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

Submission Title: [**Pulsed DS-UWB with optional CS-UWB for Various Applications**]

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Re: [Response to Call For Proposal by IEEE 802.15.4a]

Abstract [This document has been submitted for an official proposal in January 2005. Two possible technologies of direct-sequence UWB(DS-UWB) and chirp-signal UWB(CS-UWB) are combined to be optimized for various application of IEEE802.15.4a. Pulsed DS-UWB with optional CS-UWB is proposed and investigated in performance on BER, ranging resolution, complexity, power consumption, SOP and so on. The proposed system is matched with requirements.]

Purpose: [Providing technical contributions for standardization by IEEE 802.15.4a.]

Pulsed DS-UWB with Optional CS-UWB for Various Applications

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Outline

- **Requirements of TG4a**
- **Proposed system: Pulsed DS-UWB with optional CS-UWB (Chirp Signaling UWB)**
  1. General advantages of DS-UWB and CS-UWB
  2. Proposed DS-UWB with optional CS-UWB
  3. Performance examples
  4. Multiple access and SOP
  5. PHY frame structure
  6. Ranging issue
  7. Complexity and power consumption
  8. Technical feasibility
- **Concluding remarks**

Primary Technical Requirements for 15.4a

- Low complexity, low cost, and low power consumption.
- Precision ranging by PHY --- tens of centimeters.
- Communication distance is ~30m (can be extended).
- Better robustness and mobility than 802.15.4.
- Low bit rate (individual link) >= 1 kbps.
- High bit rate (aggregated) >= 1 Mbps.

Aims of the Proposal

- By using DS-UWB with optional CS-UWB, the proposed system is conscientiously designed so that it can be easily customized and generally used for various applications, while keeping low complexity with low power consumption.
- Meet all requirements of 15.4a.

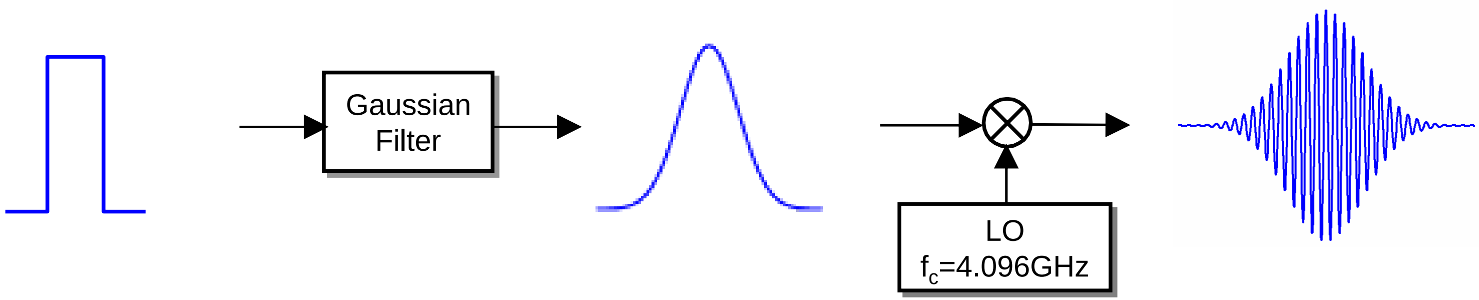
1. General Advantages of DS-UWB and CS-UWB

Both DS-UWB and CS-UWB are available for

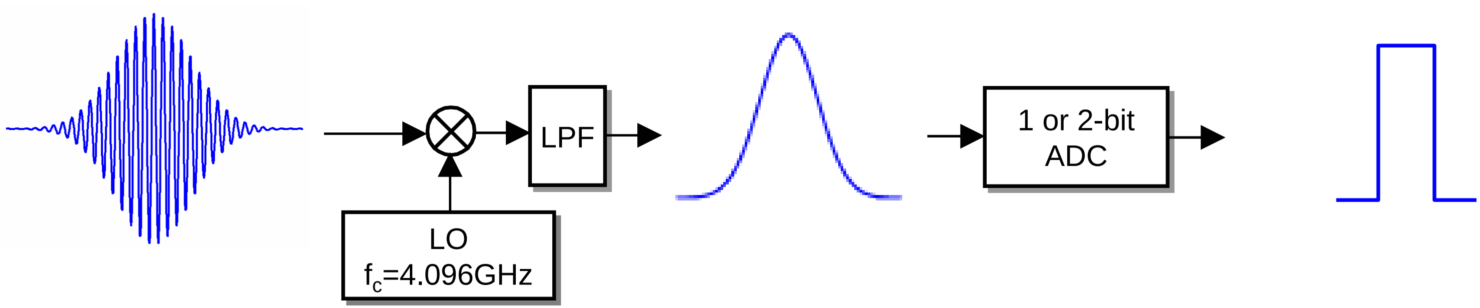
- **High frequency efficiency**
  - Uniform use of frequency within the band
- **High robustness against noise and multipath**
  - Correlated processing
- **High compatibility with other existing systems**
  - Low interference level
- **High feasibility for SOP**
  - Use of DS codes or chirp pulses

Modulation/Demodulation for DS-UWB

- Modulation.

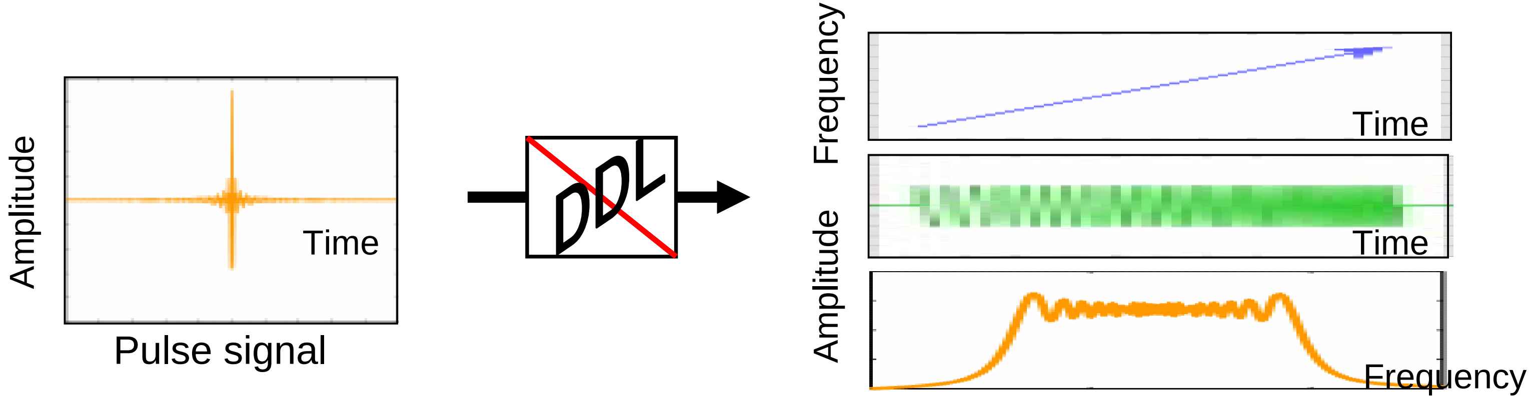


- Demodulation.

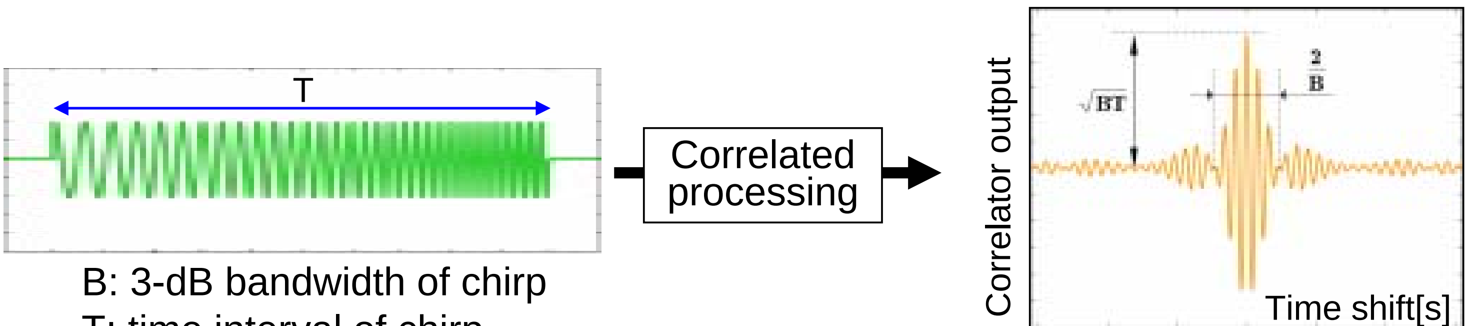


Chirp/De-chirp Processing for CS-UWB

- Chirp can be done by passing a pulse signal through a DDL.



- De-chirp is realized by doing correlated processing.



B: 3-dB bandwidth of chirp
T: time interval of chirp

Comparison between DS-UWB and CS-UWB

++ good, + fair

	DS-UWB	CS-UWB
Low complexity	++	+
Peak-to-average ratio	+	++
Effect of SOP	+	++
Ranging resolution	++	+

2. Proposed DS-UWB With Optional CS-UWB

- Transceiver structures and waveforms
- Default and optional pulse shaping
- Frequency band
- Link budget
- Scalability and optional SS operation
- Advantages
- Proposed UWB antenna

Pulsed DS-UWB System Proposal

- Spectrum Spreading: Direct sequence (DS) with spreading sequence of variable lengths. In option, additional chirp signaling (CS-UWB).
- Pulse Shaping: Gaussian monocycle and optionally variable pulse shapes with SSA (Soft Spectrum Adaptation#).
- Frequency Band: 500MHz or 2GHz in bandwidth over 3.1-10.6GHz. In option, 2.4GHz ISM band.
- Data Modulation: BPSK or others.

