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Submission Title: [**Chirp Signaling UWB scheme**]

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Company [(1)National Institute of Information and Communications Technology (NICT), (2)Fujitsu Limited, (3)Oki Electric Industry Co., Ltd.]

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Re: [Optional mode on TG4a UWB-PHY baseline]

Abstract [This document describes chirp-signal UWB(CS-UWB), which is one of the optional mode on the UWB-PHY baseline for TG4a.]

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

Chirp Signaling UWB Scheme

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Outlines

- Introduction of chirp signaling UWB.

- Technical advantages

- Link budget examples

- Performance examples on SOP

- Concluding remarks

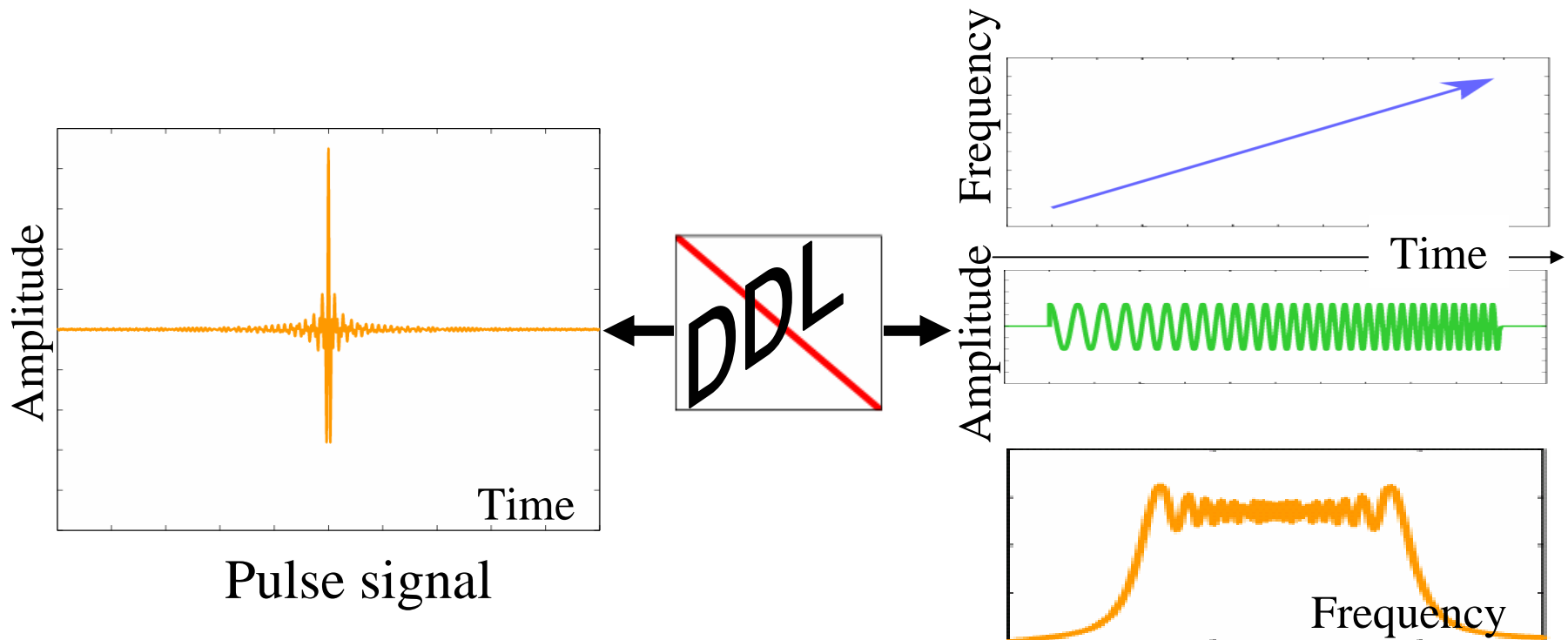Reference: 15-04-0648-02-004a

          15-04-0716-01-004a

Benefits of chirp signaling (CS) UWB

- **Additional dimension for SOP**
  - Chirp slop and/or chirp pattern
  - Available to be combined with DS-code and/or frequency subbands

- **Low Peak-to-average ratio**
  - Efficient use of FCC spectrum mask
  - Less interference level, better coexistence.

