Project: IEEE P802.15 Study Group for Wireless Personal Area Networks (WPANs)

Submission Title: Alternatives for Lower Frequency Band Extension

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Re: Proposal and Discussion of equal higher data rates for PHY for 900/868 and 2400MHz bands

Abstract: This document provides a discussion of alternatives for the extension of 2.4 GHz derivative modulation yielding higher data rates for the lower frequency band.

Purpose: Increased data rate to reduce total system power and reduce marketing difference with 900/868/2400

Alternatives for Lower Frequency Band Extension

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Presentation Contents

- Challenges for Low Band
- Alternatives
- PSSS Overview
- PSSS Linearity Requirements
- MP Fading and White Noise
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TG4b Challenges

- Provide higher data rate in sub-1-GHz bands
  - Minimum of 200 kbit/s
  - Reduce power consumption
  - Enable sufficient number of transactions/hr. in Europe
  - Receiver sensitivity similar
- Extend practically achieved indoor range and coverage
  - Increasing multipath fading robustness is required
  - Derivative of 2.4 GHz modulation required
- Allow operation in US, EU and other regulatory regimes
- Provide backward compatibility to IEEE802.15.4-2003 (868/915 MHz)
  - Avoid additional hardware to achieve compatibility to maintain low complexity and implementation cost
  - Required due to "Revision" PAR of IEEE802.15 TG4b

1: Canada, Russia, Korea

New Specifications for the Low Bands

- We can expect new frequency bands specifications for the low ISM bands (868, 915 MHz) in Europe and Asia with increasing bandwidth *in the future*
- However, it will take years until the changed SRD band specifications form CEPT are adopted by all countries

- Therefore 3 modes of *derivative modulations yielding higher data rates*[1] are desirable:
  - Higher rate in existing sub-GHz bands
  - Ready for new, upcoming European 862-868 MHz band
  - Higher rate in 915 MHz band

1: Scope as defined in PAR

Alternatives of Lower Band Extension

	„Half Rate proposal“	PSSS I/Q	PSSS BPSK/DSB
Bitrate	125 kbit/s	250 kbit/s 500 kbit/s	225 kbit/s 450 kbit/s
Bandwidth	2 Mhz at 915 Mhz	500 khz at 868 Mhz 1 Mhz at 900 Mhz	500 khz at 868 Mhz 1 Mhz at 915 Mhz
Marketability	US + few countries; Others only with regulatory change	US, Europe, Asia (some) and US *today*	US, Europe, Asia (some) and US *today*
Coding backward compatibility	Identical to existing 2.4GHz	Derivative built of blocks that are similar to 2.4 Ghz	Derivative[1] built of blocks that are similar to 2.4 Ghz
Synchronization Clock recovery	Required for BPSK *and* O-QPSK	Required for BPSK *and* QAM	Same as BPSK
RF backward compatibility	Other modulation, thus 2nd Tx+Rx core, sync, etc.	Other modulation, thus 2nd Tx+Rx core, sync, etc.	Same Rx and Tx; proposed solution is full derivative[1]

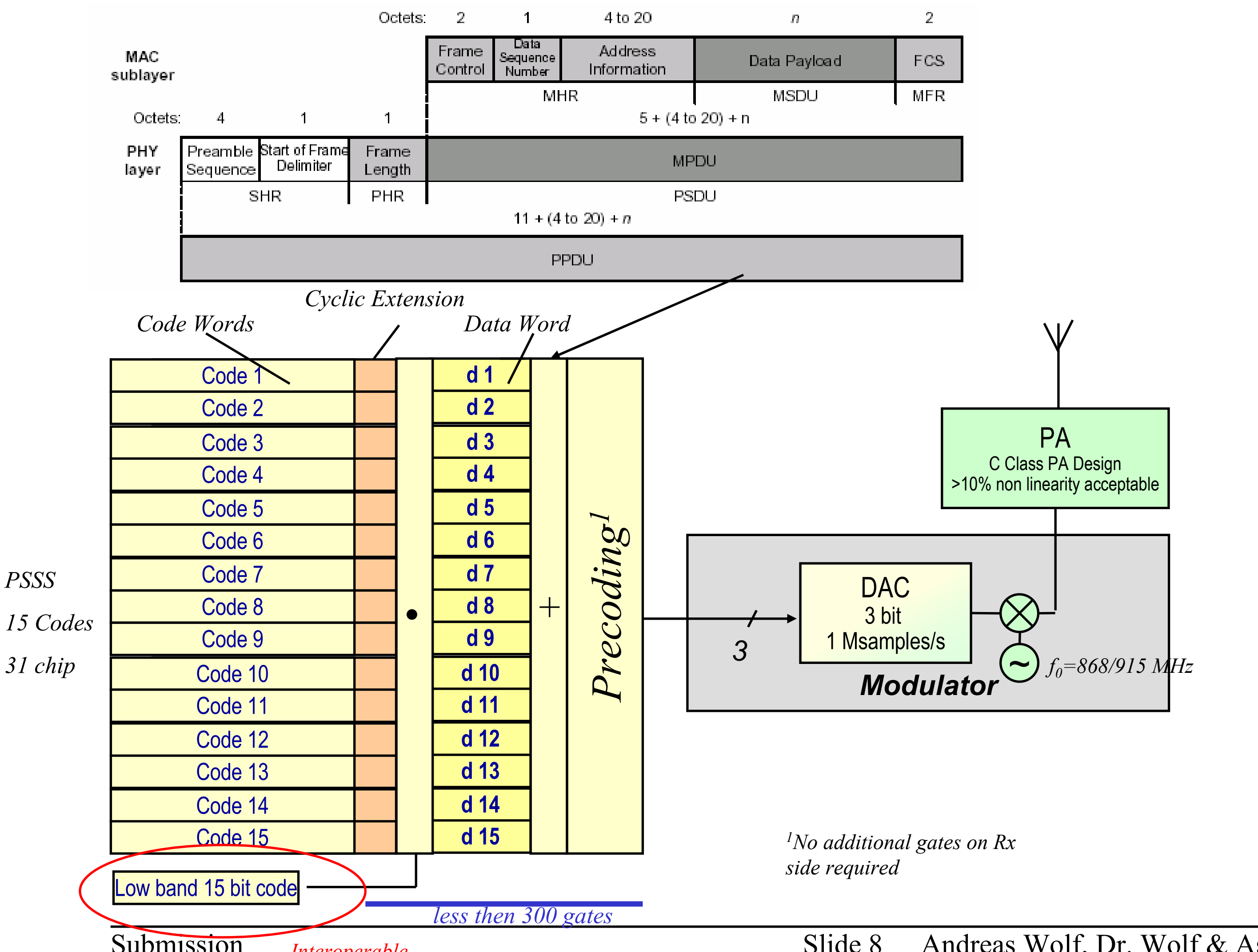
1: Derivative of IEEE802.15.4-2003; PSSS characteristics have been reviewed against PAR by TG4b, see also Anaheim minutes

Link Budget Differences

	BPSK Low Band		**PSSS BPSK/DSB**	
Band	Data Rate	Sensitivity Difference	Data Rate	Sensitivity Difference
868 Mhz	20 kbit/s	0 dB	225 kbit/s	-3 dB
915 Mhz	40 kbit/s	-3 dB	450 kbit/s	-6 dB