  Low bit rate (individual link) >= 1 kbps.

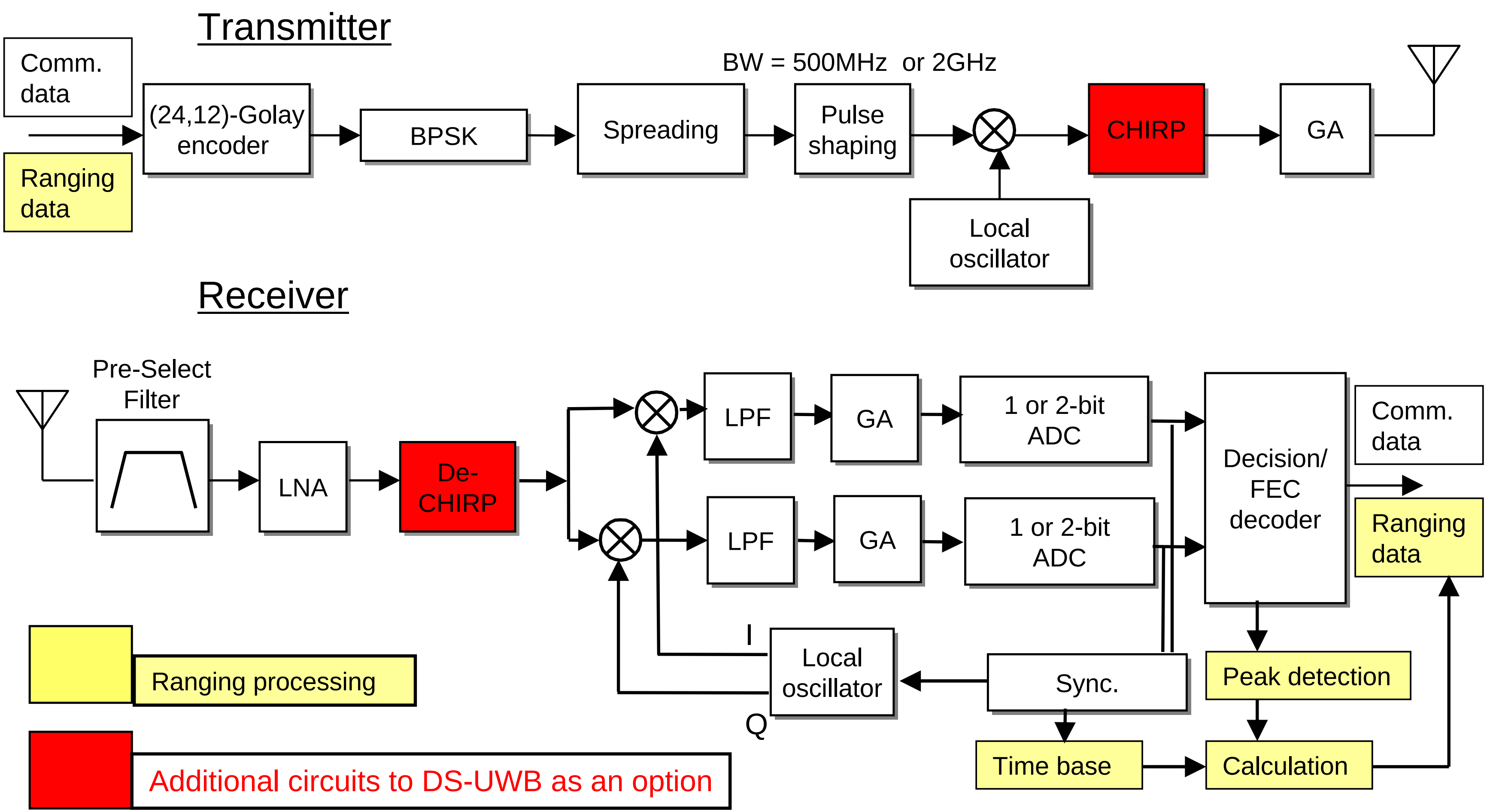
  High bit rate (aggregated) >= 1 Mbps.
- Channel Coding & Decoding: (24, 12) extended Golay code. In option, CIDD (combined iterative demapping/decoding#)

(# see 15-03-0334-05-003a)

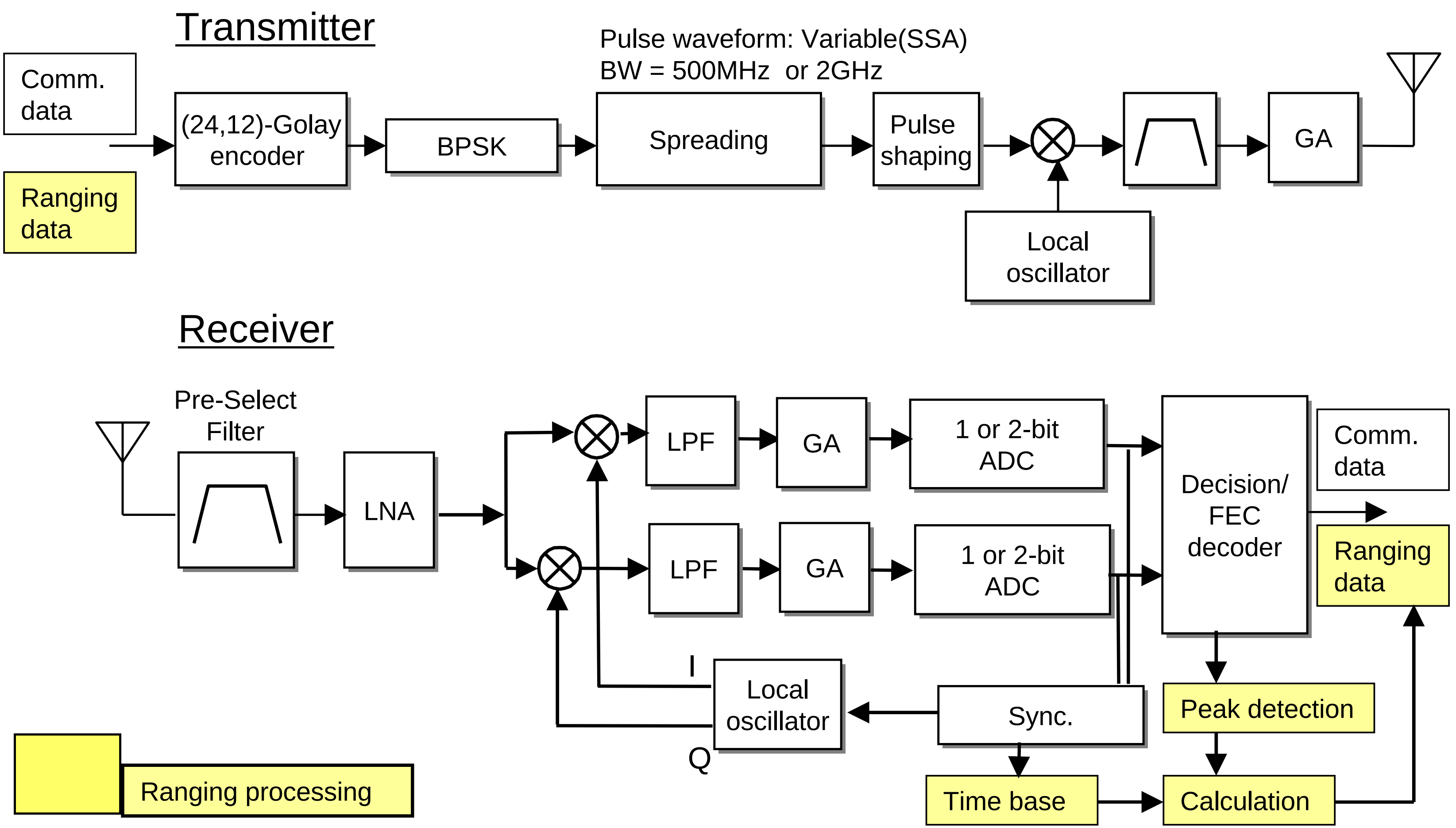
Outstanding Features of the Proposal

- **High capacity for SOP**
  - Use of independent DS codes or chirp pulses
  - Use of combined DS codes and chirp pulses
- **Multiple selectivity for FFD and RFD as well as for various Customization**
  - Chirp vs. Non chirp
  - High bit rate vs. Low bit rate
  - Optional SSA vs. Gaussian monocycle
- **Interoperability**
  - Simplified structure from high rate DS-UWB of 15.3a