- **Enhancement of robustness against multipath**
  - Better autocorrelation than DS-UWB.

- **Potential ability to increase ranging precision**
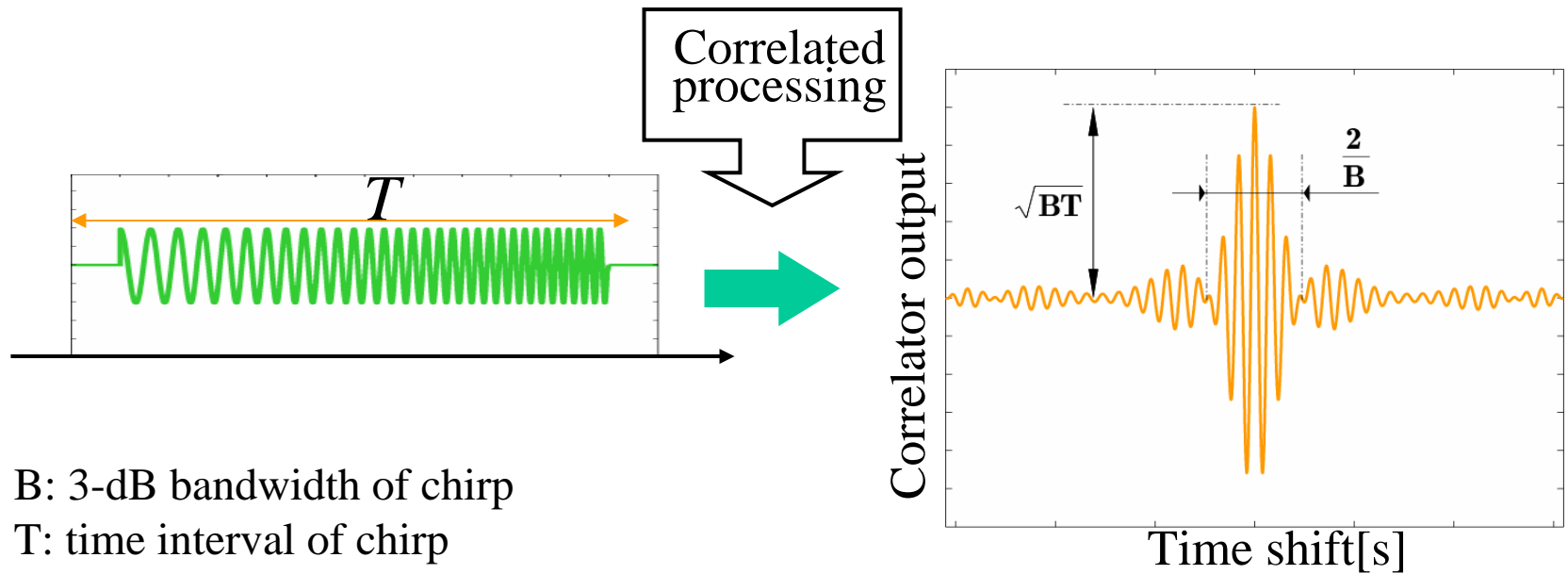 - Benefit from excellent autocorrelation

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

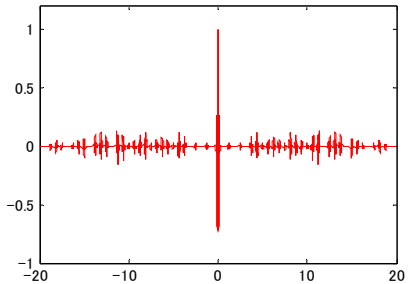- Correlated processing produces not only high precision ranging but also robustness against noise and multipath.