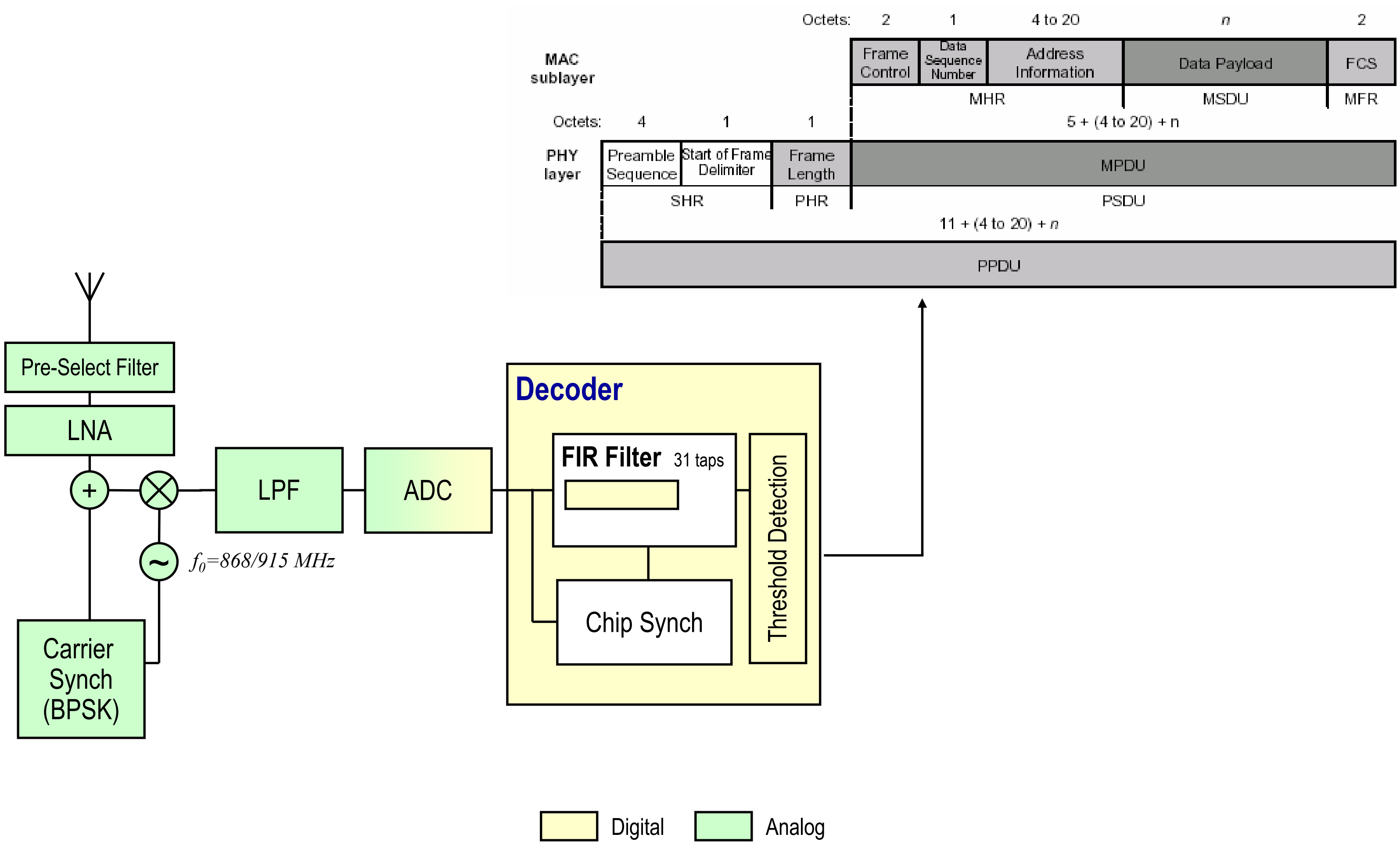
For a practical receiver the sensitivity will be better then -92 dBm

PSSS BPSK/ASK – Tx Architecture



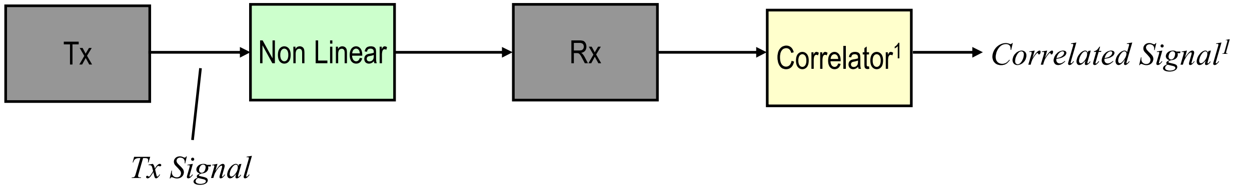
- 3 bit resolution of PSSS symbol approx. 6 amplitude levels)
- 0.45 bit/s/Hz [=15 codes/(31+2) symbol length], each second code and 2 chip cyclic extension]
- 1 Mchip/s (1MHz Bandwidth) for 900 MHz, 450 kbit/s data rate
- Backward compatible and interoperable to existing 15.4 low band phy
- Precoding

PSSS – Receiver Architechture



Simulation Model for Non Linearity

- 900/868 MHz PSSS

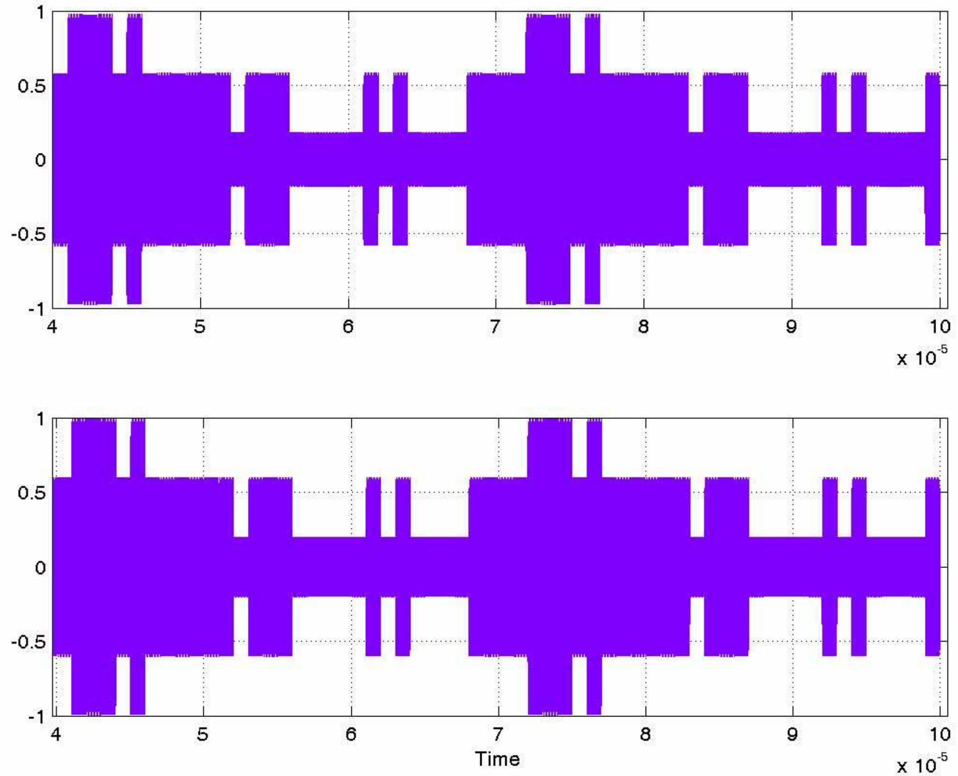


Note:

1: 2 correlators and 2 correlated signals for Half Rate due to 2 different base codes used