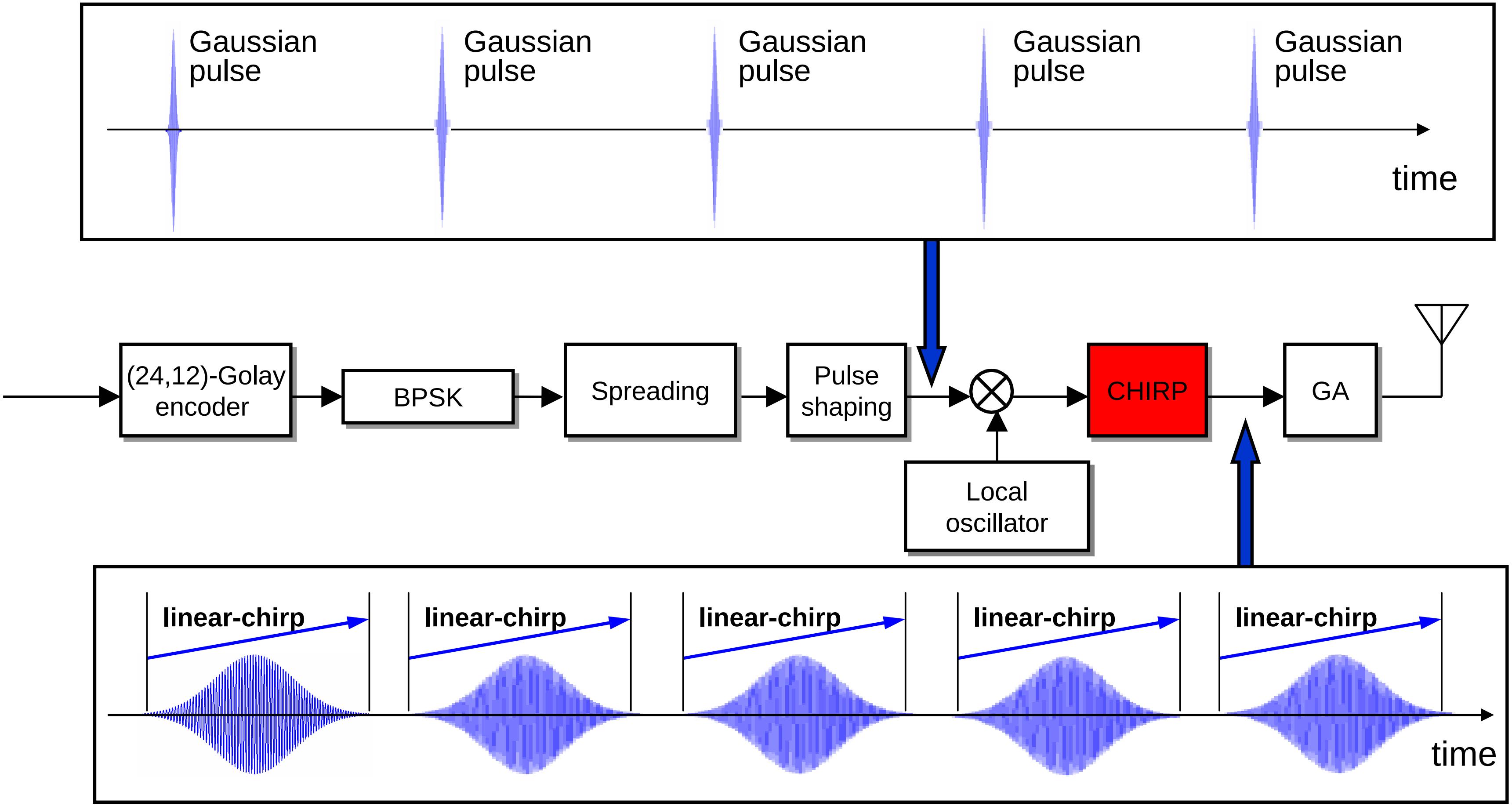
Overall Block Diagram With Optional CS



Block diagram Without Optional CS



Waveforms With & Without Optional CS

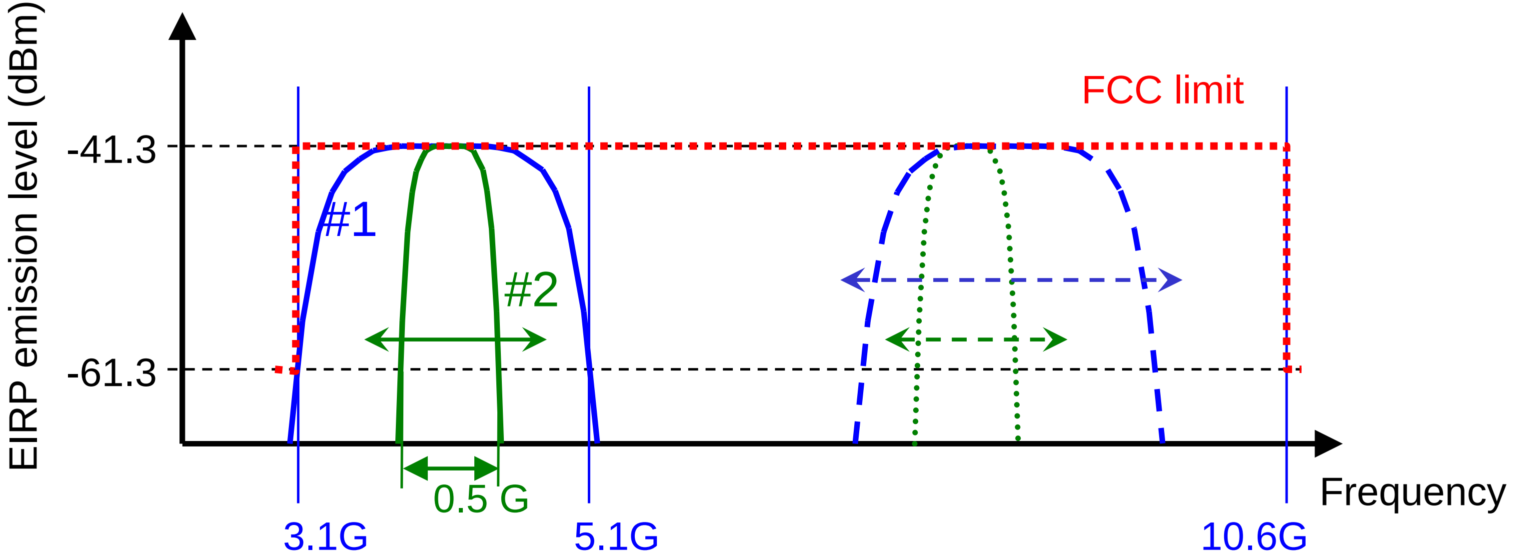


Pulse shaping

- **Gaussian monocycle is default.**
  - Easy implementation of transceiver.
  - The ratio of chip rate to carrier frequency is an integer.
  - Drawback is less efficiency in utilizing FCC mask.
- **Optional soft spectrum adaptation (SSA; see 15-03-0334-05-003a).**
  - Adaptive spectrum by considering trade-off between performance and complexity/cost.

Frequency Band

- We consider two operating bandwidths of UWB.
  #1: BW=2GHz, and #2: BW=500MHz.
  Both are selected within 3.1 - 10.6 GHz frequency band.
- In addition, 2.4 GHz ISM band is also considered as an option.



DS-UWB Link Budget (BW=2GHz)

Parameter	Value	Value	Notes
Data rate (Rb)	1	1024	(kbps)
Modulation	BPSK		Coherent detection
Coding rate (R)	1/2		(24,12)-Extended Golay Hard-decision decoding
Raw Symbol rate (Rs)	2	2048	Rs=Rb/R (ksymbol/s)
Pulse duration (Tp)	0.662		(ns)
Spreading code length (Ns)	1024	64	
Chip rate (Rc)	2.048	131.072	=Rs*Ns (MHz)
Chip duration	488.3	7.63	=1/Rc (nsec)

Parameter	Value	Value	Unit
Distance (d)	30	10	m
Peak payload bit rate (Rb)	1	1024	kbps
Average Tx power (Pt)	-10.5		dBm
Tx antenna gain (Gt)	0		dBi
Frequency Band	3.1 - 5.1		GHz
Geometric center frequency (fc)	3.98		GHz
Path loss @ 1m (L1)	44.43		dB
Path loss @ d m (Ld)	29.54	20.00	dB
Rx antenna gain (Gr)	0		dBi
Rx power (Pr)	-90.47	-80.93	dBm
Average noise power per bit (N)	-144.00	-113.90	dBm
Rx Noise Figure (Nf)	7.00		dB
Average noise power per bit (Pn)	-137.00	-106.90	dBm
Minimum required Eb/N0 (S)	6.25		dB
Implementation loss (I)	3.00		dB
Link Margin	43.28	22.72	dB
Min. Rx Sensitivity Level	-127.75	-97.65	dBm

CS-UWB Link Budget (BW=2GHz)

Parameter	Value	Value	Notes
Data rate (Rb)	1	1024	(kbps)
Modulation	BPSK		Coherent detection
Coding rate (R)	1/2		(24,12)-Extended Golay Hard-decision decoding
Raw Symbol rate (Rs)	2	2048	Rs=Rb/R (ksymbol/s)
Chirp signal duration (Tc)	100		(ns)
Spreading code length (Ns)	1024	4	
Chip rate (Rc)	2.048	8.192	=Rs*Ns (MHz)
Chip duration	488.3	122.1	=1/Rc (nsec)

Parameter	Value	Value	Unit
Distance (d)	30	10	m
Peak payload bit rate (Rb)	1	1024	kbps
Average Tx power (Pt)	-8.89		dBm
Tx antenna gain (Gt)	0		dBi
Frequency band	3.1 - 5.1		GHz
Geometric center frequency (fc)	3.98		GHz
Path loss @ 1m (L1)	44.43		dB
Path loss @ d m (Ld)	29.54	20.00	dB
Rx antenna gain (Gr)	0		dBi
Rx power (Pr)	-90.47	-80.93	dBm
Average noise power per bit (N)	-144.00	-113.90	dBm
Rx Noise figure (Nf)	7.00		dB
Average noise power per bit (Pn)	-137.00	-106.90	dBm
Minimum required Eb/N0 (S)	6.25		dB
Implementation loss (I)	3.50		dB
Link Margin	44.39	23.83	dB
Min. Rx Sensitivity Level	-127.25	-97.15	dBm

The items given in red characters have different values from those of DS

DS-UWB Link Budget (BW=500MHz)

