 1.

6.3.20.4.1 When generated

The initiating source MLME sends this primitive to its DME to confirm whether a ranging token exchange is pending.

6.3.20.4.2 Effect upon receipt

When the initiating source MLME receives a ReasonCode = ExchangeTokens it shall initiate the ranging token exchange as per clause 6.3.X.5. When the ReasonCode = DoNotExchangeTokens the source MLME shall terminate the ranging token exchange procedure and perhaps attempt ranging later. When the ReasonCode = RangingNotSupported the source MLME shall terminate the ranging token exchange and shall not initiate another range measurement with that particular destination DEV. If the second token is not received by the source DEV within the time specified by parameter "Timeout" then the ReasonCode shall be set to ReasonCode=TimeoutFailure.

7 MAC Frame Formats

7.4.1 Channel Time Allocation

The channel time allocation (CTA) information element shall be formatted as illustrated in Figure 25. Because the length parameter supports only 255 octets of payload in an information element, the PNC may split the CTA information into more than one information element entry in the beacon. The CTA blocks shall be ordered by increasing value of the CTA location with the highest value last.

octets: 8	**...**	**8**	**8**	**1**	**1**
CTA block-n	...	CTA block-2	CTA block-1	Length	Element ID

Figure 25-Channel time allocation information element format

The CTA blocks shall be formatted as illustrated in Figure 26.

octets: 2	**2**	**1**	**1**	**1**	**1**
CTA duration	CTA location	Stream Index	SrcID	DestID	Preamble Type

Figure 26-Channel time allocation block

The Preamble Type field indicates which length preamble (short, medium, or long) will be used in the CTA assignment. The Preamble Type field is defined in clause 11.6.

The DestID indicates the DEV to whom the source DEV may send the frames.

The SrcID indicates the DEV to whom the channel time is being allocated.

If the CTA is for a child piconet, the DestID and SrcID shall both be the DEVID of the DEV that is the child piconet's PNC.

If the CTA is for a neighbor piconet, the DestID and SrcID shall both be the DEVID assigned by the PNC for the neighbor piconet and shall be one of the reserved neighbor piconet addresses, 7.2.3.

The stream index indicates the stream associated with the channel time, 7.2.5.

The CTA location field indicates the start time of the allocation. The value of this field is the time offset from the start of the beacon as described in 8.6. The resolution of this field is 1 µs, so the valid range is [0-65535] µs.

The duration field specifies the duration of the CTA. The resolution of this field is 1 µs, so the valid range is [0-65535] µs. The end time of each allocation is the start time contained in the CTA location field plus the CTA duration.

7.4.4 DEV association

The DEV association information element shall be formatted as illustrated in Figure 29. This IE is used to notify current members in the piconet about one or more DEVs which have either just associated or disassociated from the piconet.

octests: 13	**...**	**13**	**13**	**1**	**1**
DEV-n assoc info	...	DEV-2 assoc info	DEV-1 assoc info	Length=(13*n)	Element ID

Figure 29—DEV association information element format

The DEV Association Info fields shall be formatted as illustrated in Figure 30.

octets: 3	**1**	**1**	**6**
DEV Characteristics	DEV status	DEVID	DEV Address

Figure 30—DEV association info fields

The DEV address field contains the address of the DEV, 7.1, that corresponds to the DEVID.
The DEVID is the identifier assigned by the PNC to a DEV.
The DEV characteristics field shall be formatted as illustrated in Figure 31

.

bits: b15-b9	b8-b1	b0
Reserved	Supported Data Rates	Assoc Status

Figure 31—DEV characteristics field format

The association status field shall be encoded as:

— 0 -> Disassociated

— 1 -> Associated

The supported data rates field is a PHY dependent mapping of the optional data rates to a 8 bit field that indicates which of the optional data rates are supported by a DEV. For the UWB PHY, this mapping is defined in Table XYZ. If the association status field indicates a DEV is disassociated, the supported data rates field shall be set to 0 upon transmission and shall be ignored on reception.

7.4.11 Capability

The Capability IE shall be formatted as illustrated in Figure 38.

octets: 7	1	1
Overall capabilities	Length (=7)	Element ID

Figure 38—Capability information element format

The Overall Capabilities field shall be formatted as illustrated in Figure 39..

3	4
DEV capabilities	PNC capabilities

Figure 39—DEV capabilities field format

The PNC Capabilities field shall be formatted as illustrated in Figure 40.

octets: 1	1	1	1
PNC rating	Max TX power	Max CTRRqBs	Max associated DEVs

Figure 40—PNC capabilities field format

The Max Associated DEVs field indicates the number of associated DEVs this DEV is able to manage if it is PNC capable and becomes the PNC. Non PNC capable DEVs shall set this field to zero.

The Max CTRqBs field indicates the number of CTRqBs the DEV is capable of handling as a PNC. This field shall be set to zero in a non-PNC capable DEV.

The Max TX Power Level field indicates the maximum transmit power that is possible for the DEV. The power level is in dBm, encoded in 2s complement notation. For example, if a DEV was capable of 14 dBm TX power, the field would take on the value 0x0E while if the DEV was capable of -4 dBm TX power, the field would take on the value 0xFC.

The PNC Rating field shall be formatted as illustrated in Figure 41. Bits b7-b4 are arranged in order of preference for PNC selection, with the highest preference (PNC capable) corresponding to the msb.

bits: b7	b6	b5	b4	b3-b0
PNC capable	PNC Des-mode	SEC	PSRC	Reserved

Figure 41—PNC rating field format

The PSRC bit shall be set to one if the DEV is receiving power from the alternating current mains and shall be set to zero otherwise.

The SEC bit shall be set to one if the DEV is capable of acting as a key originator, 9.4. Otherwise, the SEC bit shall be set to zero.

The PNC Des-Mode bit is the desired mode of the DEV. This bit shall be set to one if it is desired that the DEV be the PNC of the piconet and the PNC Capable bit is set to one. Otherwise, this bit shall be set to zero.

The PNC Capable bit shall be set to one if the DEV is capable of being a PNC in the piconet. Otherwise, the PNC Capable bit shall be set to zero.

The DEV Capabilities field shall be formatted as illustrated in Figure 42.

bits: b23-b18	b17-b16	b15-b11	b10	b9	b8	b7-b5	b4-b0
Reserved	Bands Supported	Supported TX Data Rates	Listen to Multicast	Listen to Source	Always AWAKE	Preferred Fragment Size	Supported RX Data Rates

Figure 42—DEV capabilities format

The Supported Data Rates field is a PHY dependent mapping that indicates the data rates that the DEV is capable of using. For the 2.4 GHz PHY, the mapping of a field value to a set of data rates is defined in Table 89.

The Preferred Fragment Size field is a PHY dependent mapping that indicates the maximum MAC frame size preferred to be received by the DEV when fragmentation is used. For the 2.4 GHz PHY, the mapping of a field value to a preferred fragment size is defined in Table 90.

The Always AWAKE bit shall be set to one to indicate the DEV is in ACTIVE mode and that it will listen to all CTAs, regardless of the DestID or SrcID. Otherwise the bit shall be set to zero.

The Listen to Source bit shall be set to one to indicate the DEV is in ACTIVE mode and that it will listen to all CTAs where the SrcID is equal to the DEVID of a DEV that is currently the source of a stream to that DEV regardless of the DestID of those CTAs. Otherwise, the bit shall be set to zero.

The Listen to Multicast bit shall be set to one to indicate the DEV is in ACTIVE mode and that it will listen to all multicast CTAs regardless of the SrcID or the Stream Index. Otherwise the bit shall be set to zero.

The values of the bits in the PNC Capabilities field and the DEV Capabilities field shall not change while a DEV is associated in a piconet.

7.5 Command Types

7.5.5.1 Channel time request command

The channel time request (CTR) command may be used to request, modify, or terminate CTAs associated with either isochronous streams or with asynchronous data traffic. The channel time request command structure shall be formatted as illustrated in Figure 77. The DEV that sends this command is the originator and is seeking from the PNC channel time allocations during which to communicate with a target DEV or DEVs.

octets: 13-139	...	13-139	13-139	2	2
CTRB-n	...	CTRB-2	CTRB-1	Length	Command Type

Figure 77-Channel time request command format

Each channel time request block (CTRB) corresponds to a channel time request. If the DEV is making a request for asynchronous channel time where the destinations share CTAs, then there shall be only one asynchronous CTRB in the command and it shall be the last CTRB in the CTR command. The channel time request block for a given CTR shall be formatted as illustrated in Figure 78.

octets: 1	1	2	2	2	1	1	1	1-127	1
Desired number of Tus	Minimu m number of TUs	CTR TU	CTR Interval	CTR Control	Stream index	Stream request ID	PS set index	Target ID list	Num targets

Figure 78-Channel time request block field format

The num targets field indicates the number of target DEVIDs in the target ID list. For isochronous requests, i.e. stream index not equal to the asynchronous stream index, the num targets field shall be set to 1. For asynchronous requests, the num targets fields shall take on values from 1 to 127.