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

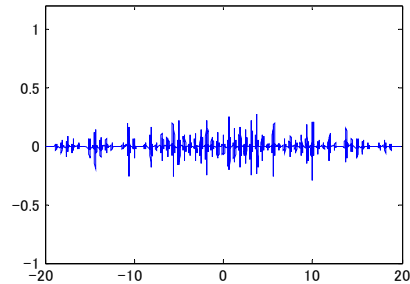The wide the bandwidth, the sharp the peak.
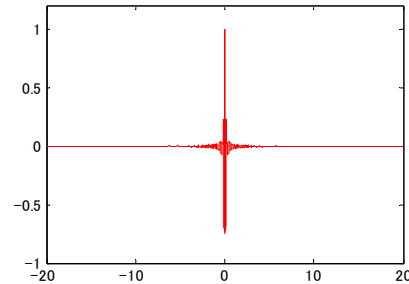
Correlation characteristics

DS-UWB

Chirp Signal

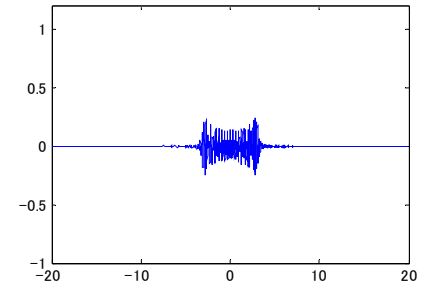