Parameter	Value	Value	Notes
Data rate (Rb)	1	1024	(kbps)
Modulation	BPSK		Coherent detection
Coding rate (R)	1/2		(24,12)-Extended Golay Hard-decision decoding
Raw Symbol rate (Rs)	2	2048	Rs=Rb/R (ksymbol/s)
Pulse duration (Tp)	2.649	2.649	(ns)
Spreading code length (Ns)	1024	64	
Chip rate (Rc)	2.048	131.072	=Rs*Ns (MHz)
Chip duration	488.3	7.63	=1/Rc (nsec)

Parameter	Value	Value	Unit
Distance (d)	30	10	m
Peak payload bit rate (Rb)	1	1024	kbps
Average Tx power (Pt)	-16.9		dBm
Tx antenna gain (Gt)	0		dBi
Frequency band	3.85 - 4.35		GHz
Geometric center frequency (fc)	4.09		GHz
Path loss @ 1m (L1)	44.68		dB
Path loss @ d m (Ld)	29.54	20.00	dB
Rx antenna gain (Gr)	0		dBi
Rx power (Pr)	-91.12	-81.58	dBm
Average noise power per bit (N)	-144.00	-114.00	dBm
Rx Noise figure (Nf)	7.00		dB
Average noise power per bit (Pn)	-137.00	-106.90	dBm
Minimum required Eb/N0 (S)	6.25		dB
Implementation loss (I)	3.00		dB
Link Margin	36.63	16.07	dB
Min. Rx Sensitivity Level	-127.75	-97.65	dBm

CS-UWB Link Budget (BW=500MHz)

Parameter	Value	Value	Notes
Data rate (Rb)	1	1024	(kbps)
Modulation	BPSK		Coherent detection
Coding rate (R)	1/2		(24,12)-Extended Golay Hard-decision decoding
Raw Symbol rate (Rs)	2	2048	Rs=Rb/R (ksymbol/s)
Chirp signal duration (Tc)	25		(ns)
Spreading code length (Ns)	1024	4	
Chip rate (Rc)	2.048	8.192	=Rs*Ns (MHz)
Chip duration	488.3	122.1	=1/Rc (nsec)

Parameter	Value	Value	Unit
Distance (d)	30	10	m
Peak payload bit rate (Rb)	1	1024	kbps
Average Tx power (Pt)	-15.38		dBm
Tx antenna gain (Gt)	0		dBi
Frequency band	3.85 – 4.35		GHz
Geometric center frequency (fc)	4.09		GHz
Path loss @ 1m (L1)	44.68		dB
Path loss @ d m (Ld)	29.54	20.00	dB
Rx antenna gain (Gr)	0		dBi
Rx power (Pr)	-89.60	-80.06	dBm
Average noise power per bit (N)	-144.00	-114.0	dBm
Rx Noise figure (Nf)	7.00		dB
Average noise power per bit (Pn)	-137.00	-106.90	dBm
Minimum required Eb/N0 (S)	6.25		dB
Implementation loss (I)	3.50		dB
Link Margin	37.65	17.09	dB
Min. Rx Sensitivity Level	-127.25	-97.15	dBm

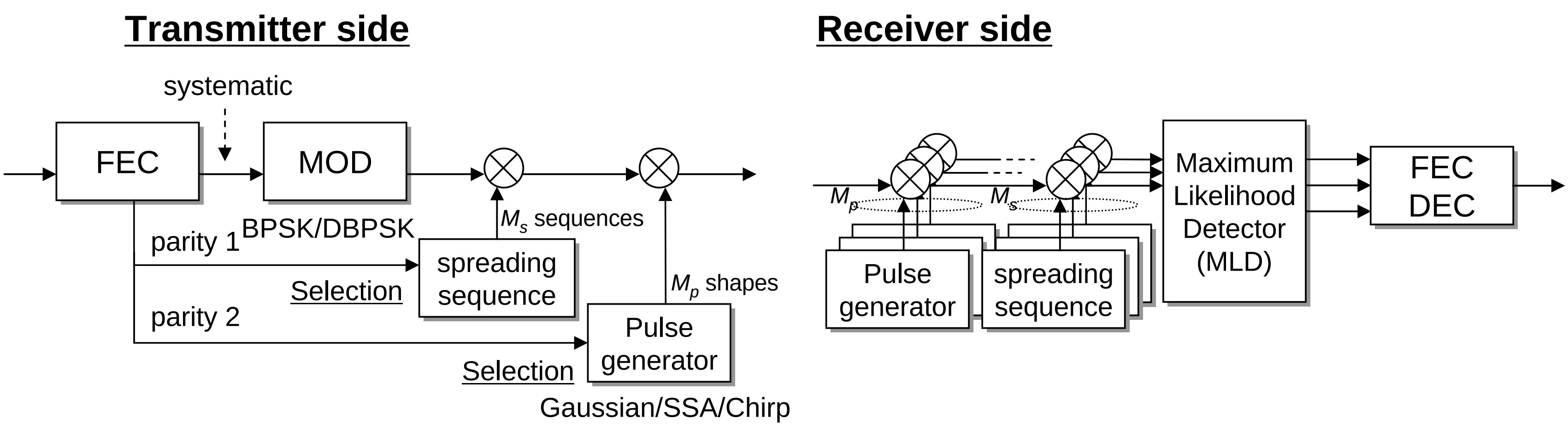
The items given in red characters have different values from those of DS

Scalability With DS Lengths

Data rate (kbps)	Raw Symbol rate (ksps)	DS Code length (chip)	Chip rate (Mcps)	Link margin at 10m (dB)	Notes
DS-UWB					
1	2	1024	2.048	52.8	0.662 (ns) pulse width
16	32	1024	32.768	40.8	
32	64	1024	65.536	37.8	
128	256	256	65.536	31.8	
256	512	256	131.072	28.7	
1024	2048	64	131.072	22.7	
2048	4096	64	131.072	19.7	Optional, use 4BOK
4096	8192	64	131.072	16.7	Optional, use 16BOK
CS-UWB (optional)					
1	2	1024	2.048	53.9	100 (ns) chirp duration
16	32	64	2.048	41.9	100 (ns) chirp duration
1024	2048	4	8.192	23.8	100 (ns) chirp duration

Optional SS Operation & Pulse Shaping

- These optional operations provide choice for FFD and RFD, and allow energy-rich codes to obtain better QoS and/or higher throughput.



Advantages of Pulsed DS-UWB with Optional CS-UWB

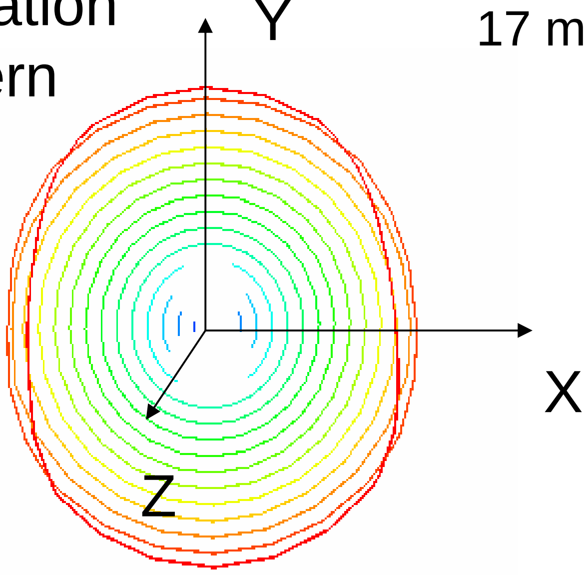
The proposed system can be widely customized for various applications but less complex with low power consumption.

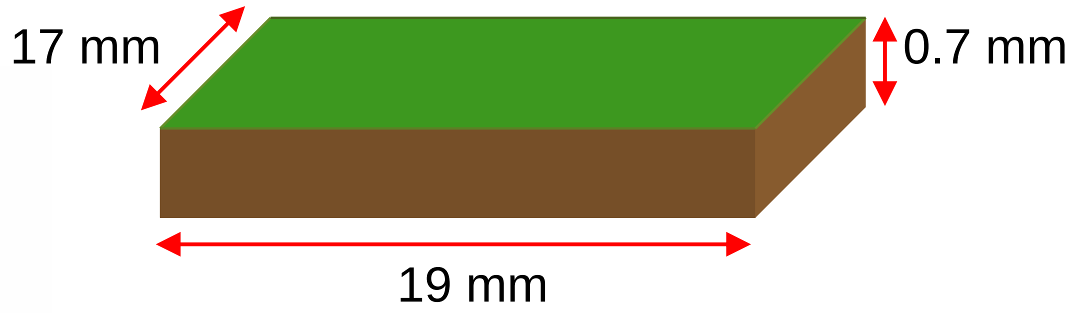
- **Low complexity**
  - Simple ADC (1 or 2-bit) is enough.
  - Optional CS-UWB can be carried out with simple chirp and de-chirp circuits in addition to the basic DS-UWB (see system diagram).
- **Variable Transmission**
  - Chirped DS-UWB signals can be demodulated by both FFD and RFD.
  - Variable data rates is realized by selecting the length of DS codes.
- **High robustness against noise, multipath, and interference**
  - Correlated processing provides robustness against noise and multipath.
  - Reduction of interference from other nodes, e.g. SOP or from other operating systems.
- **Interoperability & Coexistence**
  - Simplified structure from high rate DS-UWB of 15.3a may enable active coexistence.

UWB Antenna

- Very small antenna with excellent radiation pattern.
  - Antenna size is smaller than SD memory card size.