The target ID list is a series of DEVIDs with which the originating DEV seeks to establish communications by requesting channel time allocations from the PNC.

The PS set index field is used to identify the PS set with which the CTR is associated, if the CTR is for an SPS allocation. Only valid SPS set indices, 7.5.7.2, are allowed for an SPS allocation request. Otherwise, the field shall be set to 0 and shall be ignored on reception.

The stream request ID field is used to uniquely identify the DEV's request before it receives a stream index from the PNC. If the channel time request is for a new stream, then the stream request ID is a non-zero identifier generated by the originating DEV that is unique among the DEV's channel time requests. The stream request ID shall remain constant during the entire frame exchange sequence for establishing a new stream. If the channel time request is to modify or terminate an existing stream, the stream request ID shall be set to zero and shall be ignored on reception.

The stream index field is defined in 7.2.5. In the case where the DEV is requesting the creation of a isochronous stream, it is set to the unassigned stream value, 7.2.5, by the originating DEV. In the case where the DEV is requesting the reservation or termination of an asynchronous channel time, it is set to the asynchronous stream value, 7.2.5. When the stream index is other than the unassigned stream index or asynchronous stream index value, this CTR is either a request to modify or terminate an existing CTA. In the case where the DEV is requesting a specific MCTA interval, 8.4.4.4, the stream index shall be set to the MCTA stream value, 7.2.5.

The CTR control field shall be formatted as illustrated in Figure 79.

bits: b15-b8	**b7**	**b6**	**b5**	**b4**	**b3**	**b2-b0**
Preamble Type	Target ID list type	CTR interval type	CTA type	CTR type	Stream termination	Priority

Figure 79-CTR control format

The priority field is defined in Table A.1.

The stream termination field shall be set to 1 if this is a request to terminate an existing stream and shall be set to 0 otherwise.

The CTR type field indicates the type of request. It shall be set to 0 for an ACTIVE channel time allocation and shall be set to 1 for an SPS channel time allocation.

The CTA type field shall be set to 1 if the channel time request is for a pseudo static CTA and shall be set to 0 otherwise.

The CTR interval type field shall be set to 0 when the CTR interval field represents the number of super-rate CTAs, and shall be set to 1 when the CTR interval field represents the number of sub-rate CTAs. A superrate allocation includes the case where the CTR interval type is equal to 1, i.e. only one allocation requested every beacon. A sub-rate CTA is one where the allocation occurs once every N superframes while a superrate CTA is one where the allocation occurs N times in every superframe, including the case where it occurs once per superframe.

If the CTR interval type field is set to 1, the value contained in the CTR interval field shall be a power of 2. A PNC shall support at least 8 slots per stream in the same superframe.

Regardless of the value present in the CTR interval type field, the CTR interval field shall not be set to zero.

If the CTRB is for an MCTA interval, only the CTR interval field and stream index shall be interpreted by the PNC. All other fields except the stream index and num targets fields shall be set to 0.

The target ID list type field shall be set to 0 in an asynchronous request if the originating DEV is requesting to replace all previous asynchronous requests or if there is more than one TrgtID in the CTRB. Otherwise, it shall be set to 1.

The Preamble Type field indicates which length preamble (short, medium, or long) will be used in the CTA assignment. The Preamble Type field is defined in clause 11.6.

The CTR time unit (TU) field indicates the unit of time that the DEV is using for its request. This allows the PNC to know the units of CTA time the DEV is able to make use of so that the PNC will efficiently allocate CTA time. It also enables the PNC to fragment a CTA if necessary. The resolution of this field is 1 μs and therefore has a range of [0-65535] μs.

For an isochronous request, the minimum number of TUs field indicates the minimum number of CTR TUs required by the originating DEV to support the stream.

For an isochronous request, the desired number of TUs field indicates the number of CTR TUs per CTA that is desired by the requesting DEV. The desired number of TUs shall be greater than or equal to the minimum number of TUs.

For an asynchronous request, the concatenation of the minimum number of TUs field and the desired number of TUs field indicates the total number of TUs that are requested for this allocation, i.e. it is interpreted as a single, 2-octet field. Note that this is a request for a total amount of time rather than a recurring use of time in the superframe. The use of this field is defined in 8.5.2.

7.5.11

Table 2—Additional to Clause 7.5, Table 65

Command type hex value	Command name	Sub-clause
0x0024	Ranging Command	7.5.11

7.5.11 Ranging

The ranging command is used to initiate a ranging token exchange between two devices. The issuance of a ranging command shall result in the following activity between DEV A and DEV B:

1. DEV A sends a ranging token to DEV B
2. DEV B holds onto the token for a time t and then sends the token back to DEV A
3. Next DEV A sends a second ranging token to DEV B
4. DEV B holds onto the token for a time 2t and then sends the token back to DEV A
5. DEV A calculates the ranging information as discussed above

The source device calculates the ranging information. If the destination device wants range information it will have to send a ranging command in the reverse direction. The command structure is shown below.

Table 3—Ranging Command

Octest 2	**2**	**2**	**2**	**1**	**1**
Command Type	Length	Source PNID	Destination PNID	Timeout uS	ReasonCode

The Timeout field has the resolution of uS and is used to timeout the ranging process.

The reason code field has the following values:

- ExchangeTokens = 0x01
- DoNotExchangeTokens = 0x02
- RangingNotSupported = 0x03
- TimeoutFailure = 0x04

The definition of the reason codes is presented in clause 6.3.20.4.2.

8 MAC Functional Description

8.17 Ranging and Ranging Token Exchange

Figure 1 illustrates the message sequence involved when requesting a range measurement. The ranging command initiates the precise exchange of a ranging token between the source DEV and the destination DEV as shown in the message sequence chart below.

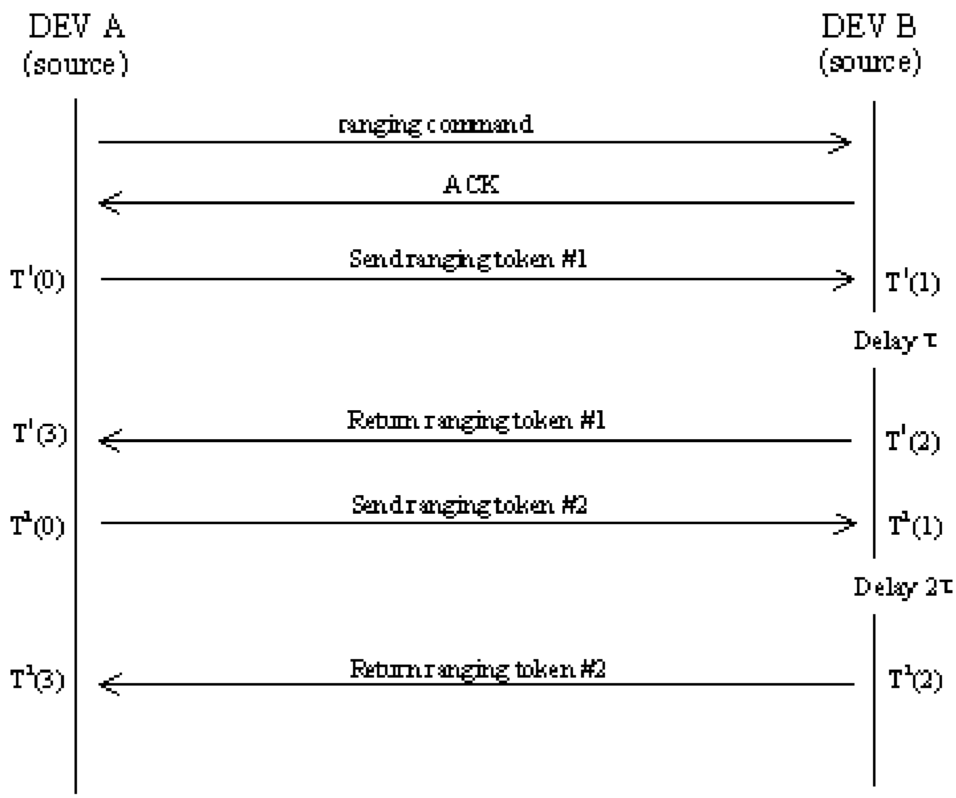


Figure 1 - MSC for ranging token exchange

Device A must receive the second token from device B within the amount of time indicated in the command Timout field. The ranging token itself is PHY dependent and is described in clause 11.X. The time of flight between the two devices is then calculated as

Tflight = {T1(3)- T1(0)} - [{T2(3)- T2(0)}/2]

where the time epochs are defined in Figure 1. The calculated range is then stored as PHY Management object PHYPIB_Range (clause 6.6.9 draft 09).