Transfer Function for Non Linear System

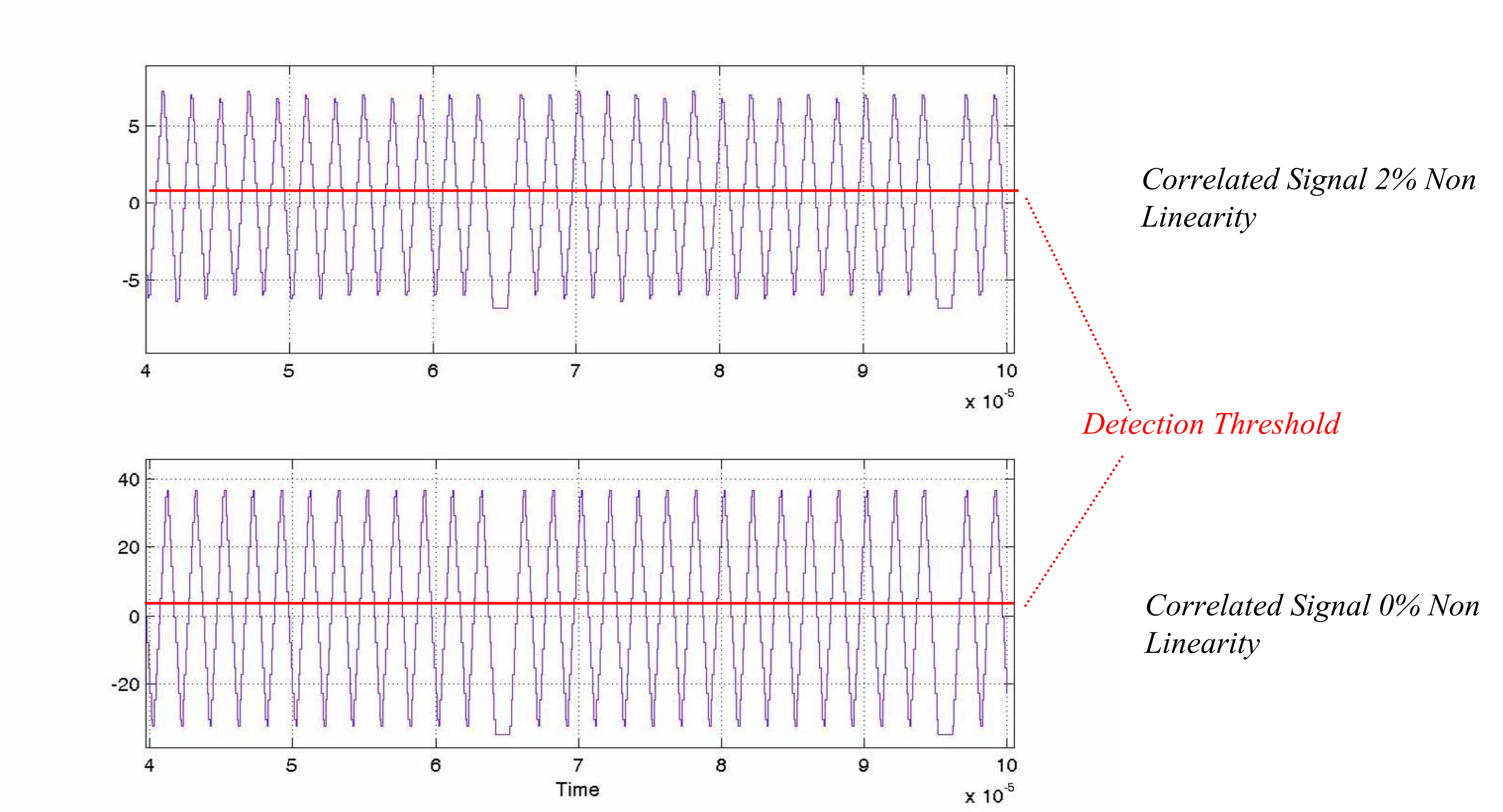
PSSS – Non Linearity 2% - Tx Signal



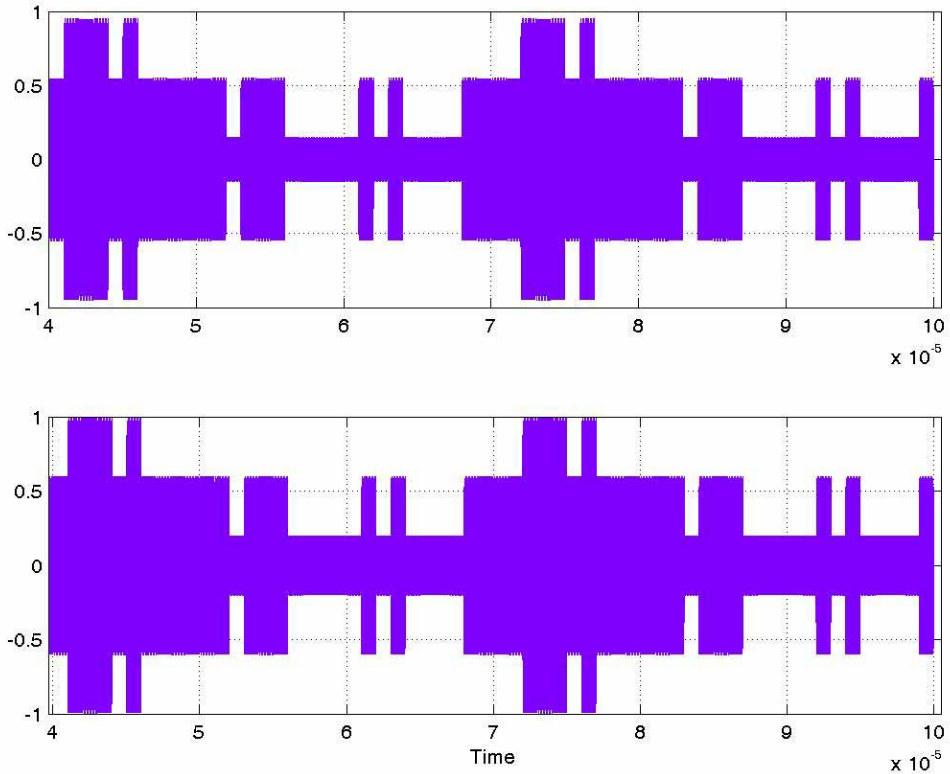
Tx 2% Non Linearity

Tx 0% Non Linearity

PSSS – Non Linearity 2% - Correlated Signal