Radiation Pattern

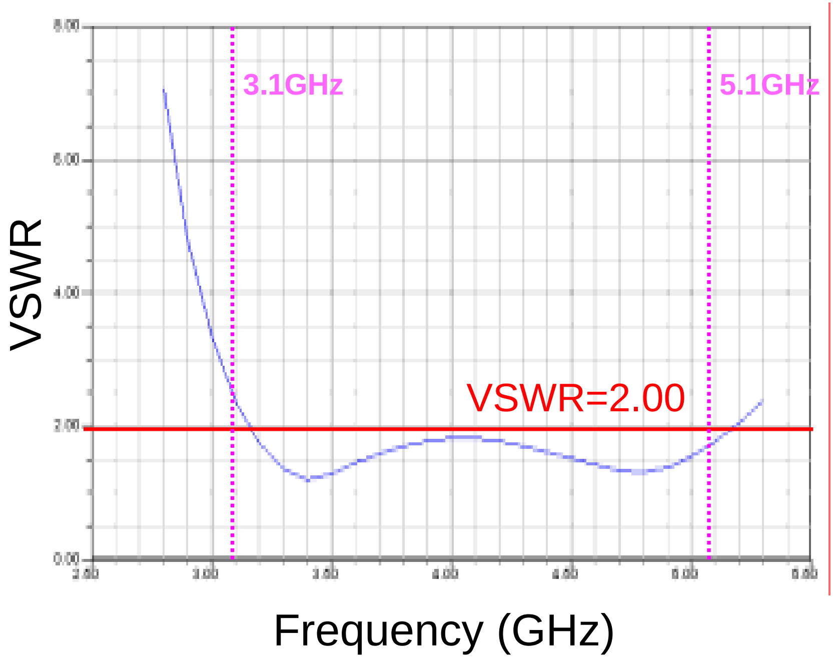


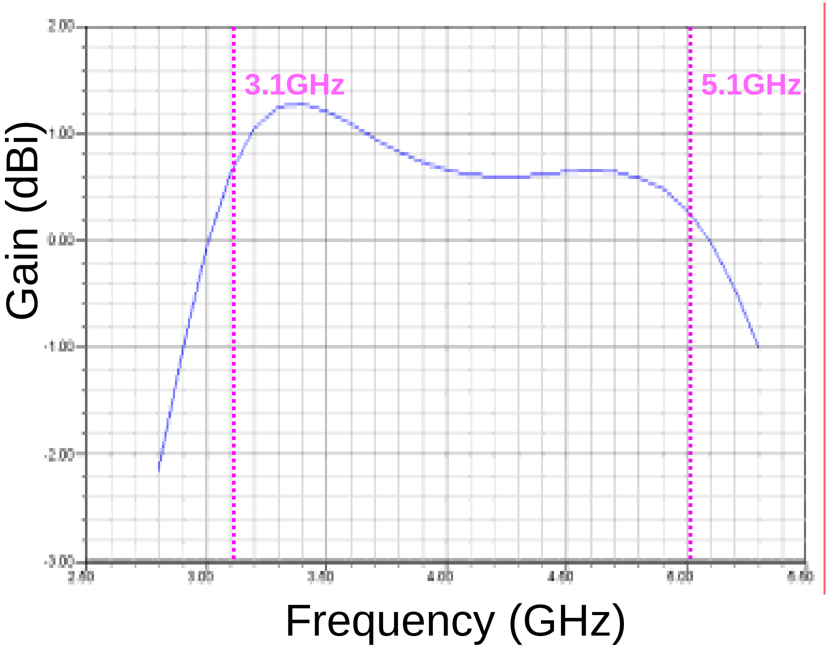


Substrate: Silicon
Patch: Copper

Antenna Characteristics

- VSWR <= 2 in total band and nearly linear gain.

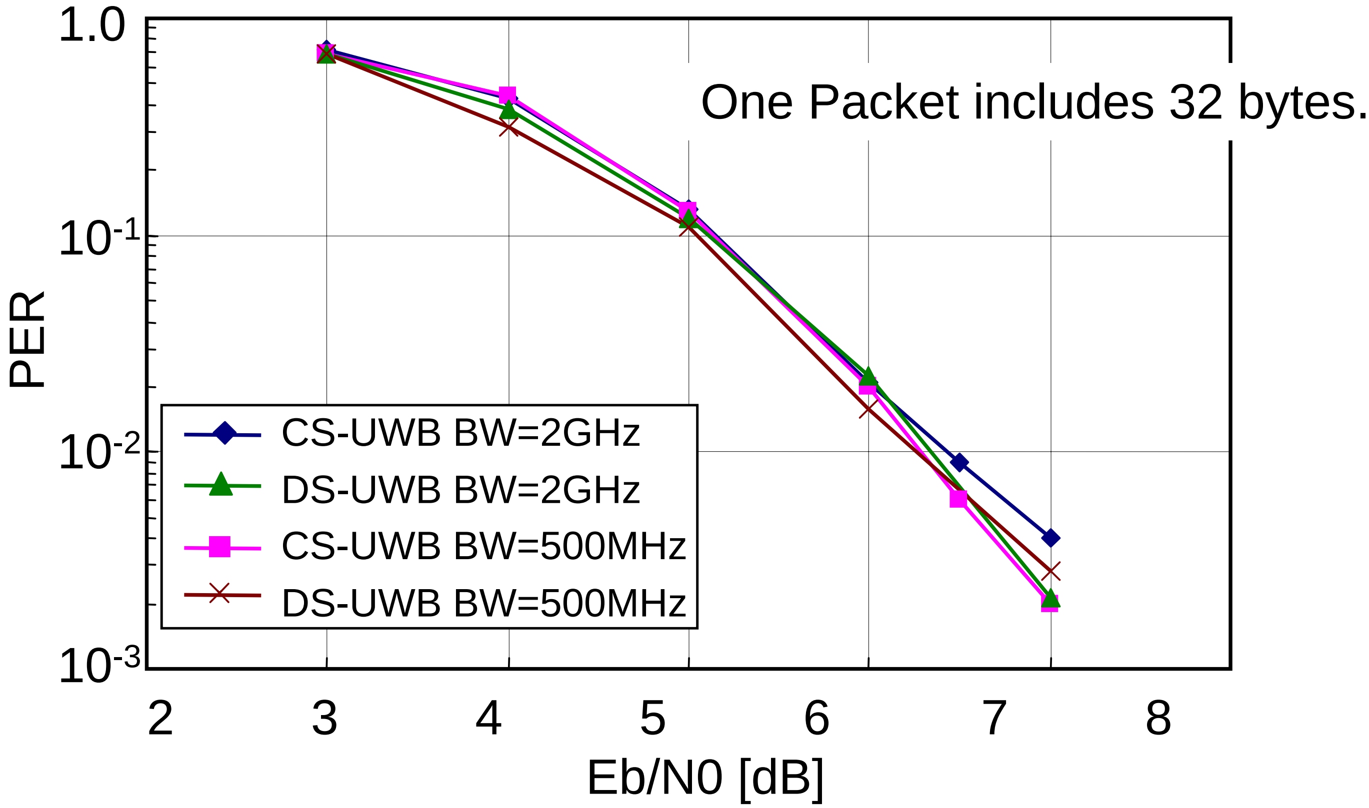




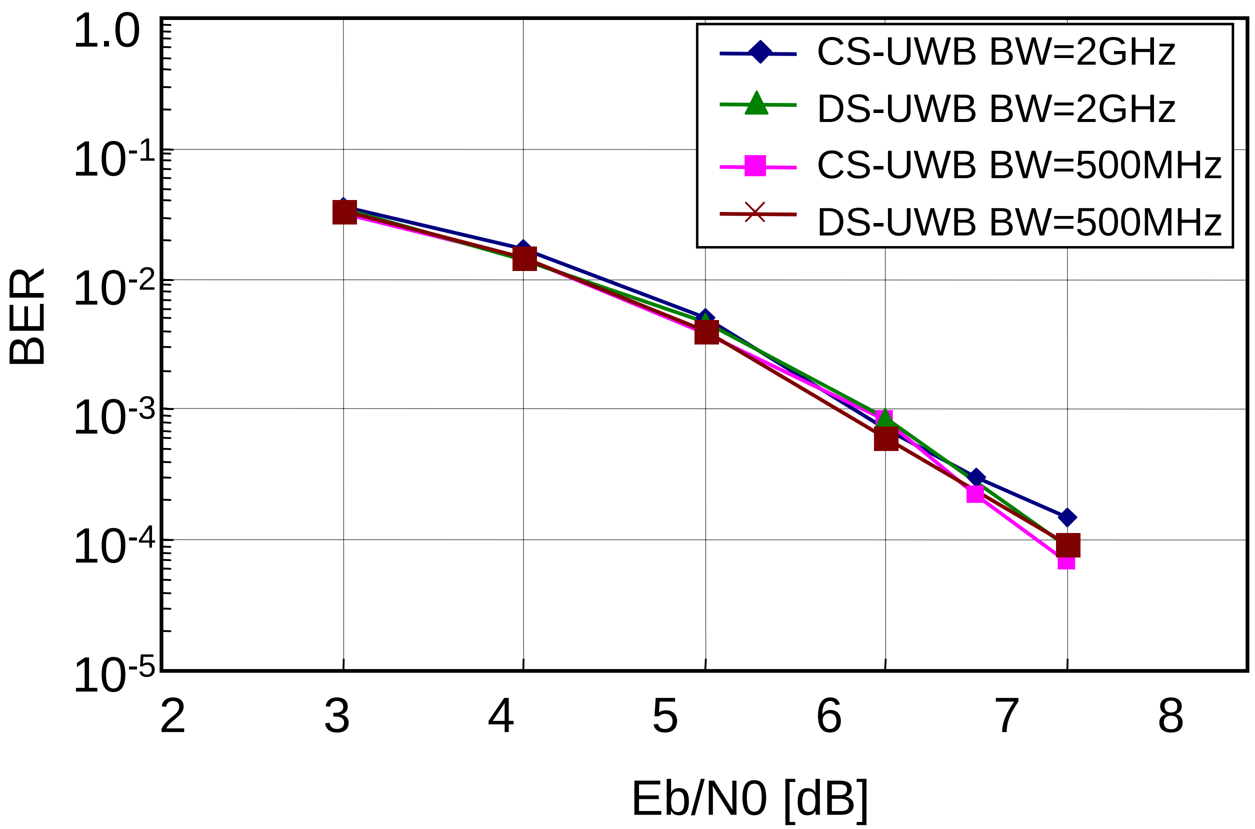
3. Performance Examples

- Performance under AWGN channel
- Performance with 15.4a channel models
- Anti-interference performance (IEEE802.11a and MB-OFDM)

