

**Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)****Submission Title:** [Pulsed DS-UWB with optional CS-UWB for Various Applications]**Date Submitted:** [January 2005]**Source:** [Huan-Bang Li(1), Kenichi Takizawa(1), Kamyay Yekeh Yazdandoost(1), Akifumi Kasamatsu(1), Shigenobu Sasaki(1), Shinsuke Hara(1), Makoto Itami(1), Tetsushi Ikegami(1), Ryuji Kohno(1), Toshiaki Sakane(2), Kiyohito Tokuda(3)]

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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. ]**Notice:** This document has been prepared to assist the IEEE P802.15. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.**Release:** The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15.

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

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# Outline of presentation

- Requirements of TG4a
- Proposed System: Pulsed DS-UWB with Optional CS-UWB (Chirp signaling UWB)
  - ✓ Advantages of using DS-UWB and CS-UWB
  - ✓ Comparison between DS-UWB and CS-UWB
  - ✓ Pulsed DS-UWB System Proposal
  - ✓ Frequency band
  - ✓ Transceiver structures
  - ✓ Optional SS Operation and Pulse Shaping
  - ✓ UWB Antenna for TG4a
  - ✓ Advantages of Pulsed DS-UWB with Optional CS-UWB
  - ✓ Generation of CS-UWB, Correlated processing, and Cross-Correlation Property
  - ✓ Dual Mode Demodulation
  - ✓ Performance with 15.4a channel models
  - ✓ Link budget
  - ✓ Ranging issue
  - ✓ Complexity and Power Consumption
  - ✓ Technical Feasibility
- Conclusion

# 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)  $\geq 1$  kbps.
- High bit rate (aggregated)  $\geq 1$  Mbps.

# Advantages of DS-UWB and CS-UWB

Both DS-UWB and CS-UWB are available for

- **High precision ranging**
  - Be up to tens of centimeters
  - Depend on pulse width (bandwidth)
- **Low complexity/Low power consumption**
  - Simple ADC (1 or 2-bit)
- **High frequency efficiency**
  - Uniform use of frequency within the band.
- **High robustness against noise and multipath**
  - Correlated processing

# Comparison between DS-UWB and CS-UWB

++ good, + fair

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

# Pulsed DS-UWB System Proposal

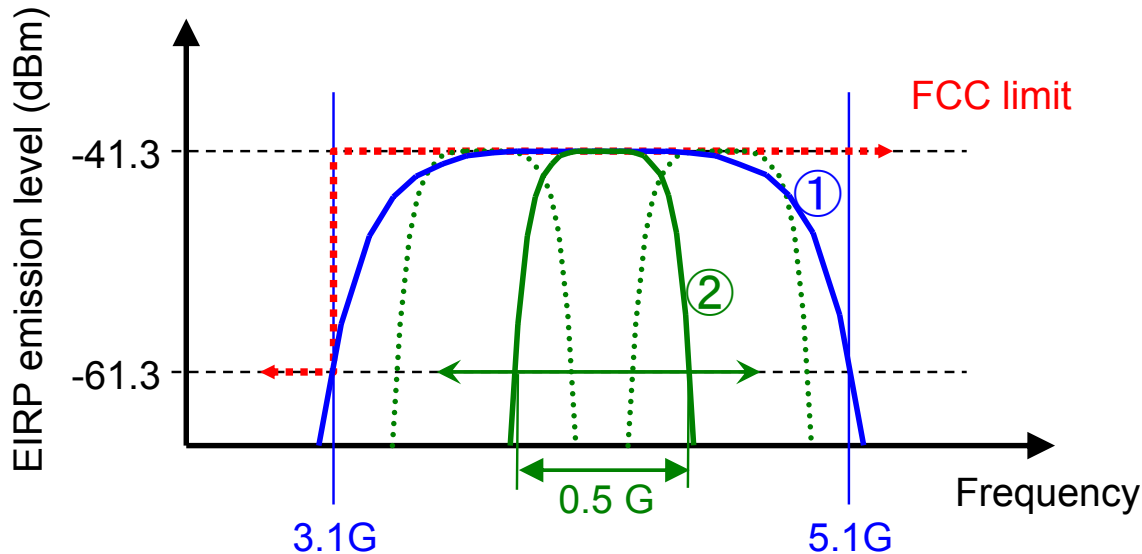
- **Spectrum Spreading:** Direct sequence (DS) with spreading sequence of 1024 or 64 chips.  
In option, chirp signaling (CS-UWB).
- **Pulse Shaping:** Gaussian monocycle and optionally variable pulse shapes with SSA(Soft Spectrum Adaptation).
- **Frequency Band:** 500MHz or 2GHz in bandwidth during 3.1-5.1GHz.
- **Data modulation:** BPSK or others  
Low bit rate (individual link)  $\geq 1$  kbps.  
High bit rate (aggregated)  $\geq 1$  Mbps.
- **Channel Coding and Decoding:** (24, 12) extended Golay code with optional CIDD (combined iterative demapping/decoding; see 15-03-0097-05-003a)

# Frequency Band

Consider two operating bandwidths of UWB.

- ① BW=2 GHz (Center frequency = 4.1 GHz)
- ② BW=500 MHz (selected within 3.1 – 5.1 GHz frequency band)

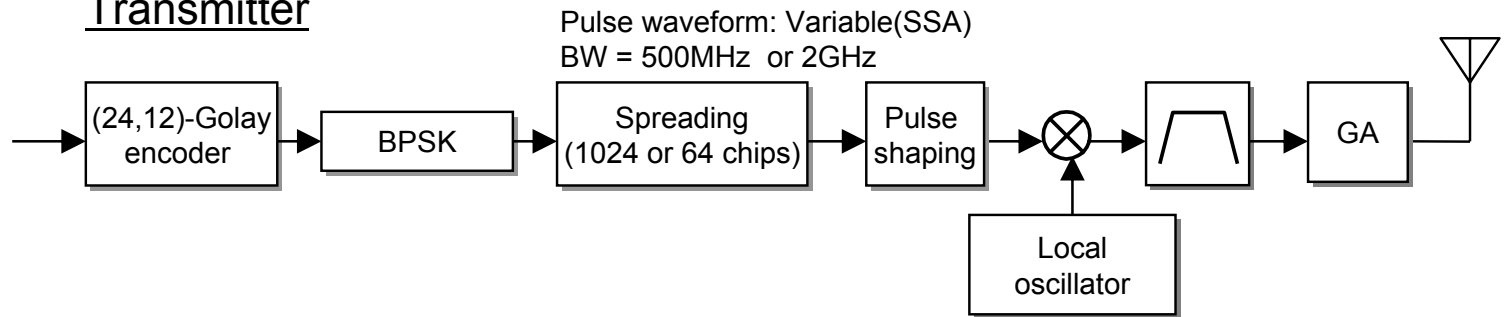
In addition, 2.4 GHz ISM band is also considered as an option