11.0 PHY Specification for UWB

11.1 Introduction

This clause specifies the PHY for a dual band Ultra Wideband (UWB) modulation format that supports multiple data rates using a constant chip rate and fixed length CDMA codewords. The formats, coding and data rates are given in this clause.

The physical layer coding and modulation are summarized in the block diagram in Figure 1.

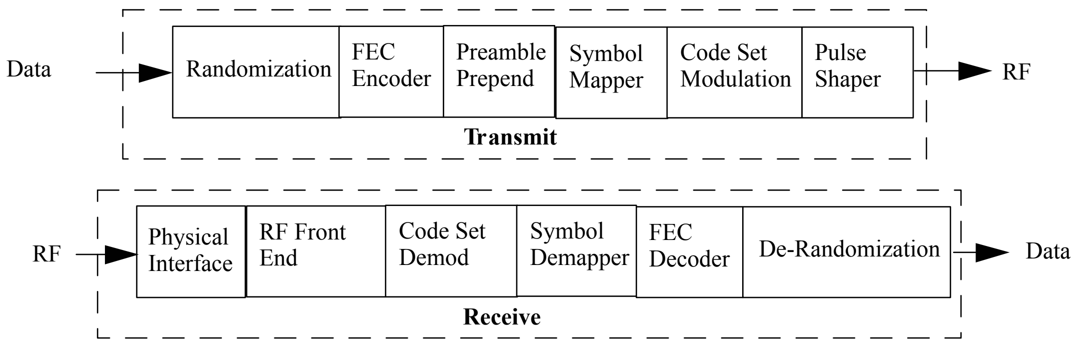


Figure 1 PHY Signal Processing Flow

11.1.1 PHY Overview

The UWB PHY waveform is based upon dual band bi-phase modulation with root raised cosine baseband data pulses. A summary block diagram is shown below

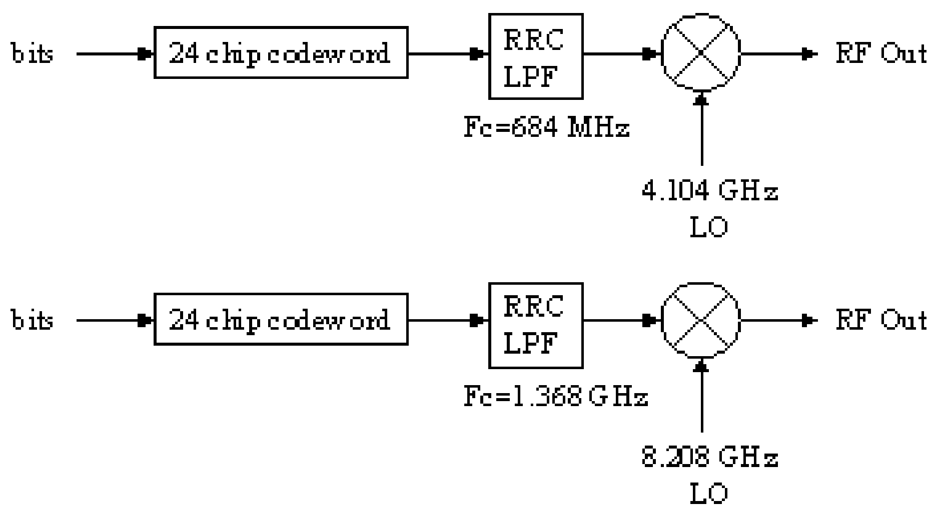


Figure 2 Modulation Block Diagram

There are two bands of operation located on either side of the UNII band. The lower band occupies the spectrum from 3.1 GHz to 5.15 GHz and the upper band occupies the spectrum from 5.85 GHz to 10.6 GHz. Each band has a nominal carrier frequency with four carrier frequency offsets, one for each of four possible co-located piconets. The nominal carrier frequencies are 4.104 GHz and 8.208 GHz. M-BOK code words are used to carry multiple bits per code symbol (up to 4 bits per symbol) with 24 chips per symbol. The symbol rate on the lower band is 57 Ms/s and the symbol rate on the upper band is 114 Ms/s. There are two modulation formats: BPSK and QPSK. For BPSK, there can be up to 4 bits/symbol the maximum bit rate is 228 Mb/s on the lower band and 456 Mbps on the upper band (no FEC). For QPSK, the maximum bit rates respectively become 456 Mb/s and 912 Mb/s.

Three levels of FEC coding are available and selected based upon the application:

1. Moderate Speed, Moderate Latency, Moderate Coding Gain FEC Mode (Convolutional)

2. High Speed, Low Latency, Low Coding Gain FEC Mode (Reed-Solomon)

3. Low Speed, High Latency, High Coding Gain FEC Mode (Concatenated: Convolutional with R-S)

The PHY Header contains information which indicates the symbol rate, the number of bits per symbol and the FEC scheme used. From this information the DEV calculates the resulting bit rate.

The PHY preamble uses one of four available piconet access codes (PACs) for acquisition (paired with the carrier frequency offset). The PNC selects the operating PAC during piconet establishment. There are 3 preamble lengths depending upon the application bit rate:

1. Short preamble: 10 uS in length that requires a high SNR with low channel dispersion - it is most suitable for high bit rate, short range links (<3 meters)

2. Nominal preamble: 15 uS in length that requires a nominal SNR with a nominal channel - it is the default preamble choice

3. Long preamble: 30 uS in length that is used for a poor SNR and/or highly dispersive channel - it is intended for extended range applications.

The preamble is used for clock/carrier acquisition and receiver training.

11.1.2 Clause Organization

This clause is organized to follow the transmit signal path; that is, in the following order:

- *PHY Frame Format*

- *Randomization*

- *FEC Encoder*

- *Code Set Modulation*

- *Preamble and Header Structure*

- *Regulatory*

- *Transmit Pulse Mask and Frequency Stability*

- *UNII Band Protection via Notch Coding*

- *General Requirements*

- *Receiver Specification*

In general, this supplement does not specify the receiver but an informative clause is provided that gives some general receiver performance guidelines.

11.2 PHY Frame Format

11.2.1 Frame Format

The PHY frame format for all data rate modes is illustrated in Figure 90. The UWB PHY prepends the PHY header, 11.4.5, to the MAC header, 7.2, calculates the HCS, 11.2.8, and appends this to the MAC header. If the size of the frame body plus FCS, in bits, is not an integer multiple of the bits/symbol, then stuff bits are added following the FCS, as described in 11.4.6. The PHY preamble, 11.4.2, is sent first in the packet, followed by the PHY and MAC header, followed by the MPDU and finally the tail symbols, 11.4.7.

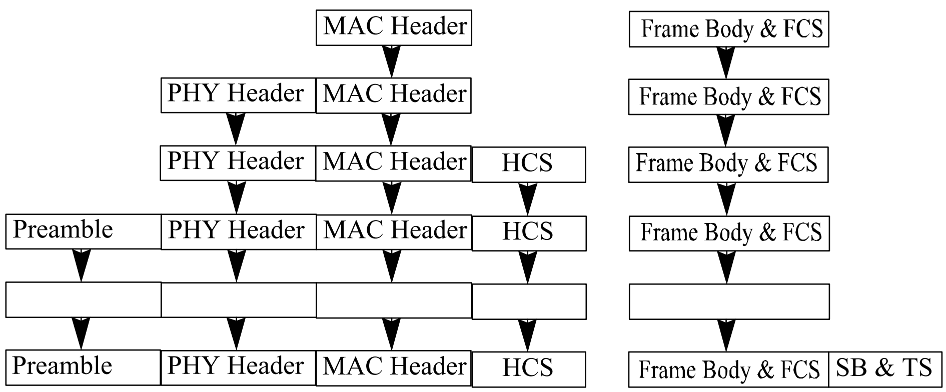


Figure 2—PHY frame formatting

11.3 Randomization

Randomization shall be employed to ensure an adequate number of bit transitions to support clock recovery. The stream of downlink packets shall be randomized by modulo-2 addition of the data with the output of the pseudo-random binary sequence (PRBS) generator, as illustrated in Figure 112.

The randomizer shall be used for the MAC header and frame body. The PHY preamble and PHY header shall not be scrambled. The polynomial, xxx, for the pseudo random binary sequence (PRBS) generator shall be

$$g(D)=1+D^{14}+D^{15} \quad (4)$$

where xxx is a single bit delay element. The polynomial forms not only a maximal length sequence, but also is a primitive polynomial [B8]. By the given generator polynomial, the corresponding PRBS, xxx, is generated as

$Xn = Xn - 14 \oplus Xn - 15$

where xxx denotes modulo-2 addition.