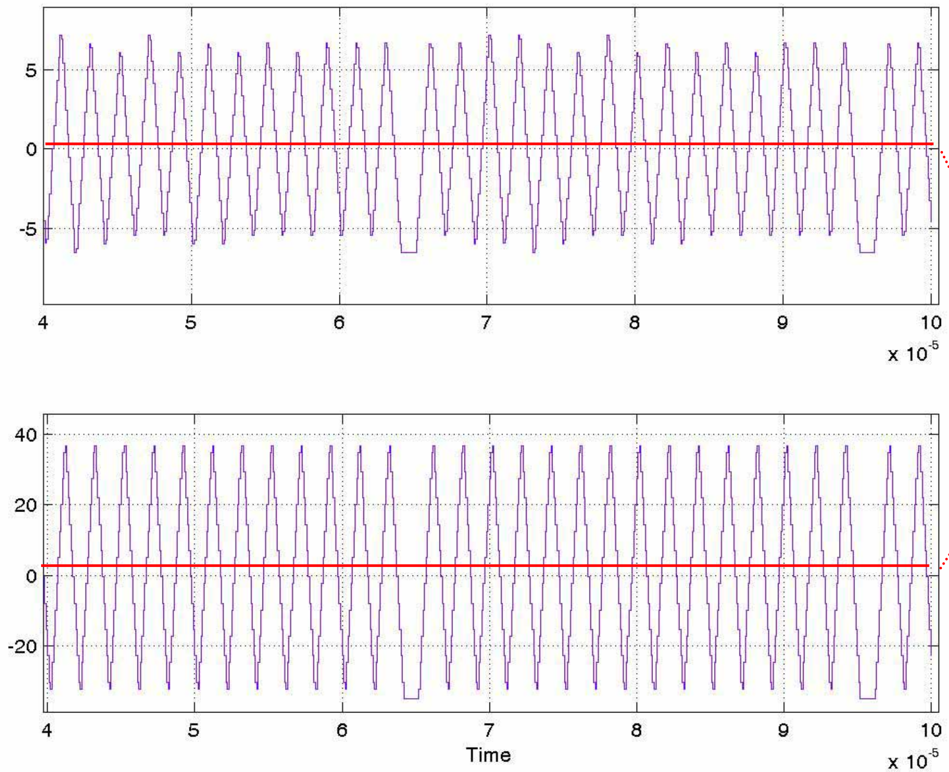
Non Linearity 5% - Tx Signal



Tx 5% Non Linearity

Tx 0% Non Linearity

Non Linearity 5% - Correlated Signal

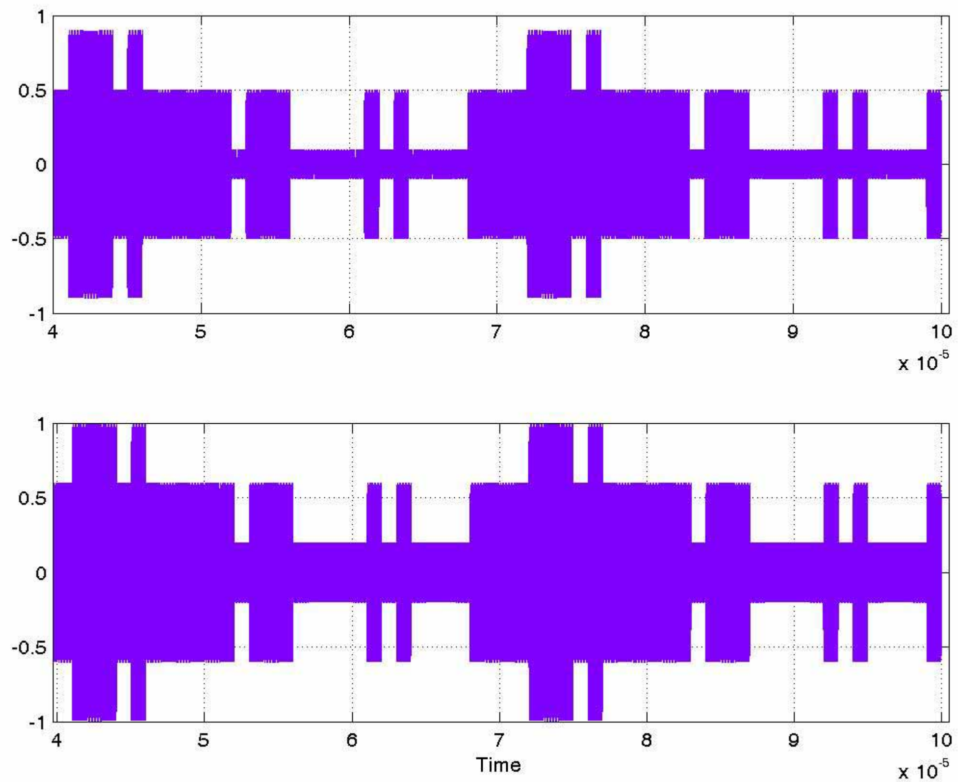


Correlated Signal 5% Non Linearity

Detection Threshold (for ‚0‘ or ‚1‘ data bits)