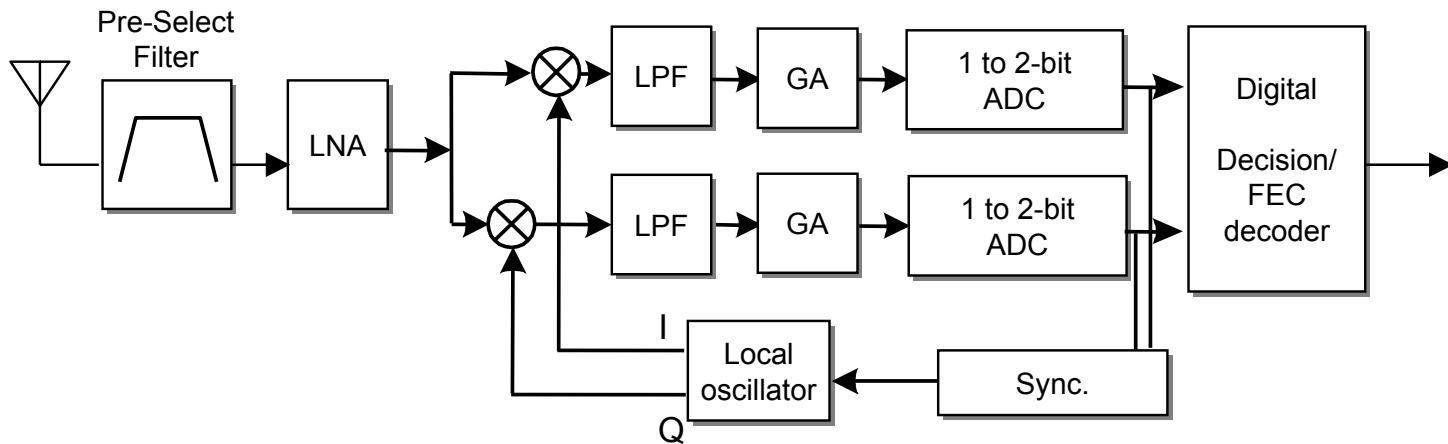


# Block diagram of Pulsed DS-UWB

## Transmitter

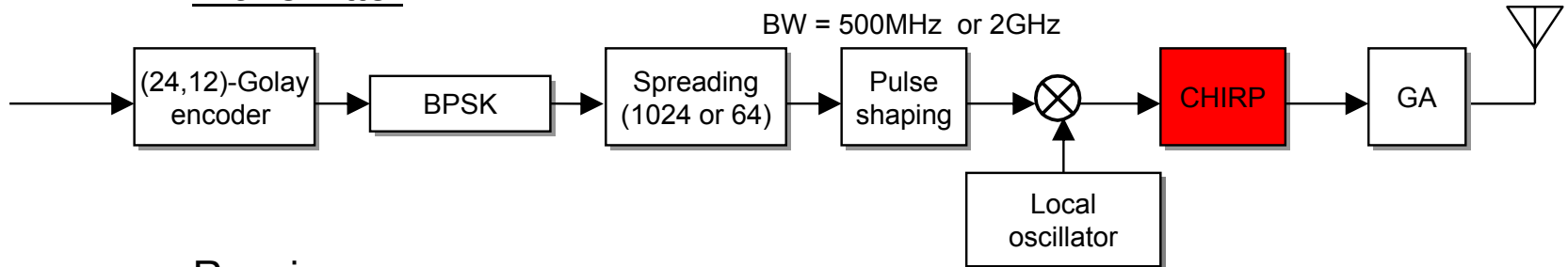


## Receiver

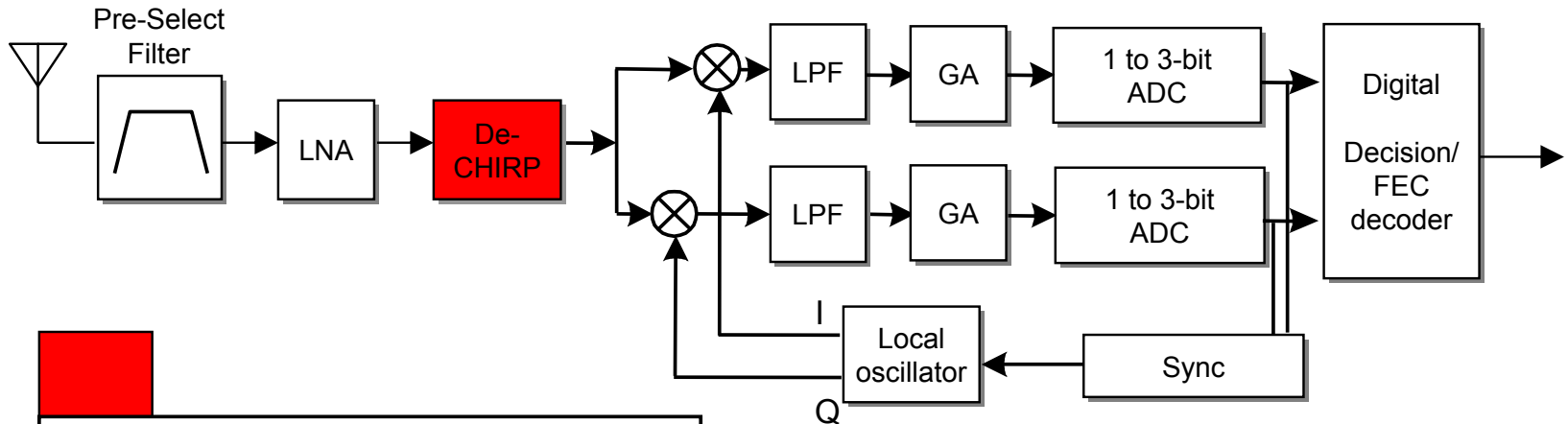


# Optional Chirp Signaling(CS) in DS-UWB

## Transmitter



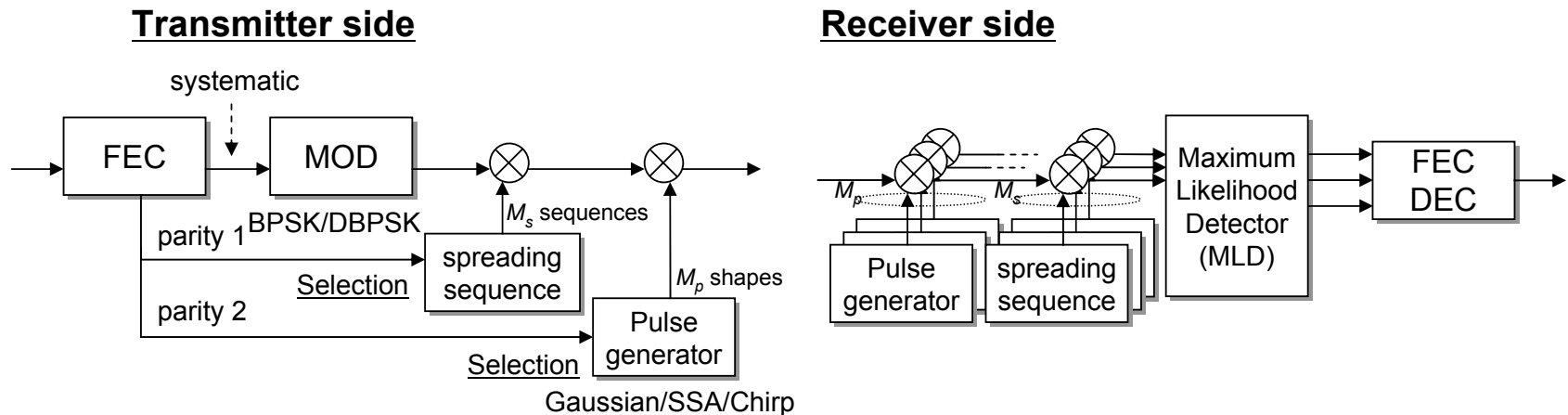
## Receiver



Additional circuits to DS-UWB as an option