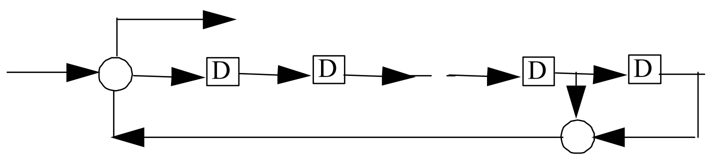


Figure 3 - Realization of the randomizer linear feedback shift registers

The following sequence defines the initialization sequence,

$x_{init}=[x^i_{n-1}\ x^i_{n-2}\ x^i_{n-3}\ x^i_{n-4}\ x^i_{n-5}\ x^i_{n-6}\ x^i_{n-7}\ x^i_{n-8}\ x^i_{n-9}\ x^i_{n-10}\ x^i_{n-11}\ x^i_{n-12}\ x^i_{n-13}\ x^i_{n-14}\ x^i_{n-15}]$ (6)

where x^i_{n-k} represents the binary initial value at the output of the k^{th} delay element.

The scrambled data bits, s_n, are obtained as follows $s_n = b_n \oplus x_n$

(7)

where b_n represents the unscrambled data bits. The side-stream de-scrambler at the receiver shall be initialized with the same initialization vector, x_{init}, used in the transmitter scrambler. The initialization vector is determined from the seed identifier contained in the PHY header of the received packet.

Table 4—Randomizer Seed Selection

Seed Identifier	Seed Value
0,0	0011 1111 1111 111
0,1	0111 1111 1111 111
1,0	1011 1111 1111 111
1,1	1111 1111 1111 111

The 15 bit seed value chosen shall correspond to the seed identifier, 11.4.5, as shown in Table 82. The seed identifier value is set to 00 when the PHY is initialized and is incremented in a 2-bit rollover counter for each packet that is sent by the PHY. The value of the seed identifier that is used for the packet is sent in the PHY header, 11.4.5.

The 15-bit seed value is configured as follows. At the beginning of each PHY frame, the register is cleared, the seed value is loaded, and the first scrambler bit is calculated. The first bit of data of the MAC header is modulo-2 added with the first scrambler bit, followed by the rest of the bits in the MAC header and frame body.

11.4 FEC Coding

The forward error correction (FEC) schemes are selectable from the types in Table 5. A DEV shall use the DEV capabilities field to report all supported FEC rates..

Table 5—FEC Code Types

Code Type	Outer Code	Inner Code
1 - Reed-Solomon	RS(255,223)	None
2 - Convolutional	None	Rate 1/2, 2/3 or 3/4, K=7, (171, 133) Convolutional Code
3 - Concatenated	RS(255,223)	Rate 1/2, 2/3 or 3/4, K=7, (171, 133) Convolutional Code

The following is a summary of the three Code Types:

a)***Code Type 1:*** *Reed-Solomon only:* Reed-Solomon decoders offer implementation advantages that extend practical bit rate limits far beyond what is possible with convolutional decoders (specifically the Viterbi algorithm decoder). Reed-Solomon codes offer high coding rate at high bit rates with moderate latency. The protection offered by the RS(255, 223) code is t =16. The code works on octets and not individual bits.

b)***Code Type 2:*** *Convolutional code:* This code is useful for low to moderate coding rates providing good coding gain with low latency. Implementation issues often limit the practical bit rate to less than 200 Mbps. The basic code is a 1/2 rate code that can be punctured to achieve a code rate of 3/4 at slightly less coding gain. Typically an interleaver can be used prior to the convolutional decoder to randomize burst errors.

b)***Code Type 3:****Reed-Solomon + Convolutional code:* A Reed-Solomon code concatenated with a Convolution code offers excellent coding gain for those applications that can tolerate the low to moderate code rate and longer latency. The bit rate is generally limited by the convolutional decoder. A symbol convolutional interleaver can be applied between the convolutional decoder and the Reed-Solomon decoder to random burst errors caused by the convolutional decoder.

11.4.1 Reed-Solomon RS(255,223) Code

RS(255, 223) codes are a class of block codes that operate on non-binary symbols. The symbols are formed from 8 bits of a binary data stream and a code block is formed with 255 symbols. In each block 223 symbols are formed from the encoder input and *2t* parity symbols are added where t=16 in this case. The code is thus a systematic code, with a code rate of 223/255, and the code is able to correct up to 16 symbol errors in a block. The RS code generation polynomial can be reduced to a *2t* order polynomial as shown below.

$g(x)=x^{2t} + g_{2t-1}x^{2t-1} + ... + g_0$.

The RS field, $GF(2^8)$, is generated by the primitive polynomial specified as below.

$P(x) = 1 + x^2 + x^3 + x^4 + x^8$

For last codeword or the MAC message less than K, shortened operation is performed. Let k' as the message length, and the shortened operation is described as:

A1) Add (K-k') zero bytes to the block as a prefix.

A2) Encode the K bytes and append the R parity bytes.

A3) Discard all of the (K-k') zero symbols.

A4) Serialize the bytes and transmit them to the inner coder or the modulator MSB first.

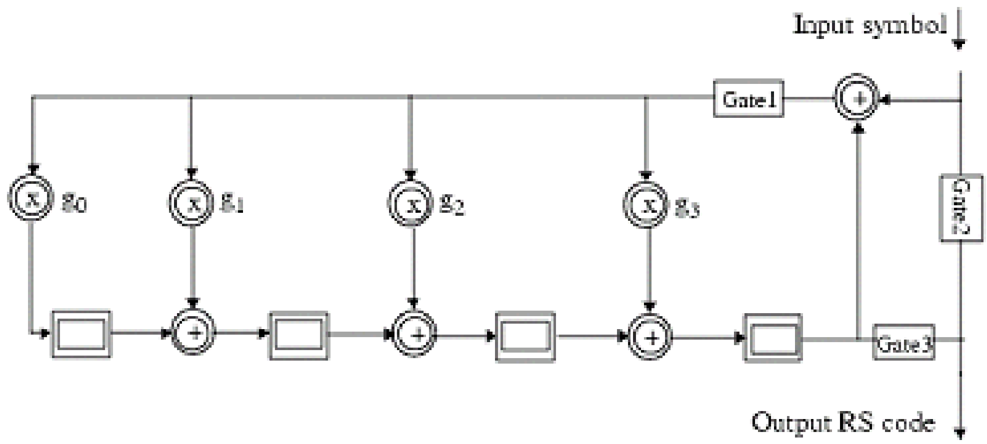


Figure X - Reed-Solomon Encoder

11.4.2 Convolutional Code

The convolutional encoder is used to encode data so that errors introduced due to noise in the channel can be corrected by the decoder. Two important characteristics of a convolutional encoder are its rate and constraint length. If k data bits are shifted in for every n encoded bits shifted out, the rate of the code equals k/n. If the maximum degree of the generator polynomials are m, then the constraint length of the code equals k(m+1). The half-rate convolutional encoder is a linear feed-forward shift register network in which, for every data bit that is shifted in, 2 encoded bits are shifted out. The structure of the encoder is specified by a set of generator polynomials go=171 and g1=133. The error correcting capabilities of a code are determined by these generator polynomials.

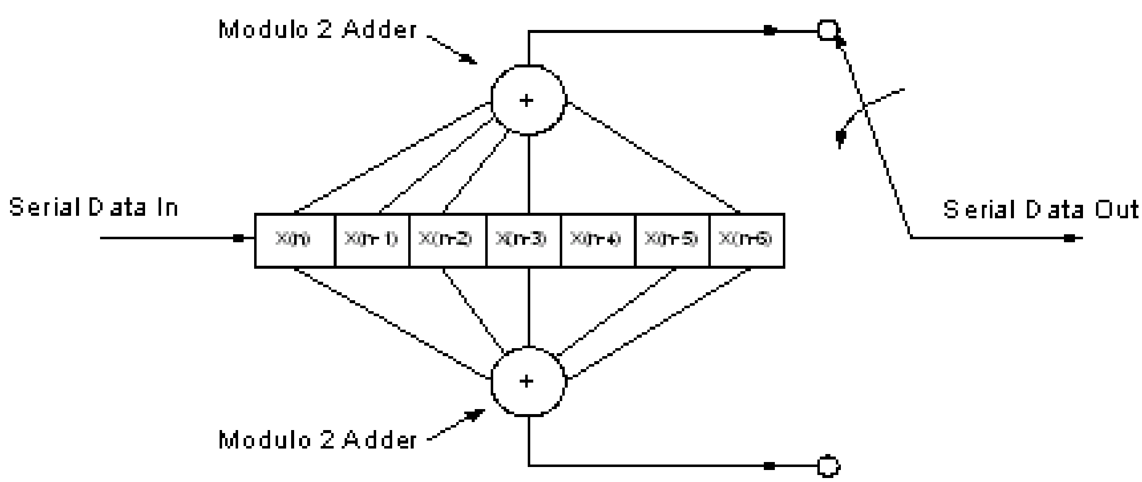


Figure X - Rate 1/2 Encoder

11.4.2.1 Convolutional Chip-wise Interleaver

The convolutional decoder is sensitive to burst errors; hence, interleaving is used to disperse burst errors as shown below.