Correlated Signal 0% Non Linearity

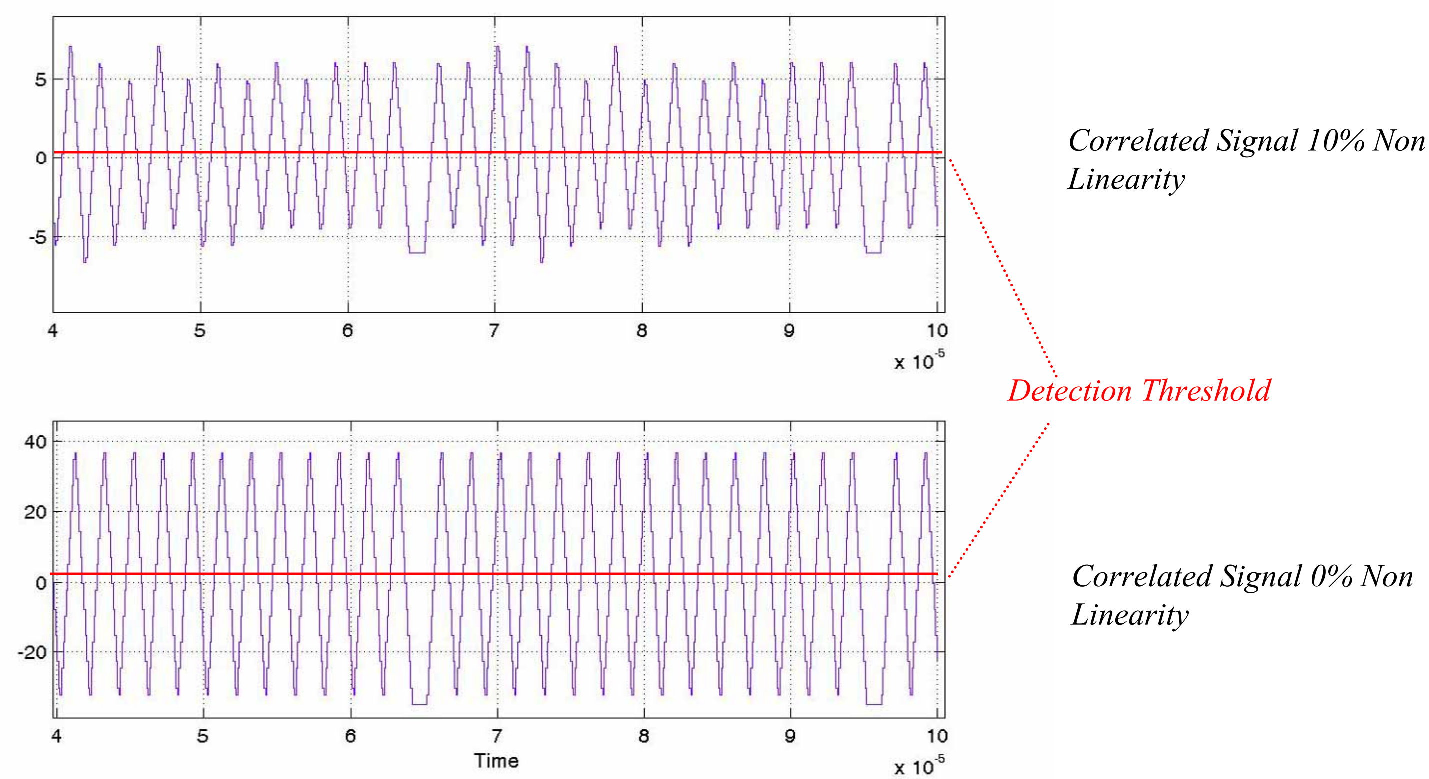
Non Linearity 10% - Tx Signal



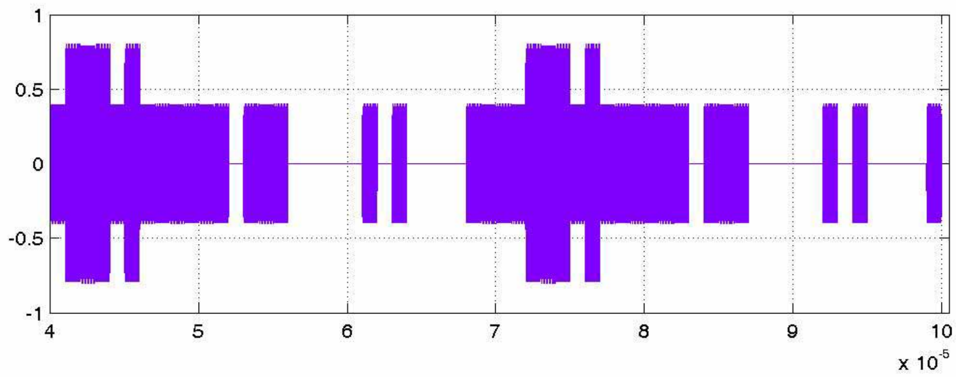
Tx 10% Non Linearity

Tx 0% Non Linearity

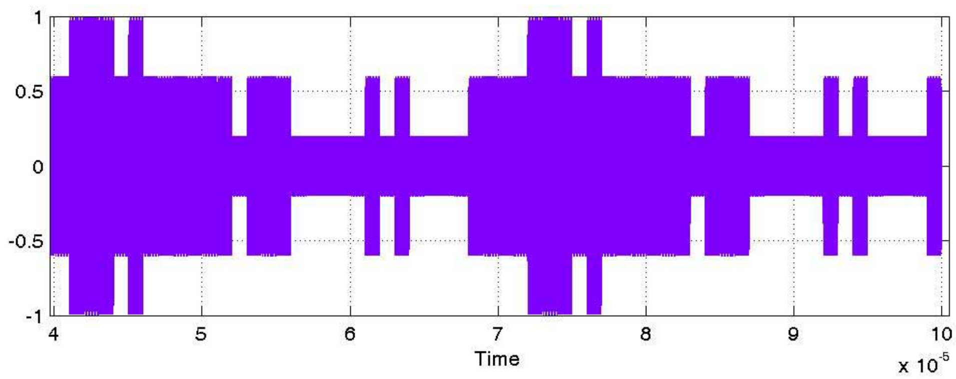
Non Linearity 10% - Correlated Signal



Non Linearity 20% - Tx Signal

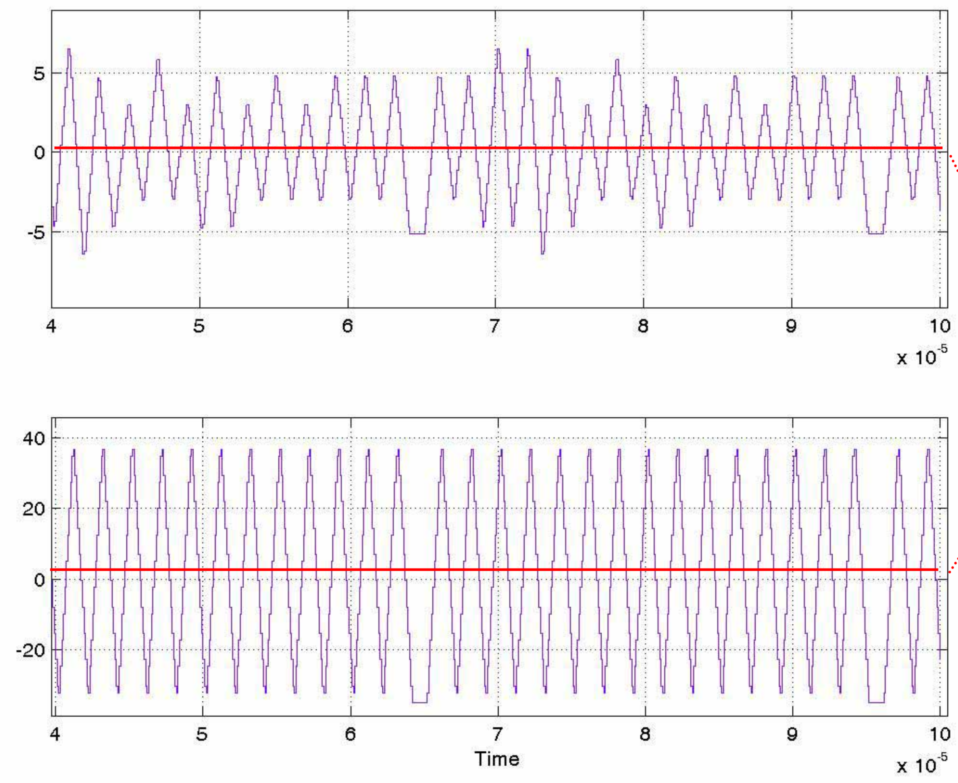


Tx 20% Non Linearity



Tx 0% Non Linearity

Non Linearity 20% - Correlated Signal



Correlated Signal 20% Non Linearity

Detection Threshold

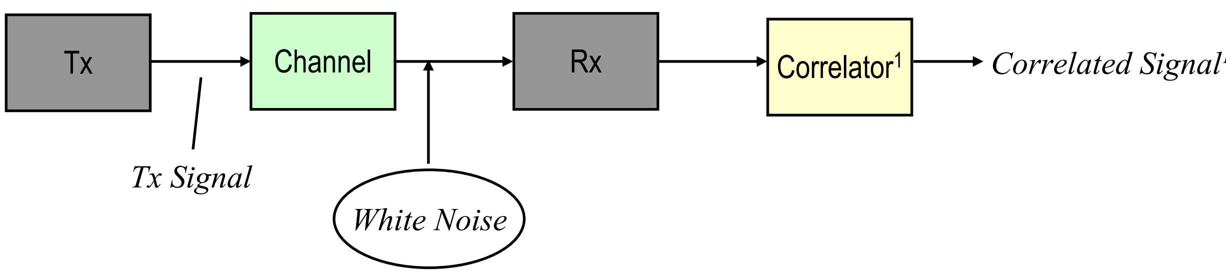
Correlated Signal 0% Non Linearity

Note:
PSSS in the configuration shown would tolerate for example up to 21 one-value chip errors per symbol without loss of data

PSSS – Conclusion on Linearity

- PSSS works even with 20% non linear PA
- PA and LNA designs are available off-the-shelf with
  - No increase in chip cost even for linearity of 2%
  - No additional power consumption compared to C class PA used in IEEE802.15.4-2003 today
- No implementation risk due linearity required for PSSS !