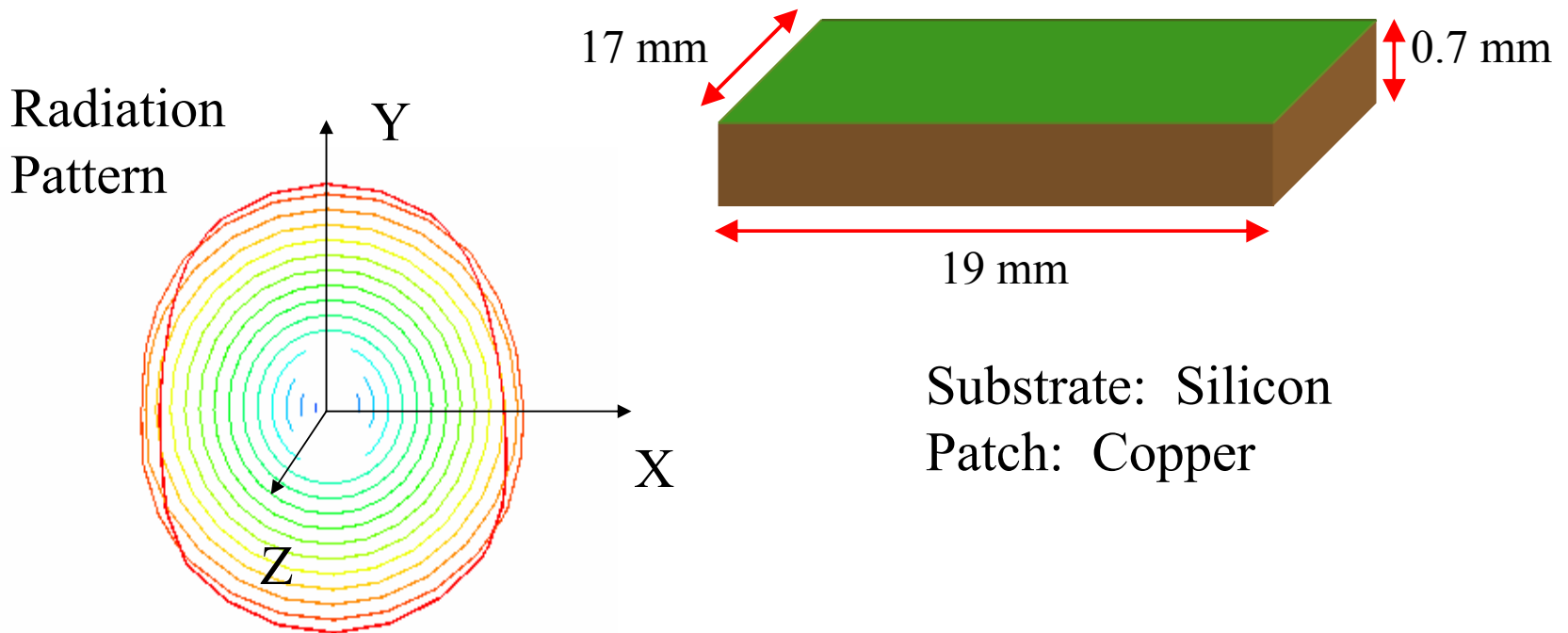
# Optional SS Operation and Pulse Shaping

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



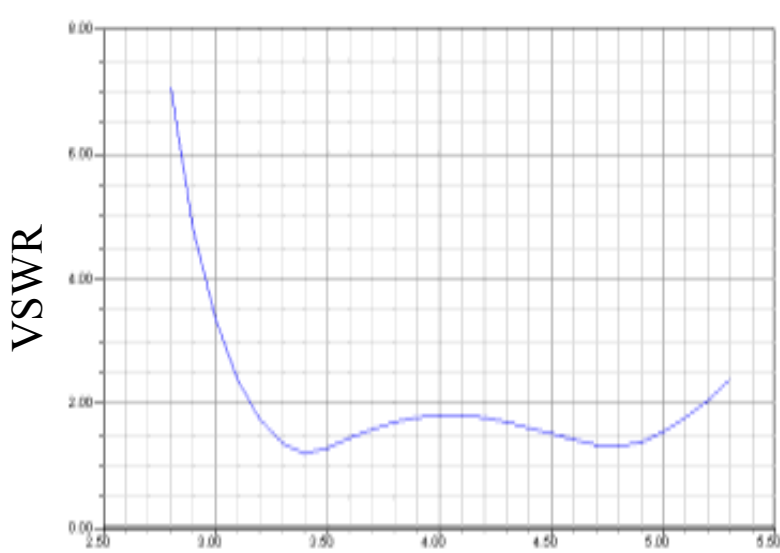
# UWB Antenna

- Very tiny antenna with good radiation pattern.

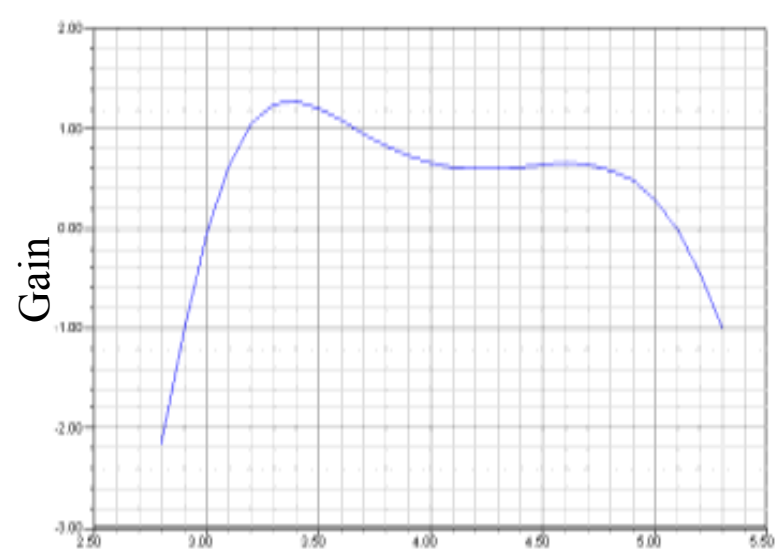


# Antenna Characteristics

- $VSWR \leq 2$  in total band and nearly linear gain.