Auto-correlation   Cross-correlation

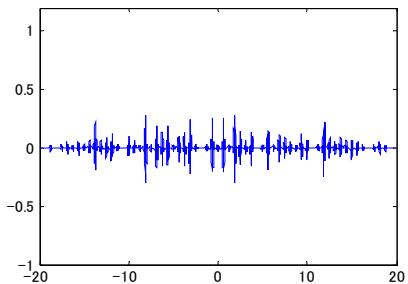Cross-correlation   Cross-correlation

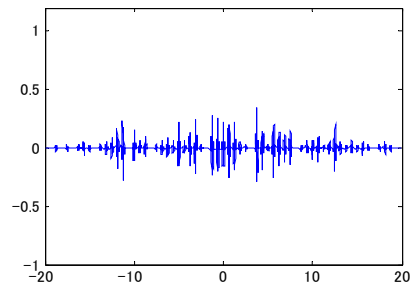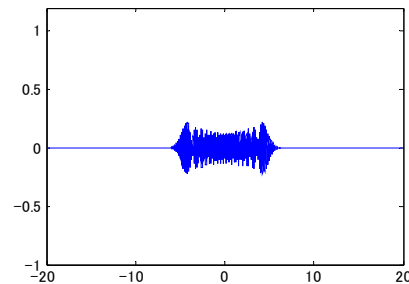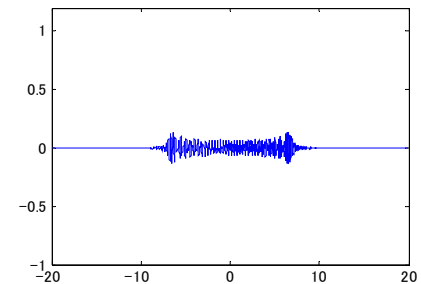Auto-correlation   Cross-correlation