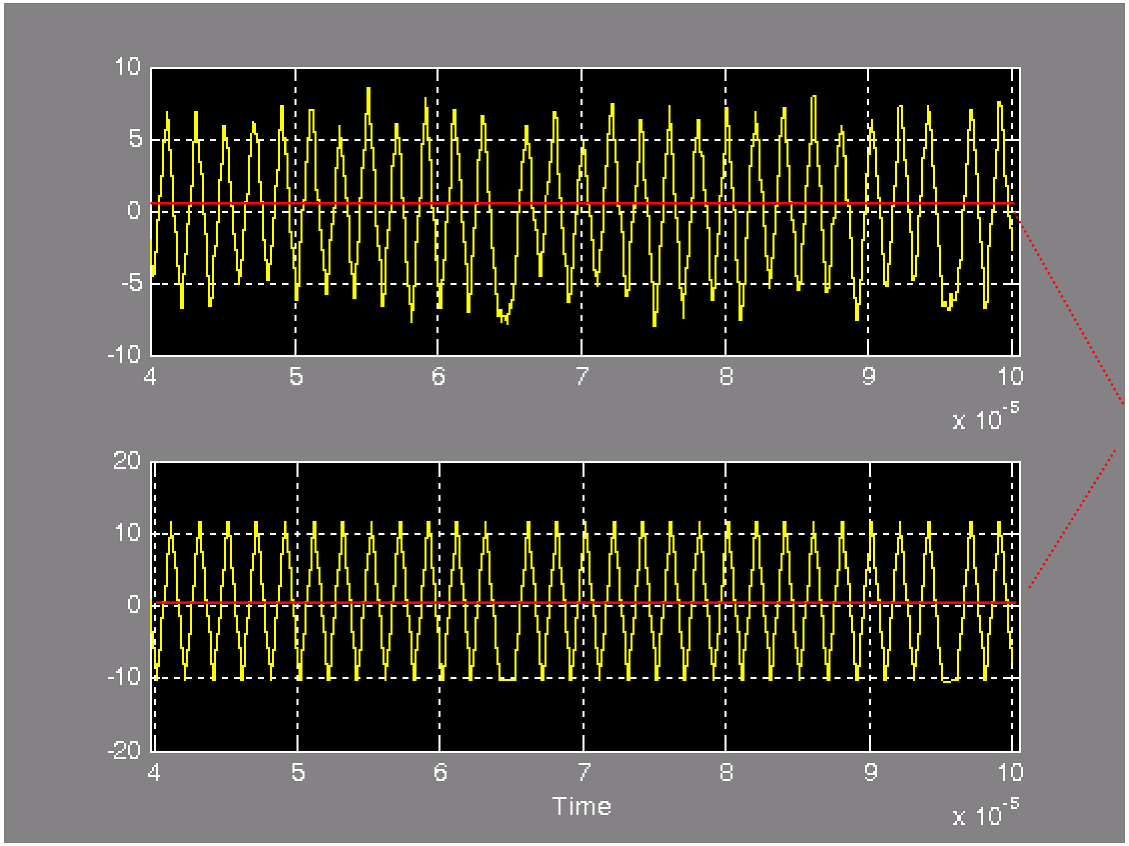
Simulation Model for MP Fading and Noise



Note:

1: 2 correlators and 2 correlated signals for Half Rate due to 2 different base codes used