Frequency (GHz)



Frequency (GHz)

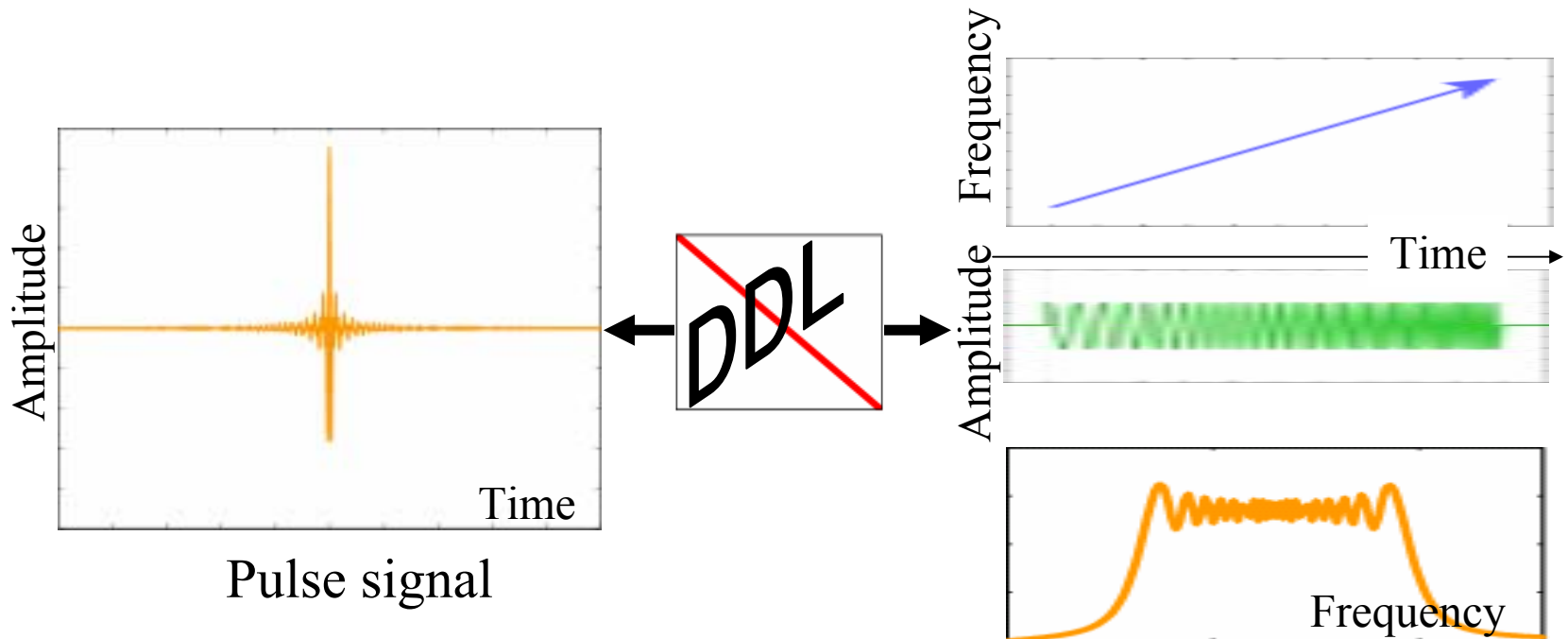
# Advantages of Pulsed DS-UWB with Optional CS-UWB

The proposed system is designed so as to be widely applicable in dual mode for various uses, but less complexity with low power consumption.

- **Low complexity**
  - Simple ADC (1 or 2-bit).
  - 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 Data Transmission**
  - Chirped DS-UWB signals can be demodulated by both FFD for high data rate and RFD for low rate.
- **High robustness against noise, multipath, and interference**
  - Correlated processing.
  - Reduction of interference from other nodes, e.g. SOP or multi-user environment.
- **Interoperability & Coexistence**
  - Simplified structure from HR-UWB of 15.3a may enable active coexistence.

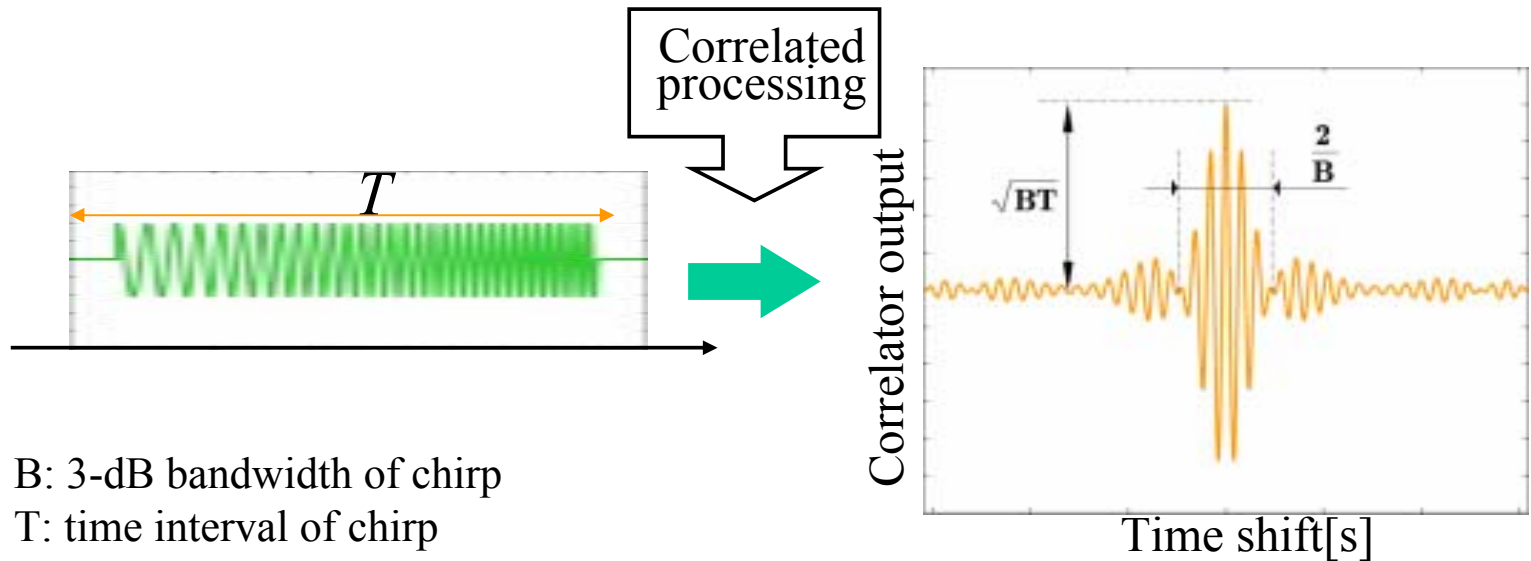
# Generation of CS-UWB

- CS-UWB can be generated by passing a pulse signal through a distributed delay line (DDL) such as a SAW DDL.



# Correlated processing

- Correlated processing produces not only high precision ranging but also robustness against noise and multipath.