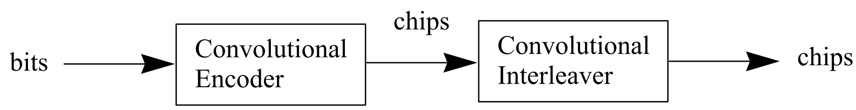


Figure X - Convolutional Encoder with Interleaving

Convolutional interleaving is used over block interleaving because of it has lower latency and memory requirements. The structure for a convolutional interleaver is shown below in Figure X. The encoded chips are sequentially shifted in to the bank of N registers; each successive register provides J chips more storage than did the preceding. The zeroth register provides no storage. With each new code chip the commutator switches to a new register, and the new code chip is shifted in while the oldest code chip in that register is shifted out. After the (N-1)th register, the commutator returns to the zeroth register and starts again. The deinterleaver performs the inverse operation, and the input and output commutators for both interleaving and deinterleaving must be synchronized.

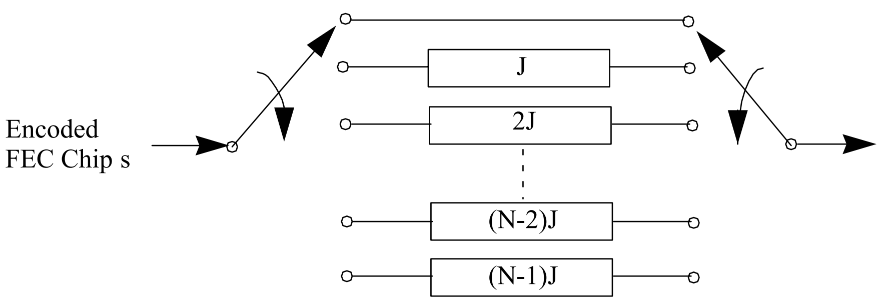


Figure X - Convolutional Chip-wise Interleaver

The chip interleaver shall have the values of J=7 and N=10.

11.4.2.2 Puncturing

Higher data rates are derived from convolutional encoders by employing "puncturing." Puncturing is a procedure for omitting some of the encoded bits in the transmitter (thus reducing the number of transmitted bits and increasing the coding rate) and inserting a dummy "zero" metric into the convolutional decoder on the receive side in place of the omitted bits. This allows a 1/2 rate code to be transformed into a 2/3 rate code or a 3/4 rate code. The puncturing patterns are illustrated in Figure X. Decoding by the Viterbi algorithm is recommended.

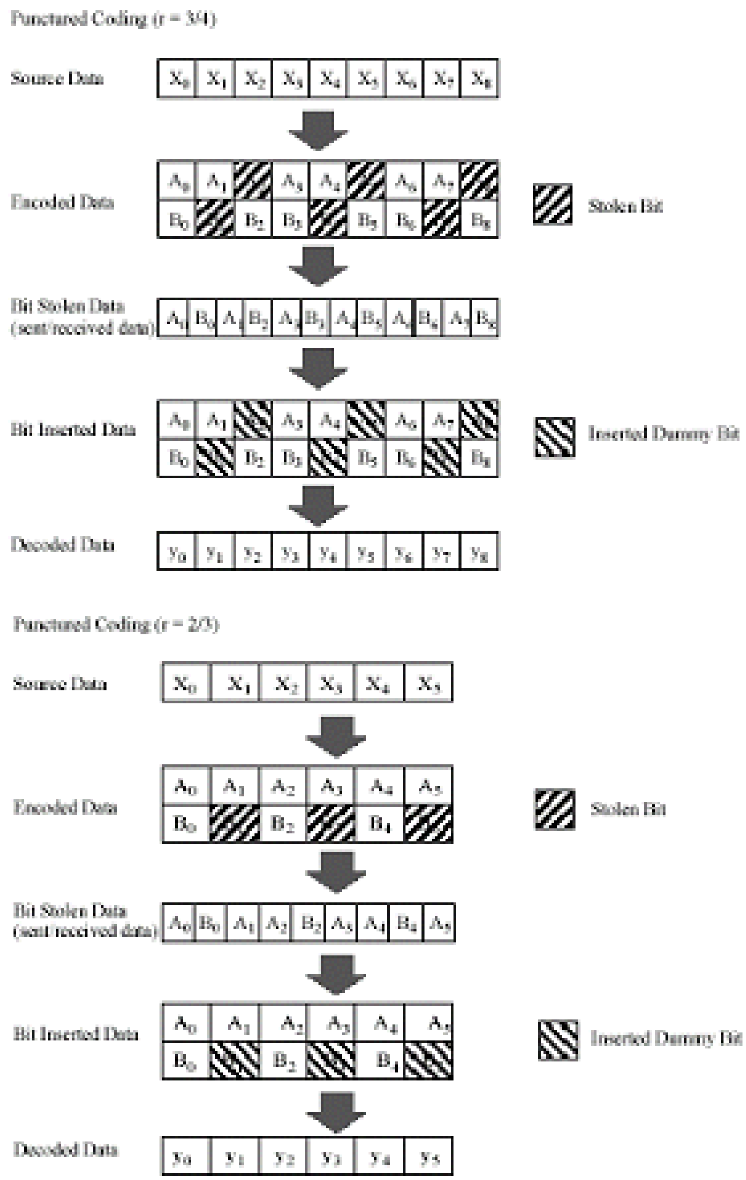


Figure X - Puncturing

11.4.3 Concatenated Code

A concatenated code is one that uses two levels of coding, an inner code and an outer. Figure X shows a concatenated encoding scheme with an interleaver between the outer encode and the inner encoder. The concatenated code shall consist of a Reed-Solomon outer code (ref. 11.4.1) and a convolutional inner code (ref. 11.4.2). A bytewise interleaver shall be used between the outer encoder and the inner encoder.

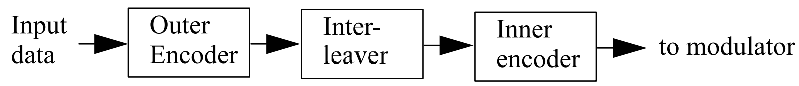


Figure X - Concatenated Coding Scheme

11.4.3.1 Convolutional Symbol Interleaver

Convolutional interleaving is used over block interleaving because it has lower latency and memory requirements. The structure for a convolutional interleaver is shown below in Figure X. The code symbols are sequentially shifted into the bank of N registers; each successive register provides J symbols more storage than did the preceding. The zeroth register provides no storage. With each new code symbol the commutator switches to a new register, and the new code symbol is shifted in while the oldest code symbol in that register is shifted out. After the (N-1)th register, the commutator returns to the zeroth register and starts again. The deinterleaver performs the inverse operation, and the input and output commutators for both interleaving and deinterleaving must be synchronized.

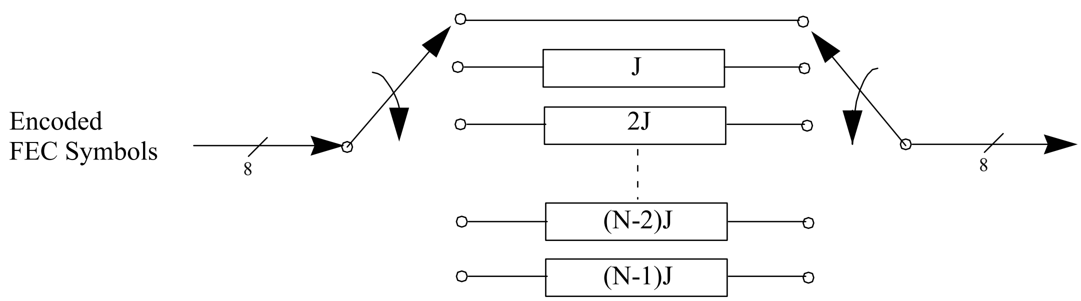


Figure X - Convolutional Symbol-wise Interleaver

The symbol interleaver shall have the values of J=21 and N=15.