PSSS at 1 Mchip/s with Multipath Fading Delay Spread 40ns and White Noise

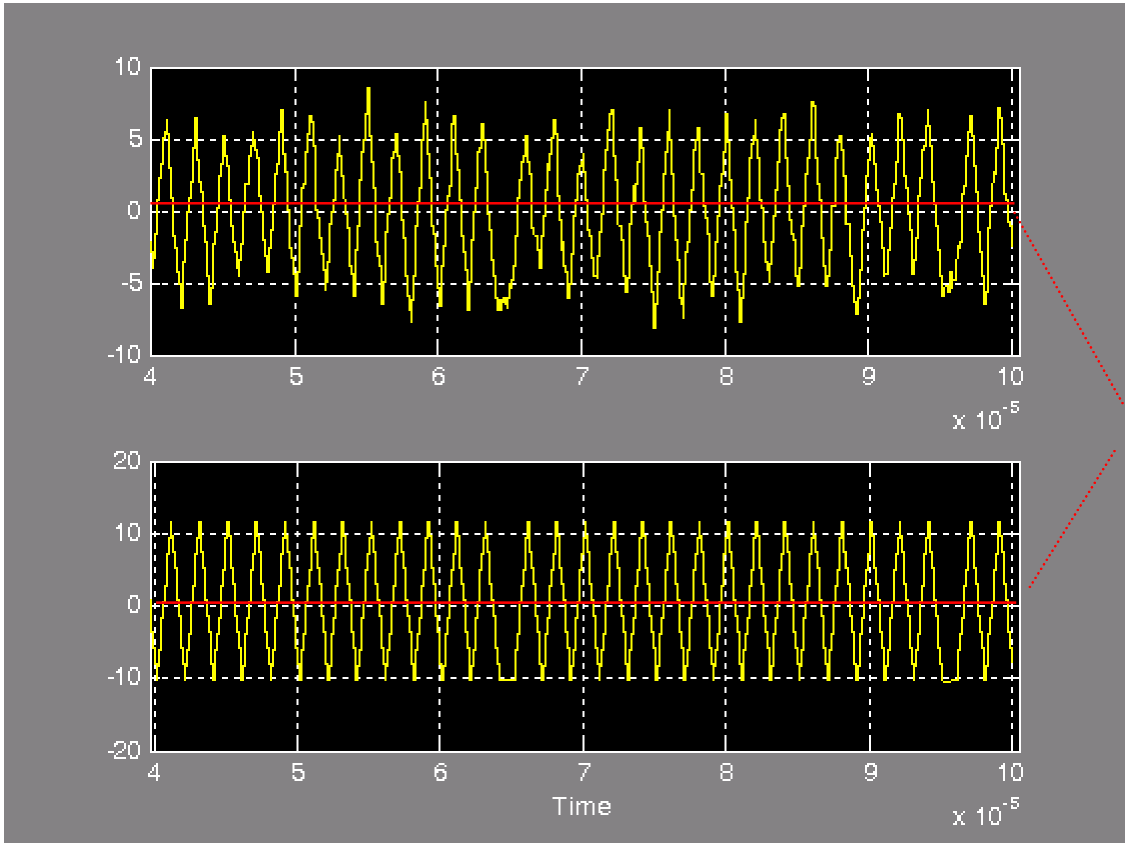


Correlated Signal Noise and Multipath Fading

Detection Threshold

Correlated Signal No noise

Half Rate at 1 Mchip/s with Multipath Fading Delay Spread 400ns and White Noise



Correlated Signal Noise and Multipath Fading

Detection Threshold

Correlated Signal No noise

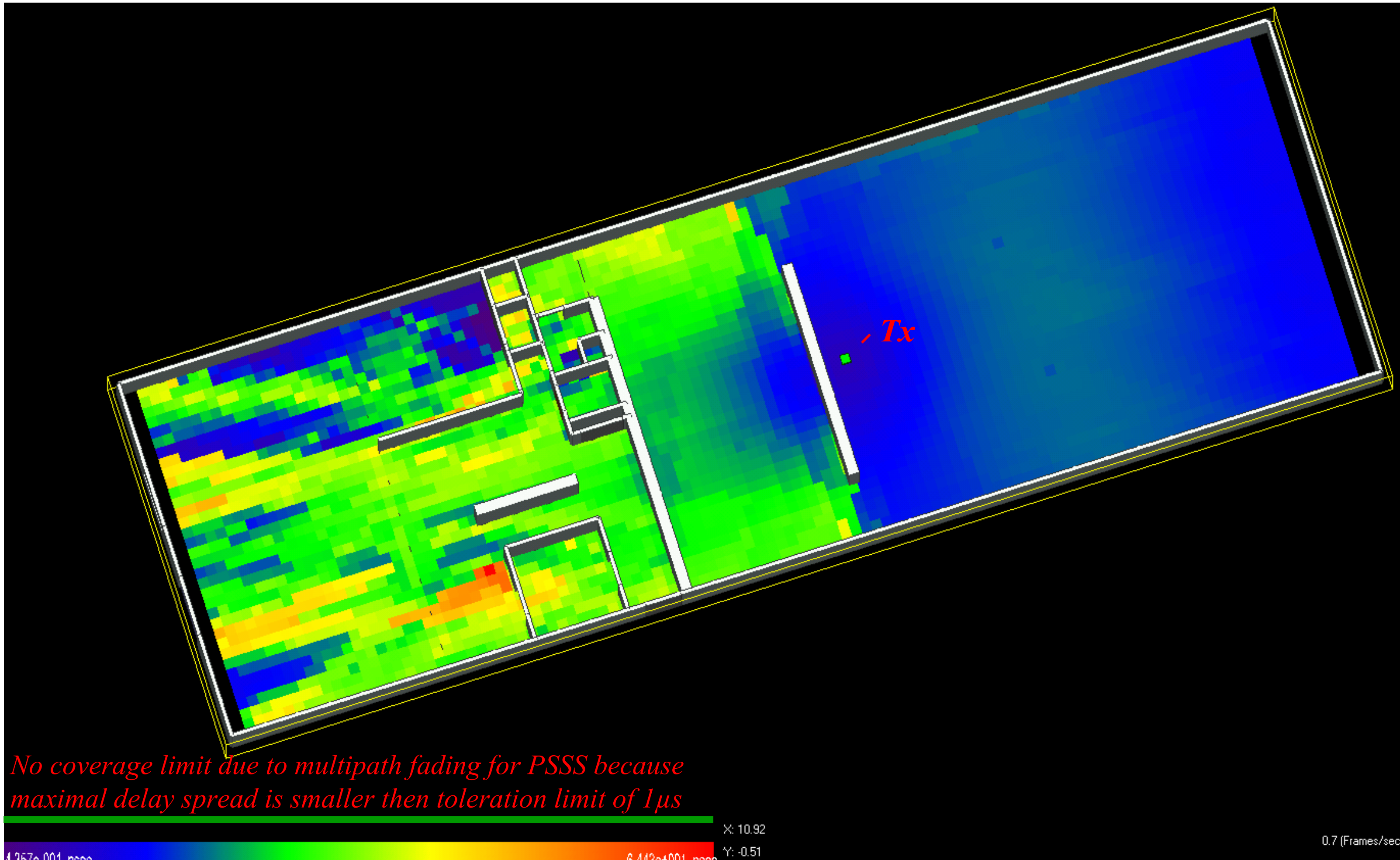
PSSS – Conclusion on Multipath Fading and White Noise

- PSSS
  - Strong robustness of PSSS against MP and noise
  - Even for higher delay spreads 400ns and more
  - Limit of 1µs for the selected coding

Coverage

- Coverage is a good indicator for the range in 3D environments.

PSSS Coverage – Office 900 MHz Tx Limited due to Delay Spread 1µs for PSSS



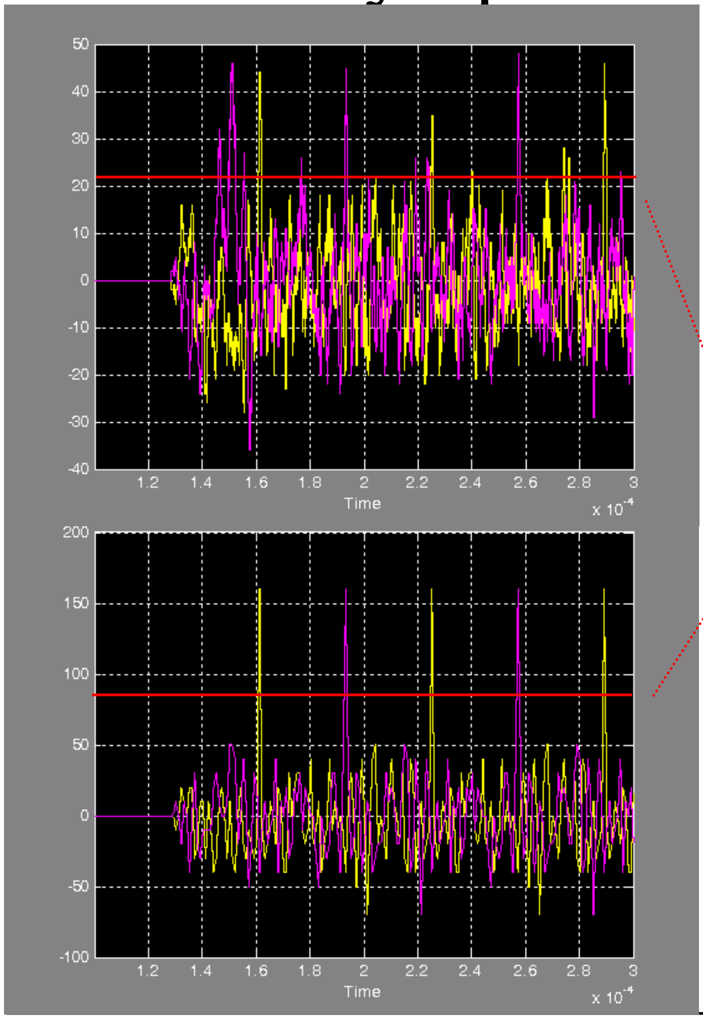
Summary

- The proposed parallel reuse of the 2.4 GHz 802.15.4 modulation technology in PSSS offers highly attractive performance improvement increasing market opportunities
- Higher date rate and multiple channels possible in both current *and* upcoming European band (and certainly also in 915 MHz band)
- 15x higher spectral efficiency through PSSS compared to the current PHY for 868/915 MHz
  (8x higher over Half Rate proposal for new European band)
  - Data rate or number of channels could be increased
  - More efficient use of spectrum and resulting better coexistence
- Significantly stronger multipath fading robustness in PSSS
  - Visibly higher range in many attractive, high volume target areas
- Very easy backward compatibility to the 2.4 GHz PHY, interoperable to existing Low Band PHY, also easy adaptation to current 868/915 MHz designs
  - PSSS is derivative superset of current 2,4 GHz PHY technology
  - Scalable data rate and automatic fallback to current standard possible

Back Up Slides

- Transfer simulations are made with Simulink from Matlab
- Coverage Simulation are made with InSite Wireless form Remcom
- Influence of Noise and MP to Half Rate Transmission
- Coverage for Half Rate