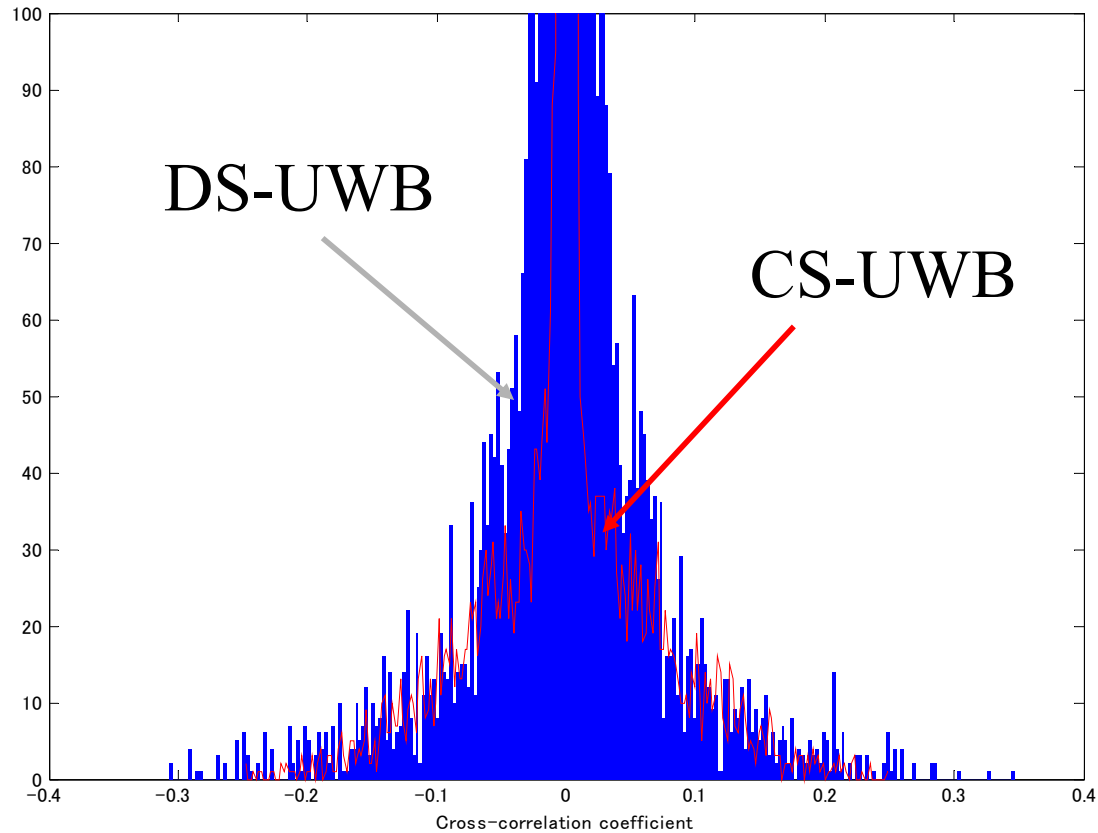
B: 3-dB bandwidth of chirp

T: time interval of chirp

The wide the bandwidth, the sharp the peak.