11.5 Code Set Modulation

11.5.1 Symbol Rate to Bit Rate Mapping

The symbol rate is mapped to a bit rate by taking into consideration the selected coding. There are 5 combinations of coding schemes that can impact the bit rate plus 2-BOK codeword combining via an overlay code

11.5.2 Base Symbol Rate

The IEEE 802.15.3a UWB physical layer standard specifies bi-phase modulated CDMA coded BPSK wavelet signalling. The base symbol rate for all modulations shall be 114 Msps (Mega Symbols per Second) for the high band and 57 Msps for the low band**.**

11.5.3 Code Sets and Code Set Modulation

This proposal enables higher data rates primarily through the use of bi-orthogonal keying (BOK). This modulation format uses a set of orthogonal codes and their inverses to send multiple bits of information in each symbol interval. This modulation allows higher data rates without the need to increase ADC clock rates and also provides more robust BER performance through lower Eb/No requirements.

11.5.4 M-BOK Codes

There are 4 piconets with up to 8 code words per piconet. The code words are 24 chips long with each chip selected from the set {-1, 0, -1}. The following tables show half of the code space. The other half of the code space is just the inverse. The codes are used for 2-BOK (first row), 4-BOK (first and second rows), 8-BOK (first, second, third and forth rows) and 16-BOK (all rows). The PNC should select the Piconet code word groups with the following priority (in order): Piconet 1 BOK Codes, Piconet 2 BOK Codes, Piconet 3 BOK Codes and then Piconet 4 BOK Codes. The reason is the best codes are found in the Piconet 1 group with slightly decreasing performance for the higher numbered groups.

Table 6—Piconet 1 BOK Codes

symbol bit mapping	codeword
0000	-1 1 -1 -1 1 -1 –1 1 -1 0 -1 0 -1 -1 1 1 1 -1 1 1 1 -1 -1 -1
0001	0 -1 -1 0 1 -1 -1 1 -1 -1 1 1 1 1 -1 -1 1 -1 1 -1 1 1 1 1
0010	-1 -1 -1 -1 1 -1 1 -1 1 -1 -1 1 -1 -1 1 -1 -1 1 1 0 -1 0 1 1
0011	0 -1 1 1 1 -1 -1 -1 -1 -1 -1 -1 1 -1 1 -1 0 1 -1 1 1 -1 -1 1
0100	-1 0 1 -1 -1 -1 1 1 0 1 1 1 1 -1 1 -1 1 1 1 -1 1 -1 -1 1
0101	-1 0 -1 1 -1 1 -1 -1 0 1 1 1 1 -1 1 1 -1 -1 -1 1 1 -1 1 1
0110	-1 -1 -1 -1 -1 -1 1 1 1 0 -1 -1 1 1 -1 1 -1 1 -1 1 1 -1 0 1
0111	-1 1 -1 -1 -1 1 –1 -1 0 -1 1 -1 -1 1 -1 0 1 1 1 1 -1 -1 -1 1

Table 7—Piconet 2 BOK Codes

symbol bit mapping	codeword
0000	-1 -1 1 0 1 1 1 -1 -1 1 -1 1 1 -1 1 0 1 -1 -1 -1 1 -1 -1 -1
0001	-1 -1 -1 1 -1 -1 -1 1 0 1 -1 1 1 -1 1 -1 -1 1 1 1 0 1 -1 -1
0010	-1 1 -1 1 1 -1 1 0 1 1 1 -1 -1 1 1 -1 1 1 1 -1 -1 -1 0 -1
0011	0 -1 1 1 1 1 -1 -1 1 1 1 -1 1 1 -1 1 1 1 -1 1 -1 0 -1 -1
0100	-1 1 -1 1 -1 -1 –1 -1 -1 -1 -1 1 1 1 -1 -1 1 1 -1 0 1 -1 0 1
0101	-1 1 -1 -1 1 0 -1 -1 1 1 -1 -1 0 1 1 1 -1 -1 -1 -1 -1 1 -1 1
0110	-1 0 1 -1 -1 -1 1 -1 1 -1 1 1 1 1 -1 -1 -1 -1 1 -1 0 1 -1 -1
0111	-1 -1 -1 -1 -1 -1 1 1 1 0 -1 1 -1 1 -1 1 1 -1 -1 1 -1 0 1 -1

Table 8—Piconet 3 BOK Codes

symbol bit mapping	codeword
0000	-1 1 -1 1 -1 -1 0 1 -1 -1 -1 1 -1 -1 1 0 -1 -1 -1 -1 1 1 1 1
0001	-1 -1 1 1 -1 -1 –1 -1 -1 -1 1 1 0 1 -1 1 1 -1 1 -1 0 -1 1 -1
0010	-1 -1 -1 1 1 1 -1 -1 -1 1 -1 -1 -1 1 -1 -1 1 -1 1 0 1 1 0 1
0011	-1 -1 1 -1 -1 1 1 1 -1 -1 1 -1 -1 -1 -1 0 1 1 -1 1 -1 1 0 1
0100	-1 -1 -1 1 -1 1 –1 1 0 -1 -1 -1 1 1 1 1 -1 1 1 -1 0 1 -1 -1
0101	-1 -1 -1 0 -1 -1 -1 -1 1 1 1 0 1 -1 -1 1 -1 1 -1 1 1 -1 -1 1
0110	-1 1 -1 1 -1 1 1 0 1 1 1 0 -1 1 1 -1 1 1 -1 -1 -1 -1 1 1
0111	-1 1 0 -1 1 -1 1 -1 -1 -1 1 -1 -1 0 1 -1 -1 1 1 1 1 -1 -1 -1

Table 9—Piconet 4 BOK Codes

symbol bit mapping	codeword
0000	-1 -1 1 1 1 -1 -1 -1 -1 -1 -1 0 -1 1 -1 1 -1 1 1 -1 1 1 -1 0
0001	-1 -1 -1 1 -1 1 1 1 1 -1 1 1 -1 1 1 -1 -1 1 1 1 0 0 -1 1
0010	-1 1 -1 1 1 1 1 0 -1 -1 -1 -1 1 -1 0 -1 -1 1 1 -1 -1 1 1 -1
0011	0 -1 -1 -1 -1 -1 -1 1 1 0 -1 1 1 -1 1 -1 -1 1 1 -1 1 -1 1 -1
0100	-1 -1 1 1 -1 -1 1 0 -1 1 1 1 1 -1 1 -1 1 -1 0 -1 1 1 1 1
0101	-1 -1 1 -1 -1 1 –1 -1 0 -1 1 -1 1 1 -1 -1 -1 1 -1 0 -1 1 1 1
0110	-1 1 0 1 -1 -1 -1 1 1 -1 0 -1 1 -1 -1 1 -1 -1 1 1 1 1 1 1
0111	-1 -1 -1 -1 1 -1 1 0 -1 1 -1 1 1 1 0 1 -1 -1 1 1 -1 -1 1 1

11.5.5 Preamble and Header Modulation Rate

The PHY header and MAC header shall be modulated at the base rate using one of the 2-BOK PNC selected formats as shown in table 10 with no FEC.

11.6 PHY Preamble and Header

There are 3 preamble options that are structurally the same except for field durations:

1. A nominal preamble used for nominal data rates and channels

2. A long preamble used for low data rates and difficult channels

3. A short preamble used for high data rates and benign channels

Table 13 is used to designate the Preamble Type.

Table 10—Preamble Type Descriptor

Preamble Type	b1-b0
Short	00
Medium	01
Long	10

When the Preamble Type Descriptor is used as part of an octet, the 6 upper bits are set to zero.

11.6.1 The General Preamble

Structure

Acq Seq 8 uS	TBD TBD uS	Training 4 uS	SFD 1 uS	PHY Header	MAC Header	data

Figure X - Preamble Structure

This clause presents the preamble structure, which is summarized below.

1. The TX MAC selects one of 4 piconet acquisition codes (PAC) and sets the corresponding carrier offset frequency.

2. The TX modulates the PAC code (one bit per PAC symbol) with random data to generate the acquisition sequence which is used by the receiver for initial acquisition (AGC and clock frequency lock)

3. Next is sent the training frame. The receiver uses this training frame to adjust the receiver.

4. The TX next sends the SFD (start frame delimiter) that indicates to the RX the next frame will be the PHY header, which contains rate information.

5. After the PHY header comes the MAC header.

6. Following the MAC header the TX starts sending data frames.

11.6.1.1 The Piconet Acquisition Codeword (PAC)

There are four PAC codewords with are given by the first row of tables 6 through 12, and the correpsonding frequency offsets are given in table 14. Each piconet uniquely uses one of these codes. The selection of the code is determined by the PNC during the initial scan prior to initiating the piconet (the PNC selects a PAC codeword that is not in use). Use of the PAC codewords provides a degree of "channel separation" between overlapping piconets during preamble acquisition, limited only by the rms cross-correlation properties of the PAC codeword set. The PAC codewords increases the probability that a DEV will train on the preamble associated with the "desired" piconet Each PNC number has an associated chipping rate offset frequency and carrier frequency offset. The relationship between the chipping rate offset and the carrier frequency offset is three. The use of these offsets helps to decorrelate the acquisition codes (and also the M-BOK codes) in addition to facilitating piconet identification during CCA..