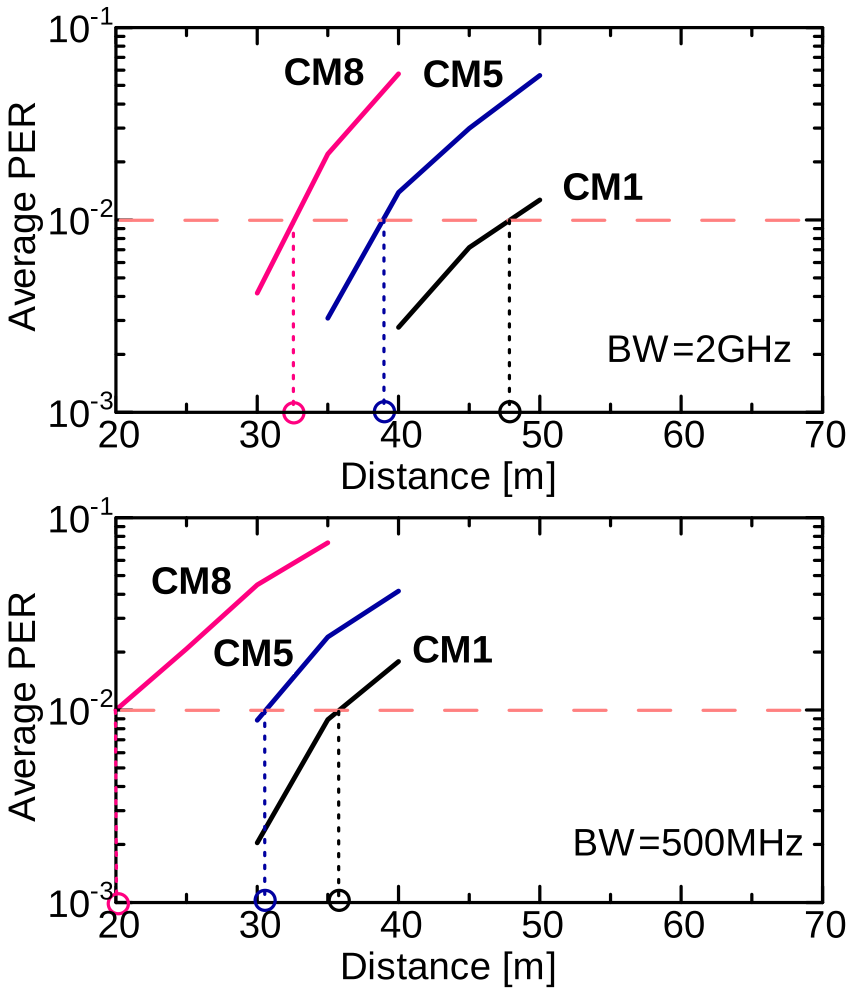
Simulation results (Single link, AWGN)



Simulation results (Single link, AWGN)



Performance With 15.4a CMs



DS-UWB

- Data rate: 1kbps (nominal)
- Modulation: BPSK
- Pulse shape: Gaussian monocycle
- Spreading code: 1024 chips
- ADC: 1Gs and 1bit
- Channel models
  - CM1: Indoor residential LOS
  - CM5: Outdoor LOS
  - CM8: Industrial environments NLOS

Interference Models Considered

- **IEEE802.11a**
  - Center frequency: 5.18 GHz
  - Emission power: 15 dBm
  - Antenna gain: 0 dBi
- **MB-OFDM**
  - Frequency band: Group 1, lower three bands
  - Emission power: -41.3dBm*528MHz*Duty cycle
  - Antenna gain: 0 dBi

Interference Evaluation Using Minimum Criteria

Interference models		Tolerable distance to achieve PER<1%
IEEE802.11a		
BW = 2GHz	Eb/N0 = inf.	0.52 m
	Eb/N0 = 10 dB	0.80 m
MB-OFDM		
BW = 2GHz	Eb/N0 = inf.	0.012
	Eb/N0 = 10 dB	0.022
BW = 500MHz	Eb/N0 = inf.	0.104
	Eb/N0 = 10 dB	0.115

UWB: Propagation distance = 1m. BW = 2 GHz, fc = 4.1 GHz.
Data rate = 2 Mbps, FEC off. BW = 500 MHz, fc = 3.35 GHz.