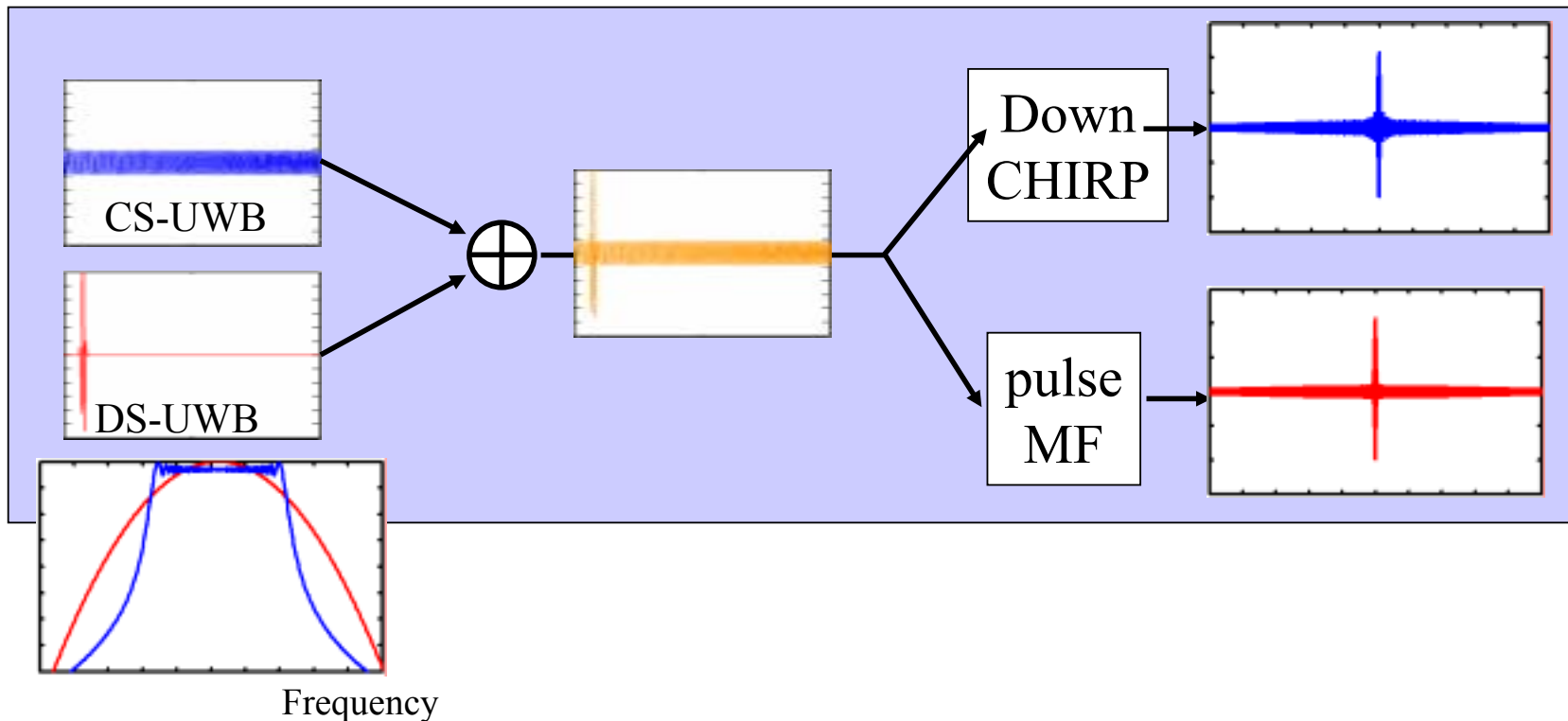


# Cross correlation coefficient

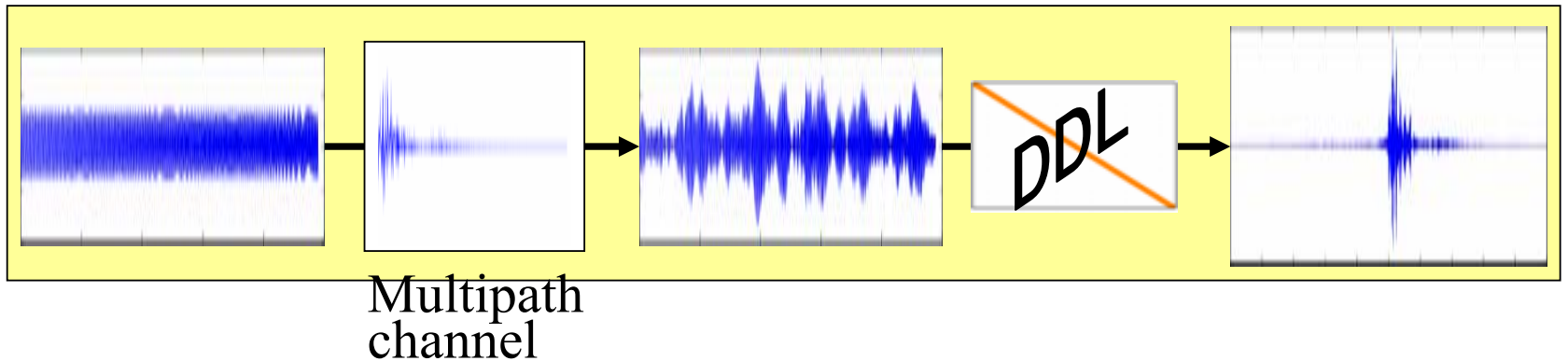


# Dual Mode Demodulation

- Chirped DS-UWB can selectively demodulate both DS-UWB and CS-UWB under condition of coexistence.