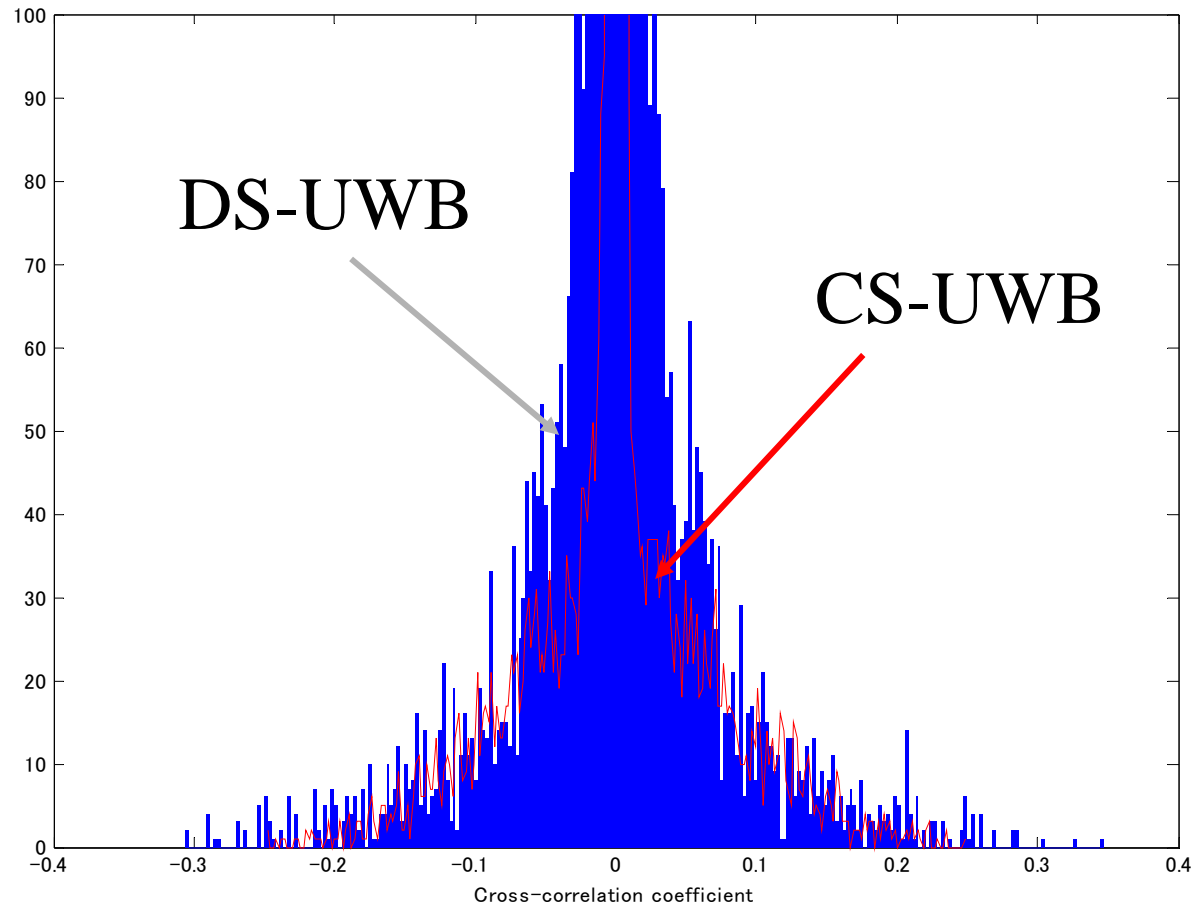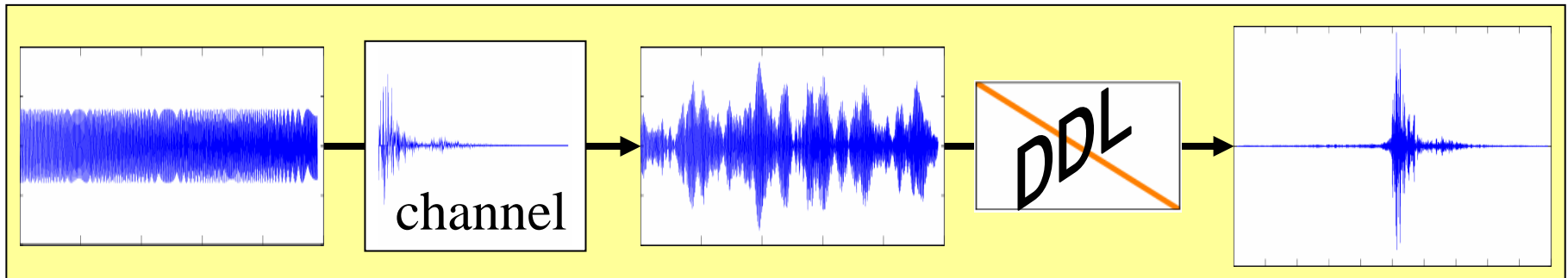
Cross-correlation   Cross-correlation
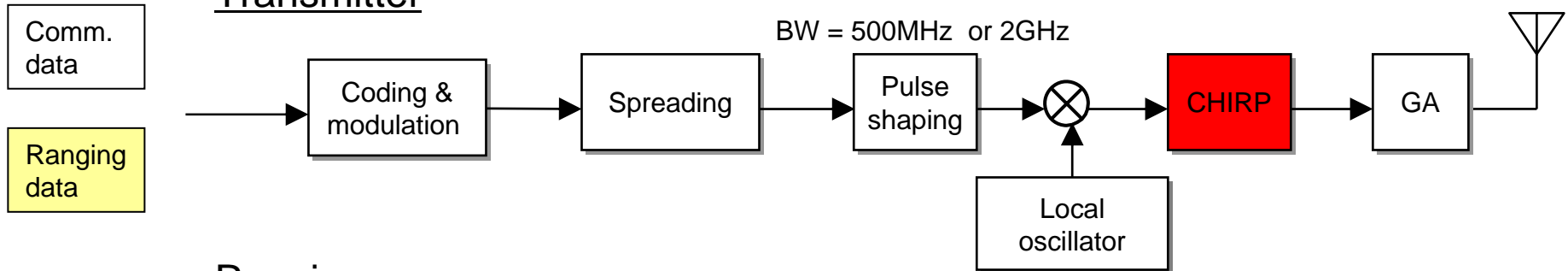
Cross correlation coefficient
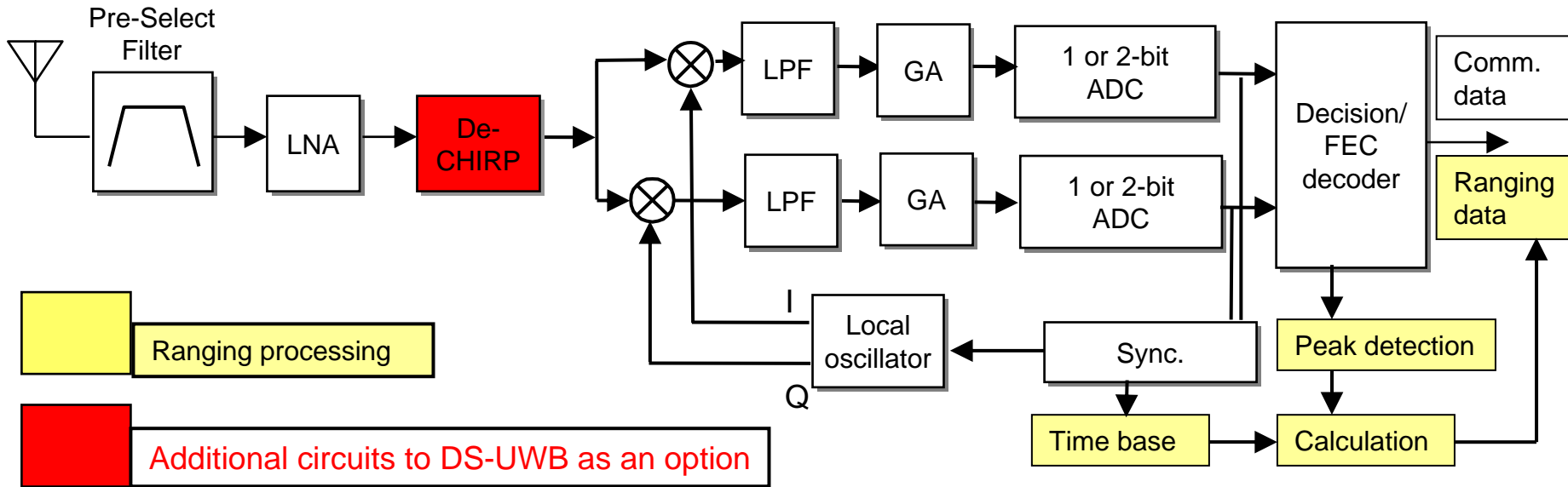
Robustness against multipath and interference