4. Multiple Access and SOP

- Multiple access method
- Simulation results

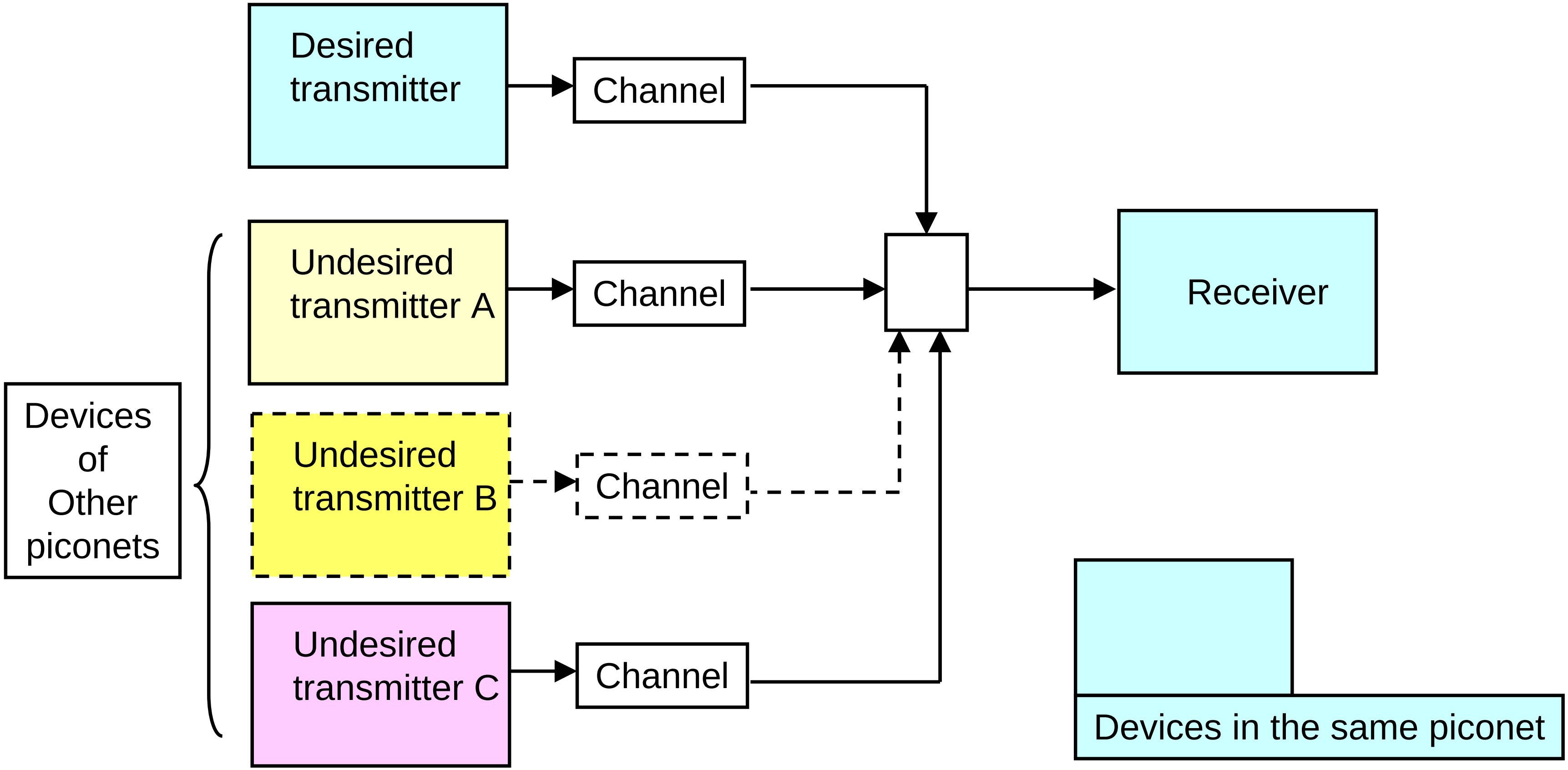
Multiple Access Method For SOP

- **DS-UWB**
  - Use different DS codes

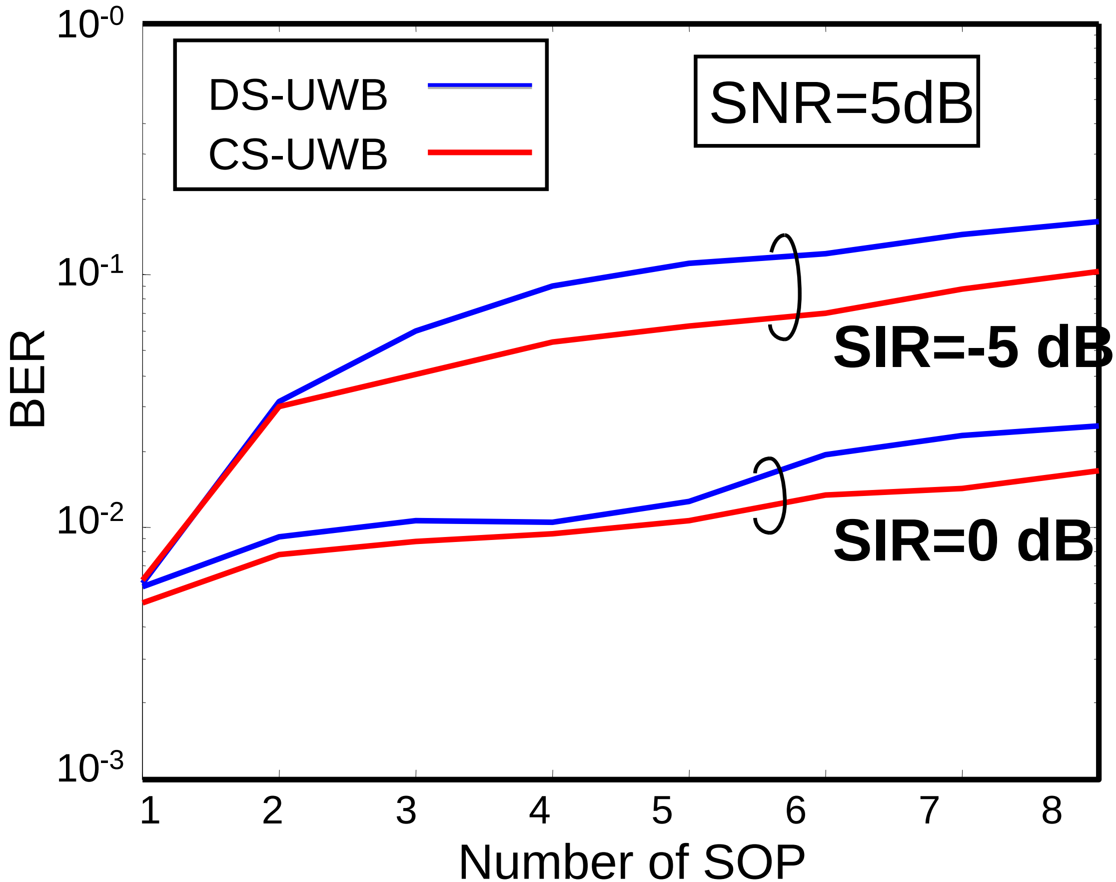
    (and/or different frequency sub bands for BW = 500MHz).

- **CS-UWB (in option)**
  - Use different chirped pulses or combination of DS codes and chirped pulses.