# Robustness against multipath

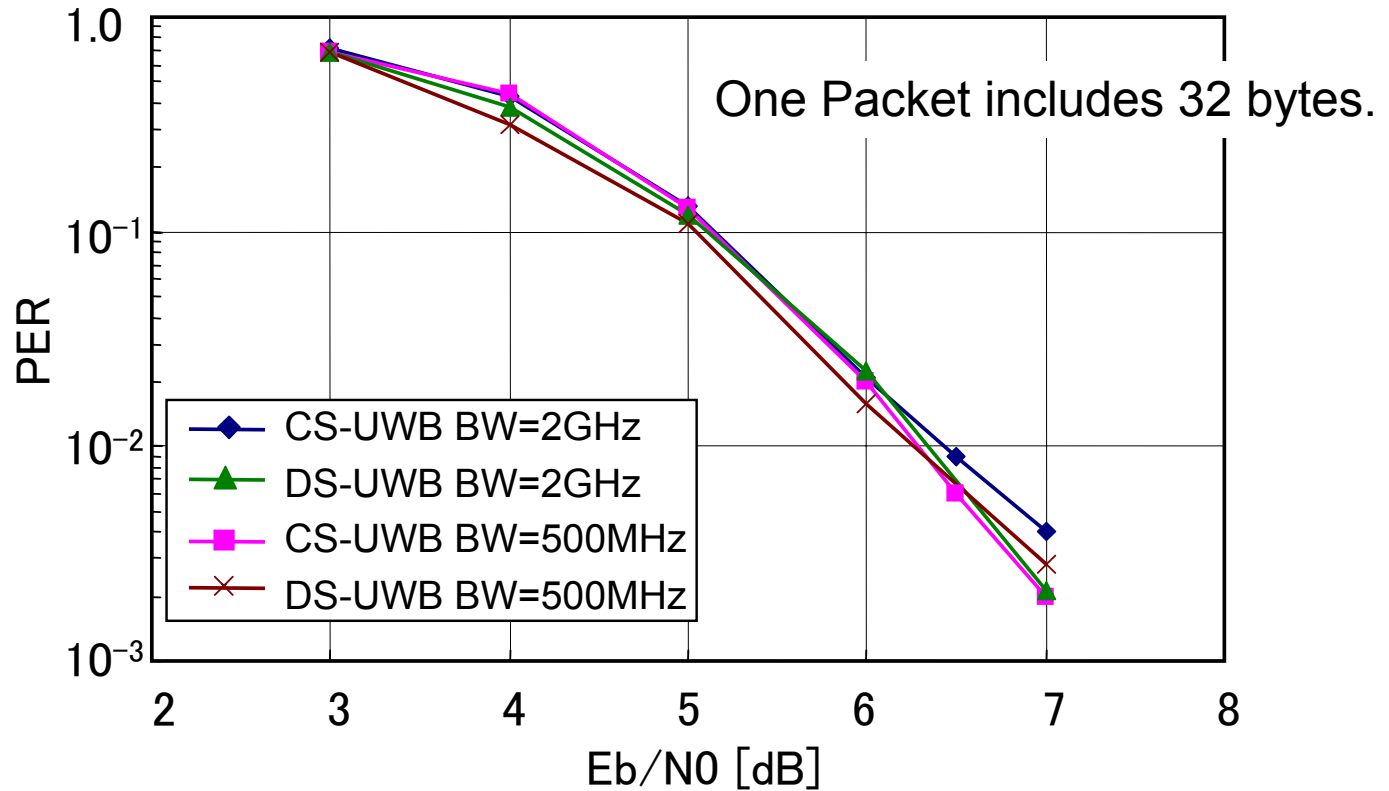


**Due to the good correlation characteristics, correlator can detect a signal even under heavy multipath channel.**

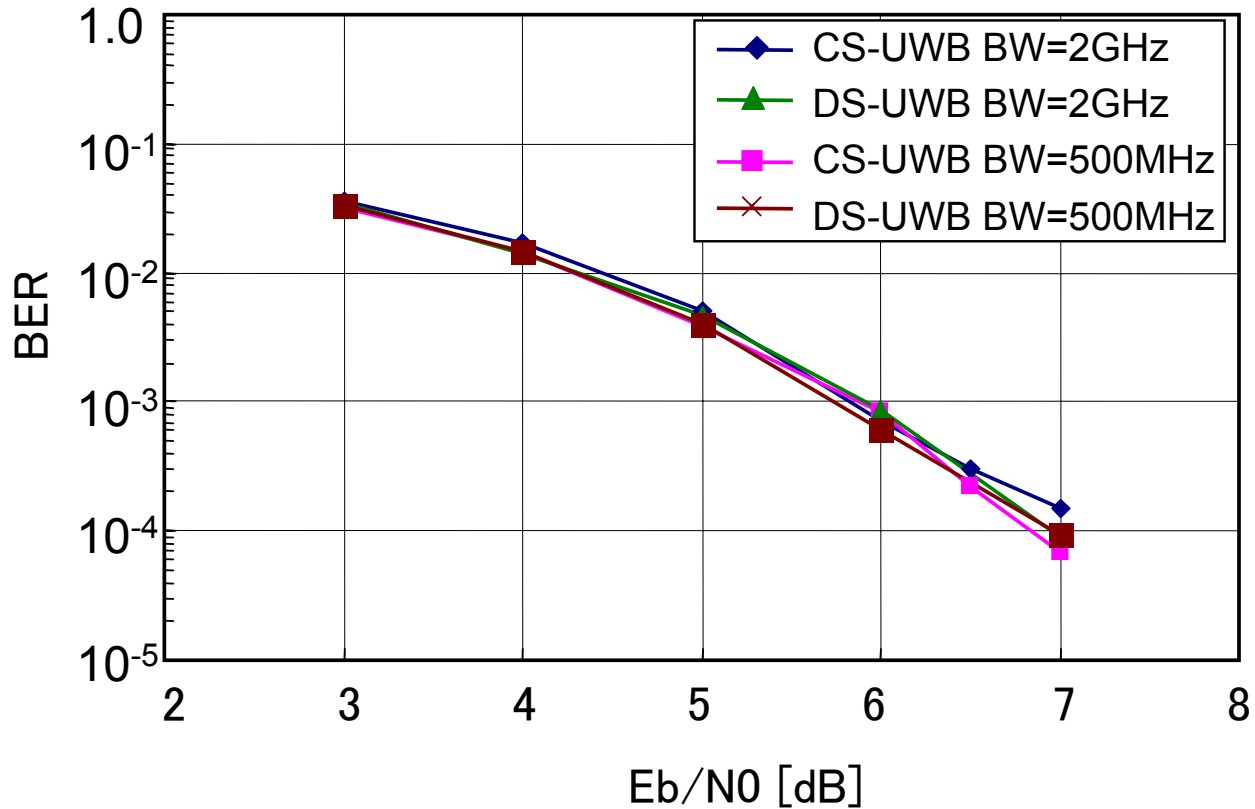
# Pulse shaping

- 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 15-03-0097-05-003a).
  - Adaptive spectrum by considering trade-off between performance and complexity/cost.

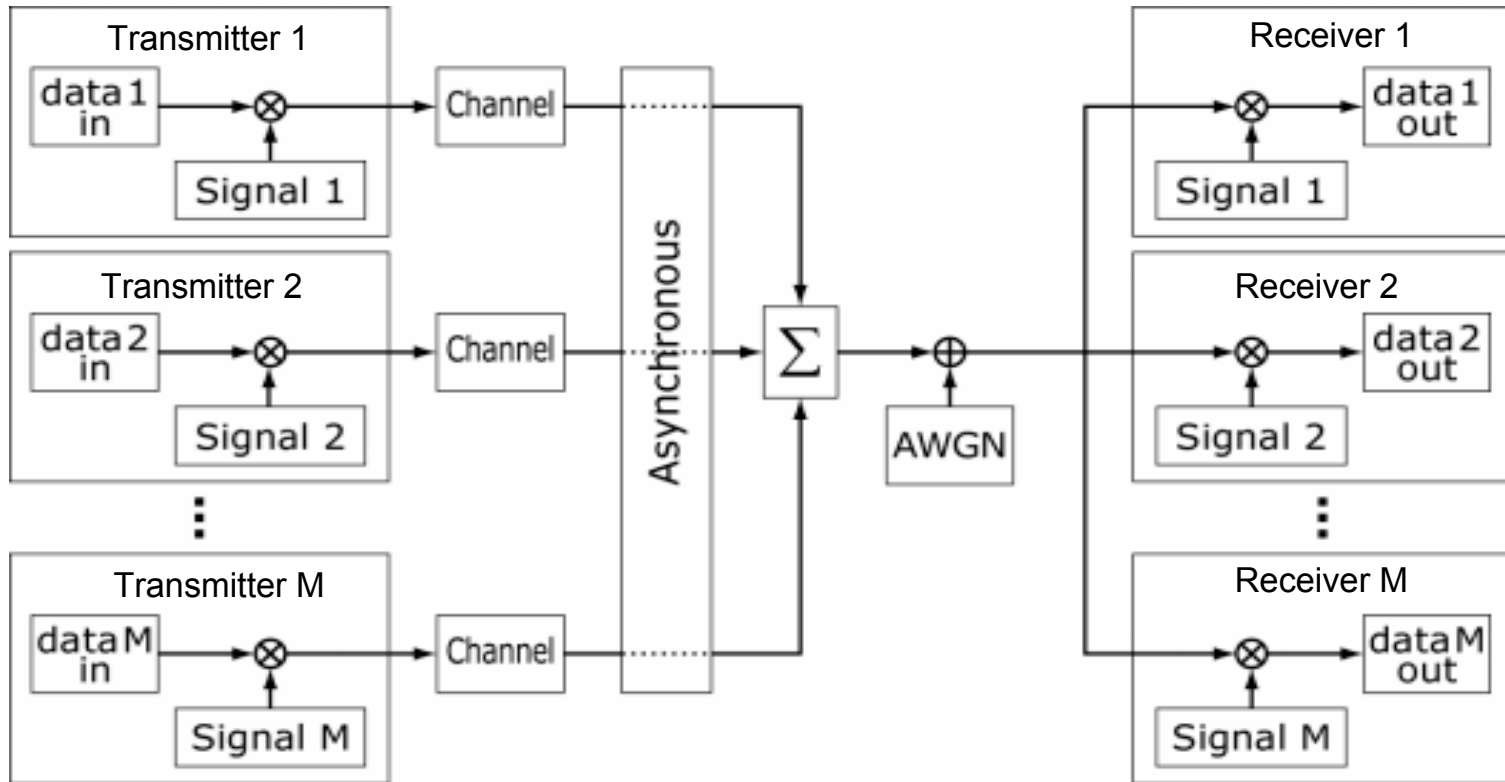
# Simulation results (Single link)



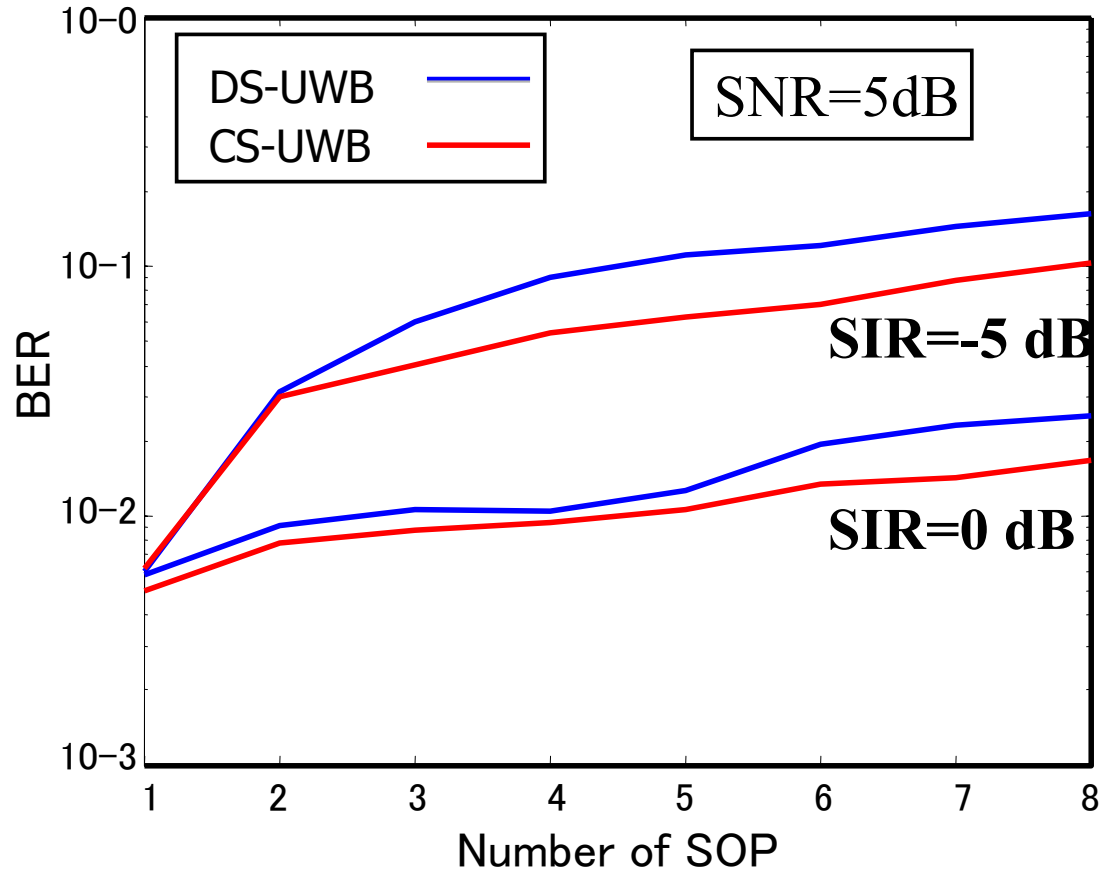
# Simulation results (Single link)