Due to the excellent correlation characteristics, correlator can detect a signal even under heavy multipath and interference channel.
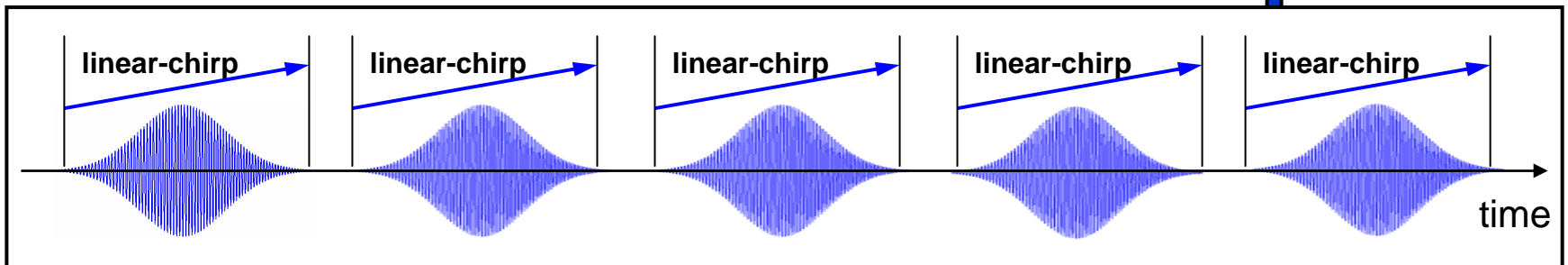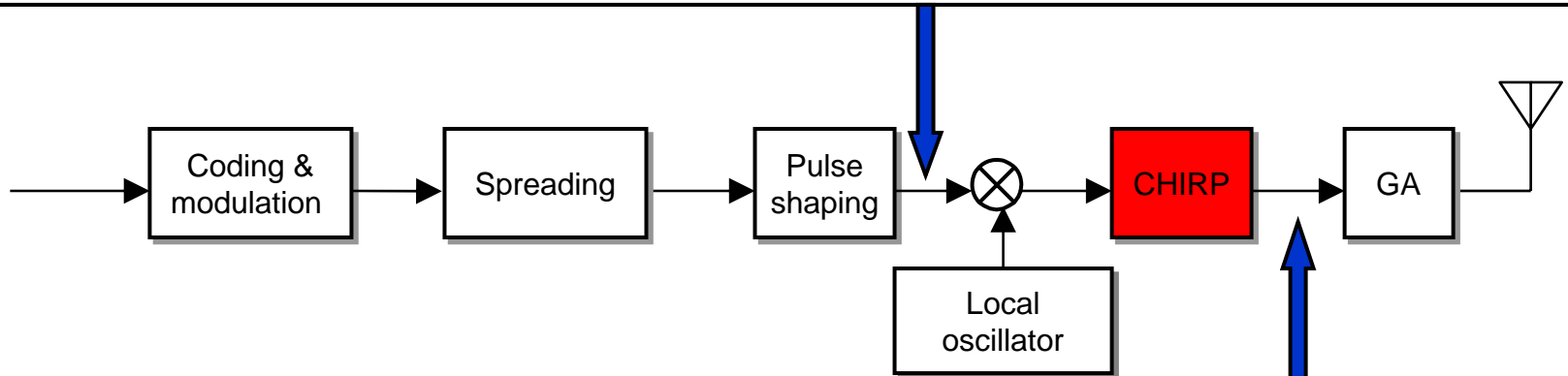
Overall Block Diagram With Optional CS