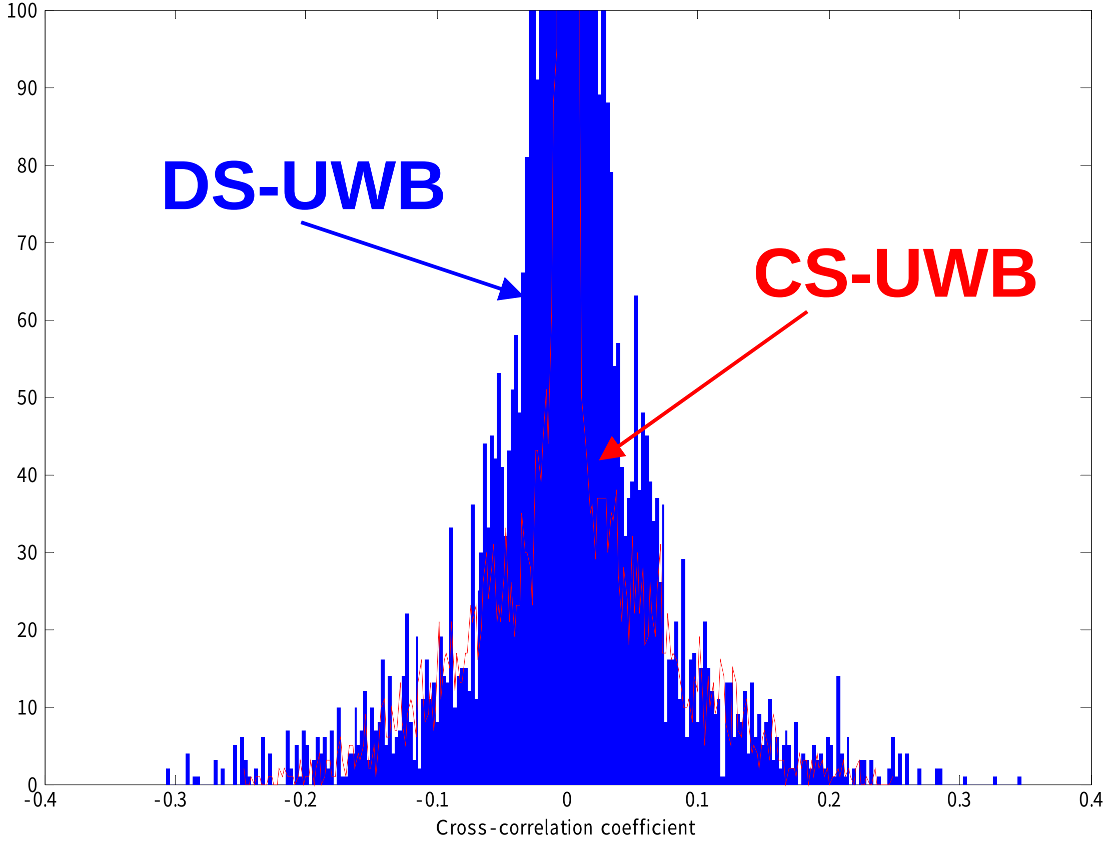
Simulation block diagram for SOP



Simulation results for SOP



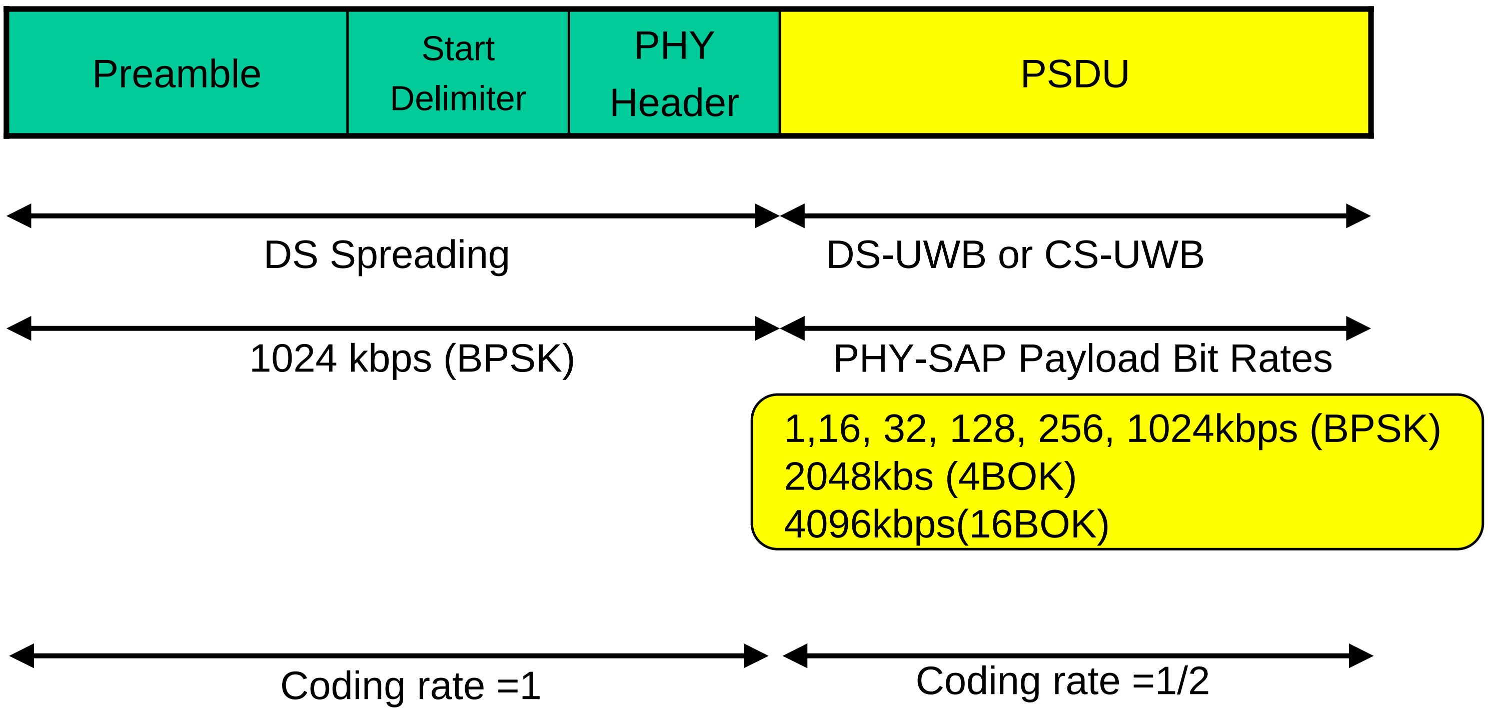
Cross correlation coefficient



5. PHY Frame Structure

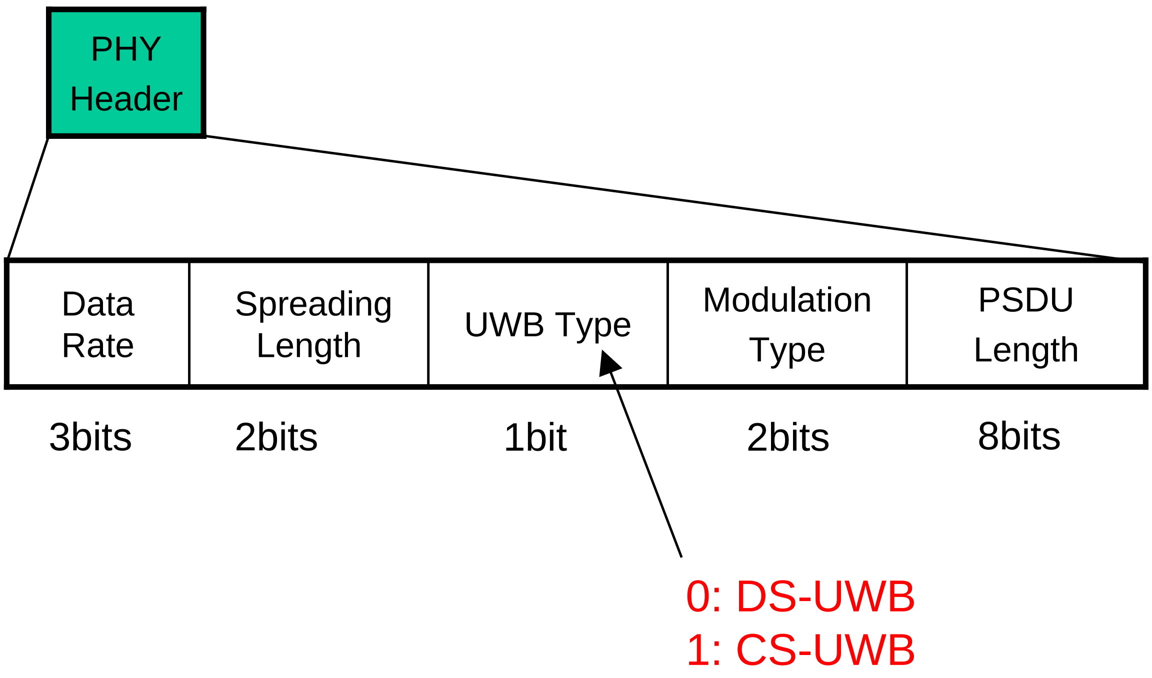
- Frame Format
- PHY header payload

PHY Frame Format



Payload of PHY Header

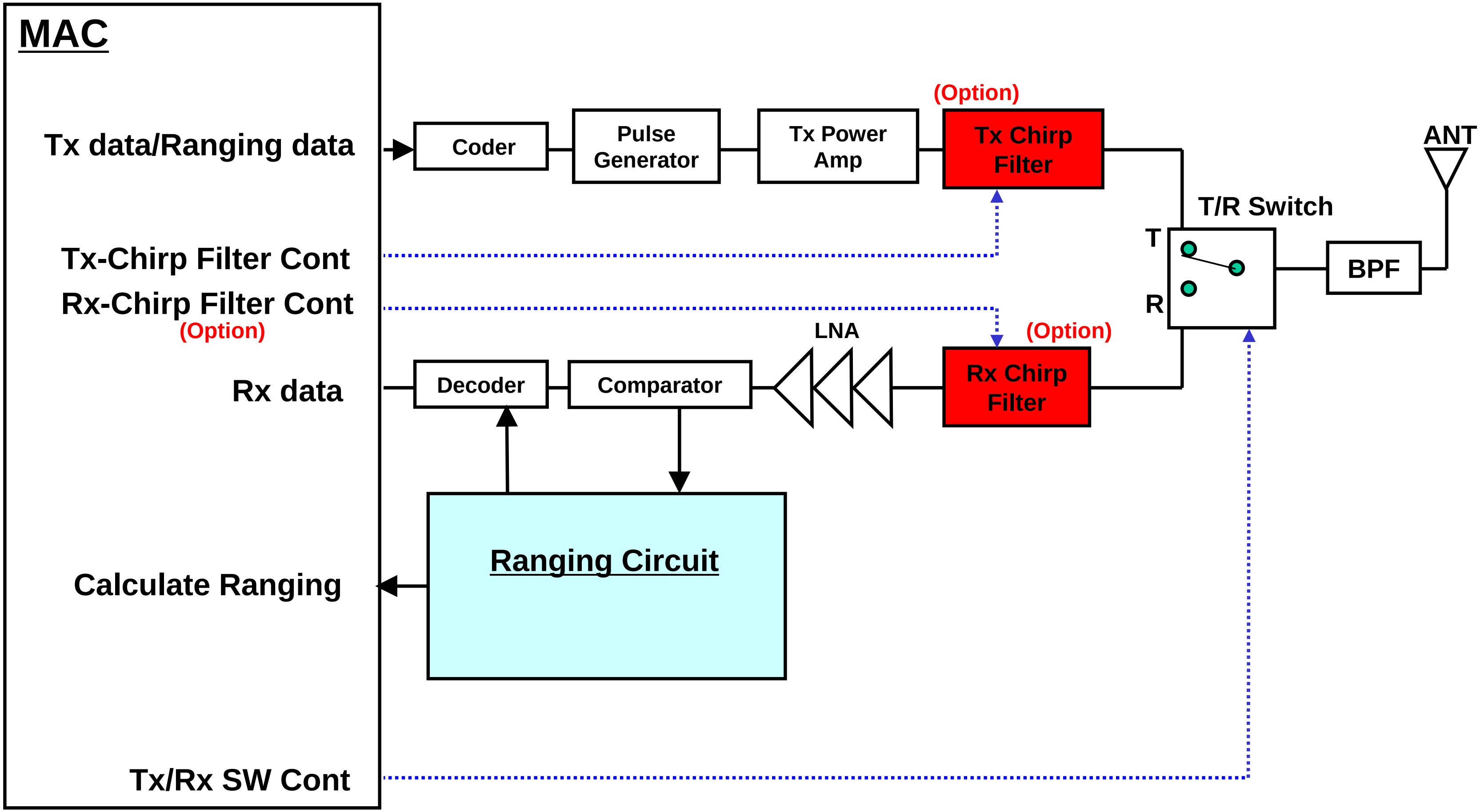
- We can use the spreading type filed bit in PHY header as an indicator to show which spreading scheme is employed in the payload, DS-UWB or CS-UWB.



6. Ranging Issue

- Ranging circuit
- Ranging period
- Ranging accuracy

Ranging Processing with TOA



Period of Ranging with TOA

Period of ranging

- Long ranging period
  - 250 sec
- Short ranging period
  - 15 msec

The ranging period is decided by referring to the superframe structure of 15.4.

Ranging Accuracy with TOA

- Ranging precision depends on the bandwidth used.
- Using a simple TOA, DS-UWB provides better precision than CS-UWB in principle.

	DS-UWB		CS-UWB	
Bandwidth (GHz)	2.0	0.5	2.0	0.5
Ranging resolution (cm)	19.86	79.47	30	120

7. Complexity/Power Consumption

Assuming standard 0.13μm CMOS technology
With intermittent operation in analog section

			Communication		Ranging	
Component	**Gate Counts (kgate)**	**Area (mm^2)**	**Power @1kbps* (mW)**	**Power @1024kbps (mW)**	**Power@slow Cycle (mW)**	**Power@fast Cycle (mW)**
Tx and Rx Mix.	-		1.2	12	1.2	12
Center Freq. Gen.	-		2	20	2	20
Tx Amp.	-		0.8	8	0.8	8
LNA	-	2.5	1	10	1	10
GA	-		1	10	1	10
ADC (2-bit)	-		1.8	18	1.8	18
Sync and Clock	-		2	20	1	10
Tx Digital	10	0.06	0.1	4	0.1	4
Rx Digital	50	0.3	0.3	20	0.2	10
Total	60	2.5 (Analog) 0.36 (Digital)	10.2	122	9.0	102

The consumption power will be dominated by 'Communication',
if 'Communication' and 'Ranging' are operated simultaneously.

8. Technical Feasibility

- Power Management
- Manufacturability
- Time to market

Power Management Mode

- Functions similar to those of 15.4 are available,
  - Sleep
  - Wake up
  - Poll

Technical Feasibility

- **Manufacturability**
  - Proposed system can be manufactured right now by conventional standard CMOS technology such as 0.13μm.
  - Basics of the system have been demonstrated in DS-UWB 802.15.3a proposal.

- **Time to market**
  - There is no difficulty on research and technique.
  - Time for design and product is needed.
  - Regulation may be a factor.

Concluding Remarks

- The proposed DS-UWB with optional CS-UWB can be widely customized and perform excellent for various applications in 15.4a.
  - The proposed system can be widely customized for different applications with pre-optimized sets of parameters.
  - Full and reduced function devices (FFD and RFD) can make choice for each of the following pairs of parameters: chirped or non-chirped DS-UWB, default Gaussian pulse or SSA, and, high or low data rate, etc..
- Feasibility and scalability are guaranteed both.
  - Low complexity, low cost, and low power consumption.
  - Variable data rate and multiple dimensions for SOP.
  - Robustness against multipath and interference.
- Communication and ranging requirements in 15.4a are both satisfied for a wide range of applications.
- Excellent performance with 15.4a channel models is confirmed and more results will come.