Half Rate at 1 Mchip/s with Multipath Fading Delay Spread 40ns and White Noise



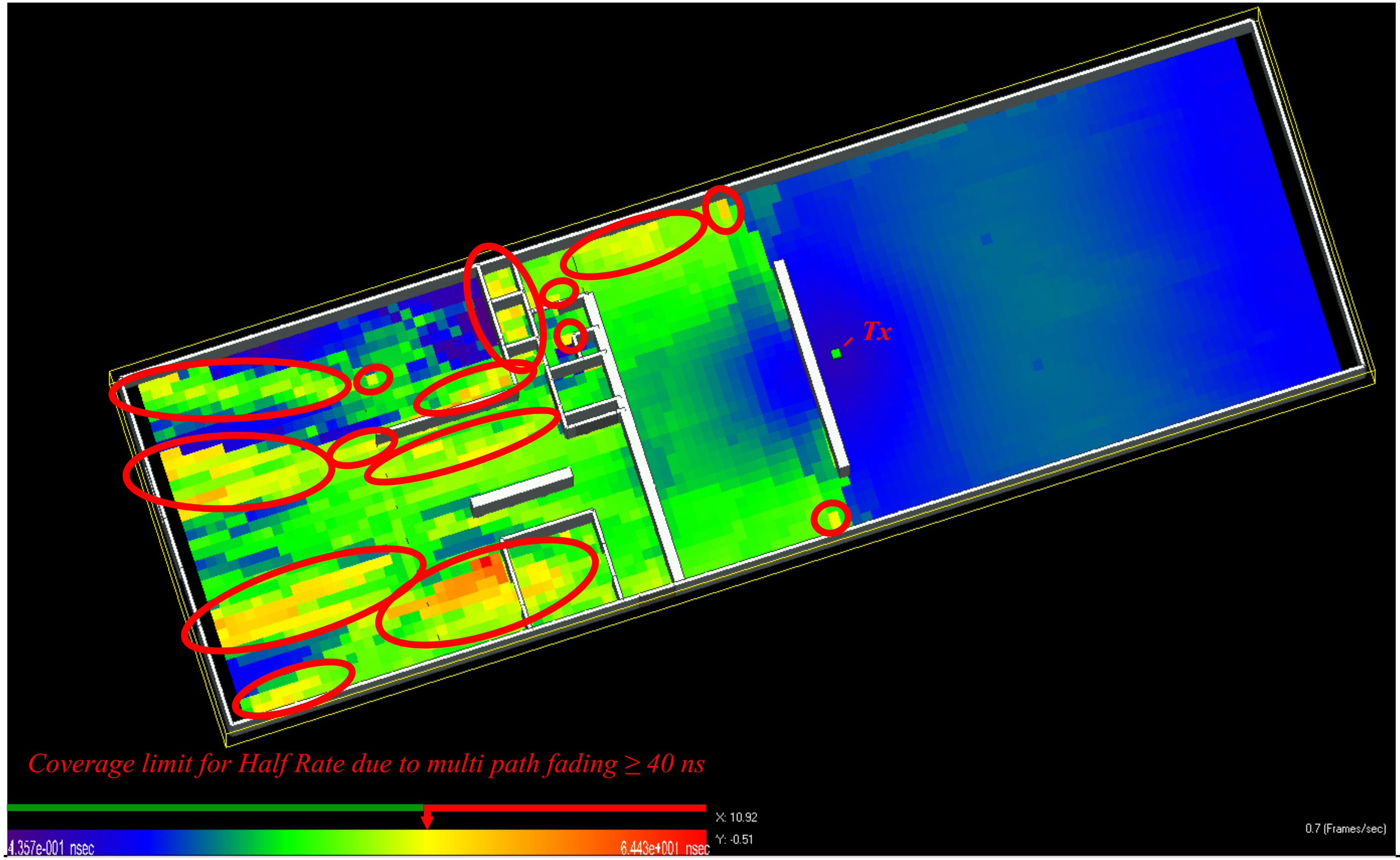
Correlated Signal Noise and Multipath Fading

Detection Threshold

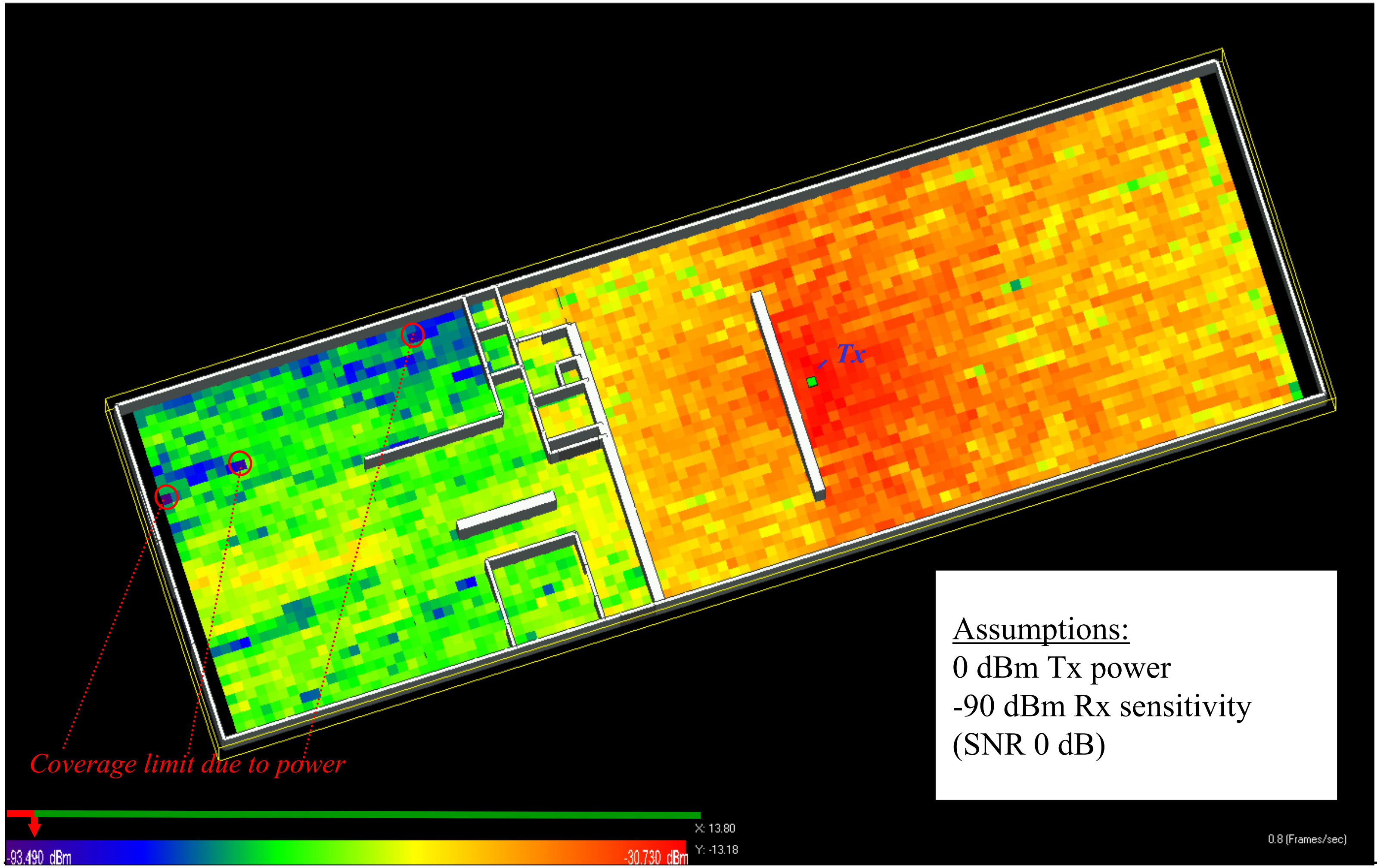
Correlated Signal No noise

Even this simple simulation is already clearly showing to reason for the known deficiencies in coverage and range under indoor MP fading conditions with IEEE802.15.4-2003 (2.4 GHz)

Half Rate Coverage – Office 900 MHz, Delay Spread 40 ns



PSSS Coverage Office 900 MHz – Limitation due Received Signal Strength



Assumptions:
0 dBm Tx power
-90 dBm Rx sensitivity
(SNR 0 dB)

PSSS – Conclusion on Multipath Fading and White Noise

- Half Rate
  - High sensitive to 40 ns delay spread plus noise
    - Reducing visibly effective indoor range
    - Causing significant holes in coverage even in the reduced range
- PSSS
  - Strong robustness of PSSS against MP and noise[1]
  - Even for higher delay spreads 400ns and more
  - Limit of 1µs for the selected coding

Notes:

1 The same channels have been used in simulations of MP fading and noise for Half Rate and PSSS