Table 11—Piconet number to carrier offset mapping

PNC Number	Chipping Offset (MHz)	Carrier Offset (MHz)
1	-3	-9
2	-1	-3
3	+1	+3
4	+3	+9

11.6.1.2 The Acquisition Sequence

The preamble starts with the acquisition sequence, which is used primarily by the receiver to set gains and achieve clock synchronization. The acquisition sequence is random bits, one bit per codeword.

11.6.1.3 The Training Frame

The length of the training frame varies depending upon the preamble length. Table XYZ indicates the bits that shall be sent during the preamble. The high band bit time duration is 1/114e6 and the low band bit time duration is 1/57e6.

Table 12—Training Frame Bit Sequence

Preamble Type	High Band Preamble Sequence (base 32)	Low Band Preamble Sequence (base 32)
Short	TBD	TBD
Medium	JNJNB5ANB6APAPCPANASASCNJN ASK9B5K6B5K5D5D5B9ANASJPJNK 5MNCPATB5CSJPMTK9MSJTCTASD 9ASCTATASCSANCSASJSJSB5ANB6 JPAPD6B5ATASCPMNCSN5D5K6K5 B9CND5JTJPBAMNK6KAMTCNJTB5 N9N6N9JNMNMTJSANMSD5K9K6K9 JNMNMPJSANCSN5JSK6JTJPMPJNJS ASCNN5DAASB9K5MSD5B7291AT2 W67PGC9Q1FNKPHH9R64FGJZRK9T YMS2KEWFCMRY31Q8NQZ8J5YNY TTS00Y87NKWHKV8J4YNPJRS2GE WQMJRSJGARPMKGHRRA84GKT1Z 3J50	JNJNB5ANB6APAPCPANASASCNJN ASK9B5K6B5K5D5D5B9ANASJPJNK 5MNCPATB5CSJPMTK9MSJTCTASD 9ASCTATASCSANCSASJSJSB5ANB6 JPN5DAASB9K5MSCNDE6AT3469R KWAVXM9JFEZ8CDS0D6BAV8CCS0 5E9ASRWR914A1BR
Long	TBD	TBD

The notation for Base32 is: 0123456789ABCDEFGHJKMNPQRSTVWXYZ

11.6.1.4 The Start Frame Delimiter (SFD)

The SFD consists of the 16-bit binary pattern 0000 1100 1011 1101 (transmitted leftmost bit first) as modulation on the selected 2-BOK code. The first bit of the SFD follows the last bit of the sync pattern. The SFD defines the frame timing in anticipation of the PHY header.

11.6.2 PHY Header

The PHY header consists of three octets that contain the number of octets in the frame body (including the FCS), the data rate of the frame body and seed identifier for the data scrambler. The fields for the PHY service field are shown in Table 13. Bit b0 is sent over the air first and the other bits follow sequentially.

Table 13—PHY service field

bits	Content	Description
b0-b1	Seed Identifier	2 bit field that selects the seed for the data scrambler, defined in Table 82
b2-b4	FEC Type	3 bit field that selects the FEC type 000 = no FEC 001 = 1/2 rate Convolutional 010 = 2/3 rate Convolutional 011 = 3/4 rate Convolutional 100 = Reed-Solomon(223, 255) 101 = Concatenated R-S, 1/2 rate 110 = Concatenated R-S, 2/3 rate 111 = Concatenated R-S, 3/4 rate
b5-b6	M-BOK	2 bit field that selects the M-BOK type 00 = 2-BOK 01 = 4-BOK 10 = 8-BOK 11 = 16-BOK
b7	PSK	1 bit field that selects the PSK type 0 = BPSK 1 = QPSK
b8-b9	Interleaver Type	2 bit field that selects the interleaver type 00 = no interleaver 01 = bit interleaver 10 = byte interleaver
b10-b23	Frame Body Length	A 14 bit field that contains the length of the frame body, in octets, MSB is b5, LSB is b15, e.g. 4 octets of data, is encoded as 0b00000000100. A zero length frame body is encoded as 0b000000000000 and there is no FCS for this packet.

11.6.3 MAC Header

The MAC header is unchanged from the 802.15.3 draft standard.

11.6.4 Header Check Sequence

The header check sequence is calculated on the combined PHY and MAC Headers. The header check sequence is appended after the MAC header and contains the 16 bit CRC for the combined PHY and MAC headers. The polynomial used is:

$$x^{16} + x^{12} + x^{5} + 1$$

This CRC is the same one used in IEEE Std 802.11b-1999. An example implementation and a calculation example are available in 18.2.3.6 of [B15].

11.6.5 Preamble Length Considerations

11.6.5.1 Preamble Field Lengths

Table 16 defines the preamble field lengths for each of the preamble duration options.

Table 14—Preamble Field Octets

	Nominal Preamble	**Long Preamble**	**Short Preamble**
Acquisition Sequence	445	1780	445
Sync Burst	12	12	12
Training Sequence	445	1780	220
SFD	2	2	2
PHY Header	2	2	2
MAC Header	TBD	TBD	TBD
HCS	TBD	TBD	TBD

11.6.5.2 Field Data Rates

All fields of the preamble are sent at the base rate as defined in clause XX.

11.7 Baseband Pulse Shaping and Modulation

11.7.1 Baseband Impulse Response

The baseband reference pulse is a root raised cosine low pass filter. For the low frequency band the filter cutoff frequency (-3 dB point) is 684 MHz and for the high frequency band the filter cutoff frequency (-3 dB point) is 1368 MHz. The implemented baseband impulse response must have a peak cross-correlation within 3 dB of the reference pulse. The excess bandwidth is shown in Table 20.

11.7.2 Reference Spectral Mask

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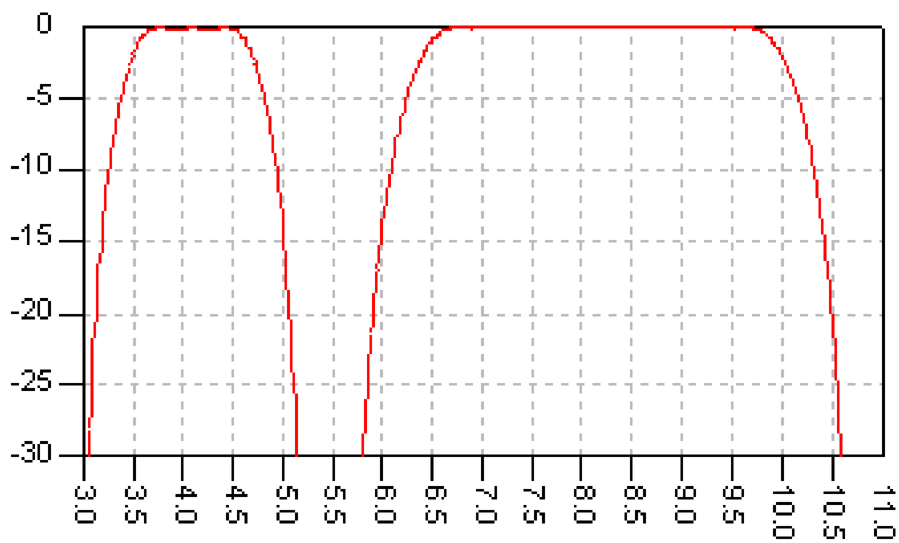
require on



11.8.

Figure X - Super-impose Lower and Upper Band Reference Pulse Spectral Mask

11.7.3 Chip Rate Clock and Chip Carrier Alignment

The chip rate clock and the chip carrier shall be provided from the same source with the frequencies shown below. The accuracy is 25 ppm.

Table 15—Chip Rate Clock and Chip Carrier Frequencies

Chip Rate	1.368 Gcps	2.736 Gcps
Carrier Frequency	4.104 GHz	8.208 GHz
RRC Excess BW	50%	50%

11.8 Regulatory

11.8.1 Regulatory Compliance

This PHY operates in the UWB frequency range as allocated by the regulatory agencies in Europe, Japan, Canada and the United States as well as any other jurisdictions that have allocated this band. The maximum allowable output power spectral density, as measured in accordance with practices specified by the appropri-ate regulatory bodies, is shown in Table 16.

Table 16—Maximum Transmit Power Levels

Geographical Region	Power Limit	Regulatory Document
Japan	TBD	ARIB STD-xxx
Europe (except Spain and France)	TBD	ETS xxx
USA	-41.3 dBm/MHz	47 CFR 15.xxx

.