Waveforms With & Without Optional CS

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

Due to the low peak-to-average ratio, CS-UWB provides 1 dB additional link margins.

Simulation results (Single link)

One Packet includes 32 bytes.

Chart legend:
- CS-UWB BW=2GHz
- DS-UWB BW=2GHz
- CS-UWB BW=500MHz
- DS-UWB BW=500MHz

Y-axis: PER
X-axis: Eb/N0 [dB]
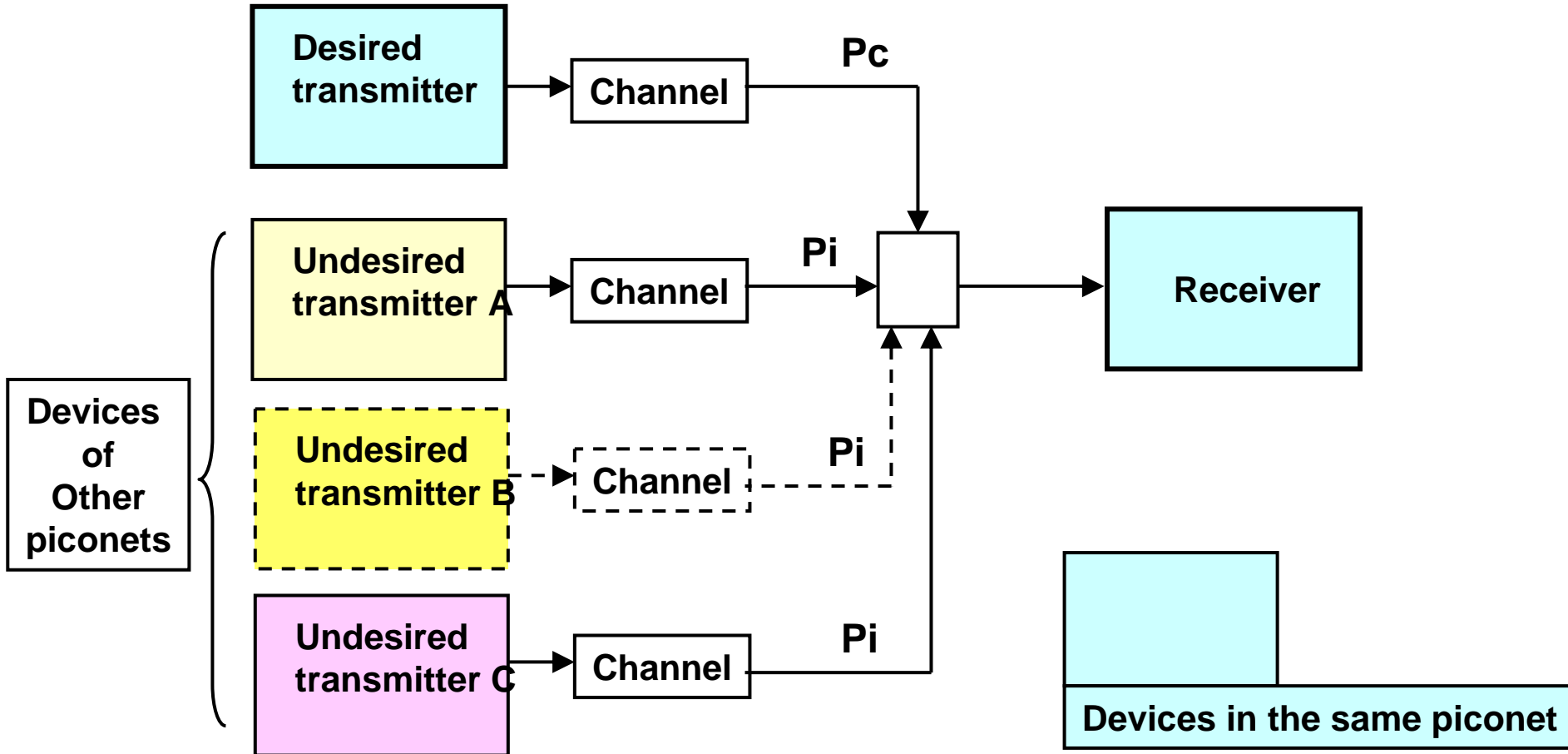
Multiple Access Methods For SOP
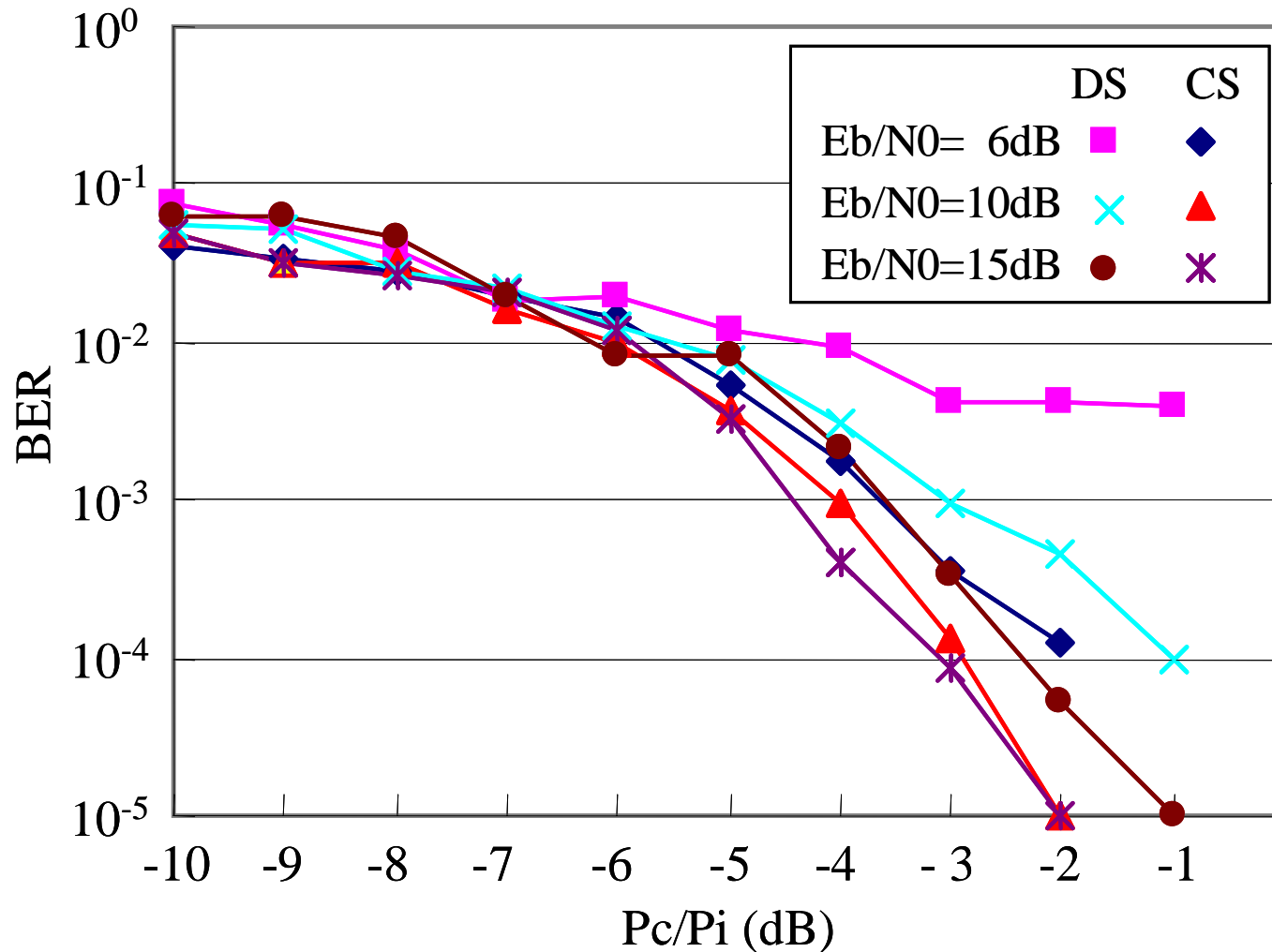
- FDM (frequency subbands)
  - Number is limited.
- CDM (different code sequences)
  - Possible codes reduced if we seek short length codes.
- Chirped pulses (in option):
  - Plenty of source ! (chirp slope and pattern)
  - Better performance than CDM !

Simulation block diagram for SOP

Simulation results for SOP

Scalability With PN Sequences

Data rate (Rb)	Raw Symbol rate (Rs)	Code length (Ns)	Chip rate (Rp)	Link margin at 10m	Notes
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)	
CS-UWB					
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

Conclusion remarks

- **High capacity for SOP**
  - Plenty of source with chirp
  - Combination with FDM and/or CDM
- **Additional link margins**
  - Low peak-to-average ratio.
- **Robustness against interference and multipath**
  - Excellent correlation characteristics
- **Potential high precision ranging.**
  - Excellent correlation characteristics
- **An selectivity for FFD and RFD**
  - Chirp vs. Non chirp