# Simulation block diagram for SOP



# Simulation results for SOP





# DS-UWB Link Budget (BW=2GHz)

Parameter	Value	Value	Notes
Data rate (Rb)	1	1024	(kbps)
Modulation	BPSK		Coherent detection
Coding rate (R)	½		(24,12)-Extended Golay Hard-decision decoding
Raw Symbol rate (Rs)	2	2048	$R_s = R_b/R$ (ksymbol/second)
Pulse duration (Tp)	0.662		(ns)
Spreading code length (Ns)	1024	64	
Chip rate (Rc)	2.048	131.072	$=R_s * N_s$ (MHz)
Chip duration	488.3	7.63	$=1/R_c$ (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
<b>Link Margin</b>	43.28	22.72	dB
<b>Min. Rx Sensitivity Level</b>	-127.75	-97.65	dBm

# DS-UWB Link Budget (BW=500MHz)

Parameter	Value	Value	Notes
Data rate (Rb)	1	1024	(kbps)
Modulation	BPSK		Coherent detection
Coding rate (R)	½		(24,12)-Extended Golay Hard-decision decoding
Raw Symbol rate (Rs)	2	2048	Rs=Rb/R (ksymbol/second)
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
<b>Link Margin</b>	36.63	16.07	dB
<b>Min. Rx Sensitivity Level</b>	-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)	½		(24,12)-Extended Golay Hard-decision decoding
Raw Symbol rate (Rs)	2	2048	$R_s=R_b/R$ (ksymbol/s)
Chirp signal duration (Tc)	100		(ns)
Spreading code length (Ns)	1024	4	
Chip rate (Rc)	2.048	8.192	$=R_s*N_s$ (MHz)
Chip duration	488.3	122.1	$=1/R_c$ (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)	3.50		dB
<b>Link Margin</b>	44.39	23.83	dB
<b>Min. Rx Sensitivity Level</b>	-127.25	-97.15	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	16	
Chip rate (Rc)	2.048	32.768	=Rs*Ns (MHz)
Chip duration	488.3	30.5	=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
<b>Link Margin</b>	37.65	17.09	dB
<b>Min. Rx Sensitivity Level</b>	-127.25	-97.15	dBm

# Multiple Access Method For SOP

- DS-UWB:
  - Use different PN codes  
(and/or different frequency sub bands for  $BW = 500\text{MHz}$ ).
- CS-UWB (in option):
  - Use different chirped pulses or combination of PN codes and chirped pulses.

# Scalability With PN Sequences

Data rate (Rb)	Raw Symbol rate (Rs)	Code length (Ns)	Chip rate (Rp)	Link margin at 10m	Notes
1	2 (ksps)	1024	2.048 (Mcps)	52.8 (dB)	0.662 (ns) pulse width
16 (kbps)	32 (ksps)	1024	32.768 (Mcps)	40.8 (dB)	
32 (kbps)	64 (ksps)	1024	65.536 (Mcps)	37.8 (dB)	
128 (kbps)	256 (ksps)	256	65.536 (Mcps)	31.8 (dB)	
256 (kbps)	512 (ksps)	256	131.072(Mcps)	28.7 (dB)	
1024 (kbps)	2048 (ksps)	64	131.072(Mcps)	22.7 (dB)	
2048 (kbps)	4096 (ksps)	64	131.072(Mcps)	19.7 (dB)	Optional, use 4BOK
4096 (kbps)	8192 (ksps)	64	131.072(Mcps)	16.7 (dB)	Optional, use 16BOK
<b>w/chirp</b>					
1	2 (ksps)	1024	2.048 (Mcps)	53.9 (dB)	100 (ns) chirp duration
16	32 (ksps)	64	2.048 (Mcps)	41.9 (dB)	100 (ns) chirp duration
128	256 (ksps)	16	4.096 (Mcps)	32.9 (dB)	100 (ns) chirp duration
1024	2048 (ksps)	4	8.192 (Mcps)	23.8 (dB)	100 (ns) chirp duration

# Performance With 15.4a CMs

	1kbps (nominal) Average PER at 30m
CM1	0
CM2	0
CM3	0
CM4	0
CM5	0
CM6	0
CM7	0
CM8	0.008

## Simulation conditions:

(1) Receiver; 1-Gsps and 2-bit ADC. (2) No rake combining. (3) Differential coded BPSK (4) (24,12)-Golay coding and hard decision decoding. (5) Modulated Gaussian waveform, bandwidth 2GHz (3.1G-5.1G), and center frequency 4.096GHz. (6) Antenna effects are not considered.

# Ranging Procedure 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 Resolution 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

# Complexity/Power Consumption

Component	Gate Counts (kgate)	Area (mm <sup>2</sup> )	Communication		Ranging	
			Power @1kbps* (mW)	Power @1024kbps (mW)	Power@slow Cycle (mW)	Power@fast Cycle (mW)
Tx and Rx Mix.	-	2.5	1.2	12	1.2	12
Center Freq. Gen.	-		2	20	2	20
Tx Amp.	-		0.8	8	0.8	8
LNA	-		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
<b>Total</b>	60	2.5 (Analog) 0.36 (Digital)	10.2	122	9.0	102

Assuming standard 0.13mm CMOS technology

\*With intermittent operation in analog section

# 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 0.13mm.
  - Basics of the system have been demonstrated in DS-UWB 802.15.3a proposal.
- **Time to market:**
  - 4H, 2005

# Conclusions

- Pulsed DS-UWB with optional CS-UWB can perform best for various applications in 15.4a.
  - Generalized structure is flexible for different applications with pre-optimized sets of parameters.
  - Full and reduced function devices (FFD and RFD) can choose chirped DS-UWB and simple non-chirped DS-UWB for high and low speed transmission, respectively.
- Feasibility and scalability are guaranteed both.
  - Low complexity, low cost, low power consumption.
  - Precision ranging.
  - Robustness.
- Transmission and ranging performance are well balanced in option for various applications.