11.8.2 RF Spectral Line Components

Any RF spectral lines shall be at least 15 dB below the wavelet spectral mask power, measured in 1 MHz bandwidth, and measured at any frequency below 100 GHz. A 100 kHz resolution bandwidth shall be used to perform this measurement. (TBR)

11.9 General Requirements

11.9.1 Channel Assignments

A total of 8 logical channels are assigned for operation, 4 CDMA channels per band with two bands. A compliant 802.15.3 implementation shall support at least one band of operation and optionally both bands of operation. The assigned channels are shown in table 19 along with the associated carrier frequency offsets..

Table 17—UWB PHY Channel Plan

CHNL_ID	Center Frequency	Piconet Code Set	Frequency Offset
1	4.104 GHz	1	-9 MHz
2	4.104 GHz	2	-3 MHz
3	4.104 GHz	3	+3 MHz
4	4.104 GHz	4	+9 MHz
5	8.108 GHz	1	-9 MHz
6	8.108 GHz	2	-3 MHz
7	8.108 GHz	3	+3 MHz
8	8.108 GHz	4	+9 MHz

PHYPIB_CurrentChannel is the CHNL_ID of the current channel. For the purpose of the remote scan commands, 7.5.6.3 and 7.5.6.4, the channel index is the CHNL_ID in Table 19.

11.9.2 RF Power Measurements

Unless otherwise stated, all RF power measurements, either transmit or receive, shall be made at the appro-priate transceiver to antenna connector. The measurements shall be made with equipment that is either matched to the impedance of the antenna connector or is corrected for any mismatch. For devices without an antenna connector, the measurements shall be interpreted as EIRP (i.e. a 0 dBi gain antenna) and any radi-ated measurements shall be corrected to compensate for the antenna gain in the implementation.

11.9.3 Operating Temperature Range

A conformant implementation shall meet all of the specifications in this standard for ambient temperatures from 0 to 40 C.

11.9.4 Interframe Spacing

A conformant implementation shall support the interframe spacing parameters given in Table 13

Table 18—Interframe Spacing Parameters

802.15.3 MAC Parameter	Corresponding PHY parameter	Definition
SIFS	aRXTXTurnaroundTime	11.9.6

11.9.5 Receive-to-Transmit Turnaround Time

The RX-to-TX turnaround time, aRXTXTurnaroundTime, shall be no less than TBD µs and no more than TBD µs. The RX-to-TX turnaround time shall be measured at the air interface from the trailing edge of the last symbol received until the first symbol of the PHY preamble is present at the air interface.

11.9.6 Transmit-to-Receive Turnaround Time

The TX-to-RX turnaround time shall be less than TBD µs. The TX-to-RX turnaround time shall be measured at the air interface from the trailing edge of the last transmitted symbol until the receiver is ready to begin the reception of the next PHY packet.

11.9.7 Channel Switch Time

The channel switch time is defined as the time from when the last valid bit is received at the antenna on one CDMA channel until the DEV is ready to transmit or receive on a new CDMA channel. The channel switch time shall be less than TBD seconds.

11.9.8 Maximum Frame Length

The maximum frame length allowed, pMaxFrameSize, shall be 4096 octets. This total includes the frame body and FCS but not the PHY preamble, PHY header or MAC header.

11.9.9 Transmit Power Control

A compliant transmitter is allocated power on a power density basis. It shall be capable of transmitting no more than -2.5 dBm (TBR) and shall be capable of reducing its power to less than -10 dBm in monotonic steps no smaller than 3 dB and no larger than 5 dB. The steps shall form a monotonically decreasing sequence of transmit power levels. A compliant device shall have its supported power levels indicated in its PHY PIB based on its maximum transmit power and power level step size.

The minimum TX power level required to support TPC, aMinTPCLevel, shall be -10 dBm

11.10 Receiver Specification

11.10.1 Error Rate Criterion

The error rate criterion shall be a packet error ratio (PER) of less than 8% with an frame body length of 1024 octets of pseudo-random data generated with a PN23 sequence as defined in $x_{n+1} = x_n^{23} + x_n^{5} + 1$. Note that the packets used for measuring the error rate criterion include not only the frame body of 1024 octets, but also the PHY preamble, PHY header, MAC header and the FCS.

11.10.2 Receiver Sensitivity

The receiver sensitivity is the minimum power level of the incoming signal, in dBm, present at the input of the receiver for which the error rate criterion in 11.10.1 is met. The error ratio shall be determined after any error correction has been applied. Compliant systems may have a lower actual sensitivity than the reference sensitivity. A compliant device shall achieve at least the reference sensitivity listed in Table 14 for each of the modulation formats that the device supports.

Table 19—Reference Sensitivity Levels for Modulation Formats

Modulation	Reference Senisitivity
TBD	-xx dBm
TBD	-xx dBm
TBD	-xx dBm
TBD	-xx dBm
TBD	-xx dBm

11.10.3 Receiver Maximum Input Level

The receiver maximum input level is the maximum power level of the incoming signal, in dBm, present at the input of the receiver for which the error rate criterion in 11.6.1 is met. A compliant receiver shall have a receiver maximum input level of at least -20 dBm for each of the modulation formats that the device supports.

11.10.4 Receiver Jamming Resistance

The jamming resistance levels are given in Table 18.

Table 20—Receiver Jamming Resistance Requirements

Interfering Frequency	Rejection
850 MHz	TBD
1.9 GHz	TBD
2.4 GHz	TBD
5.5 GHz	TBD
9 GHz	TBD
TBD	TBD
TBD	TBD

The interference rejection shall be measured as follows: the desired signal shall be a conformant 802.15.3a signal of pseudo-random data modulated with one of the modulation code types listed in clause 11.7.2. The desired signal is input to the receiver at a level 5 dB above the reference sensitivity for that modulation as given in Table 17. A conformant 802.15.3a signal is input at the relative level specified in Table 18. The interfering signal is to be a sinusoidal tone. The receiver shall meet the error rate criteria defined in 11.10.1 under these conditions. A compliant implementation shall satisfy the receiver jamming test for all of the modulations types supported by the device. In addition, the test shall be performed for only one interfering signal at a time.

11.10.5 Receiver RSSI

RSSI is defined as the power relative to the maximum receiver input power level, 11.10.3, in 8 steps of 8 dB with +/- 4 dB step size accuracy. The range covered shall be a minimum of 40 dB. The steps shall be mono-tonic. The RSSI power shall be the average power measured during the training sequence of the PHY preamble, 11.5.5. This number shall be reported via the PHY-RXSTART.indication, 6.9.4.15.

11.10.6 Link Quality Indication

The link quality indication (LQI) shall be reported using an SNR estimation. The SNR shall be measured at the decision point in the receiver. The SNR includes the thermal noise, distortion, uncorrected interference and other signal impairments at the decision point in the receiver. The receiver shall report the SNR as a 5 bit number that covers a range of TBD dB to TBD dB of SNR. The value 0x00000 shall correspond to less than or equal to TBD (lower limit) dB SNR and 0x11111 shall correspond to more than or equal to TBD dB (upper limit) SNR with equal steps in between. The LQI SNR shall be measured during the training sequence, which occurs after the PSTS, as shown in clause 11.5.5. This number shall be reported via the PHY-RX-START.indication, 6.9.4.15

11.11 UWB PHY Management

The PHY PIB comprises the managed objects, attributes and notifications required to manage the PHY layer of a DEV.

The PHY dependent PIB values for the UWB PHY are given in Table 21. .

Table 21—UWB PHY PIB Parameter Definitions

PIB Parameter	Value
PHYPIB_RSSI_max	
PHYPIB_LQI_max	
PHYPIB_NumTxPowerLevels	
PHYPIB_PowerLevelVector	
PHYPIB_CCA_Threshold	

There are 3 fields related to supported PHY data rates in the Capability IE, 7.4.11: the Supported RX Data Rates field, the Supported TX Data Rates field, and the Bands Supported field. The RX and TX supported rates fields are described in Table 22..

Table 22—UWB PHY Supported Data Modes

Bits	Content	Description
b0-b1	FEC Type	2 bit field that indicates supported FEC types 00 = no FEC 01 = Convolutional FEC 10 = Reed-Solomon(223, 255) 11 = Concatenated
b2-b3	M-BOK	2 bit field that indicates supported M-BOK types 00 = 2-BOK 01 = 4-BOK 10 = 8-BOK 11 = 16-BOK
b4	PSK	1 bit field that indicates supported PSK types 0 = BPSK 1 = QPSK

The Bands Supported field is described in Table 23.

Table 23—Bands Supported

Supported Bands	b0
Only Current Band	0
Both Bands	1