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Submission Title: [Results and Feasibility on DS-UWB with Optional CS-UWB]

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Source: [Huan-Bang Li(1), Kenichi Takizawa(1), Shigenobu Sasaki(1), Shinsuke Hara(1), Makoto Itami(1), Tetsushi Ikegami(1), Ryuji Kohno(1), Toshiaki Sakane(2), Kiyohito Tokuda(3)]

Company [(1)National Institute of Information and Communications Technology (NICT),

(2)Fujitsu Limited, (3)Oki Electric Industry Co., Ltd.]

Contact: Huan-Bang Li.

Voice:[+81 46 847 5104, E-Mail: lee@nict.go.jp]

Abstract: [Results and discussion on an earlier proposed DS-UWB with optional CS-UWB are presented. Perspective on the technique is provided.]

Purpose: [To forward the discussion within 15.4a group]

Results and Feasibility on DS-UWB With Optional CS-UWB

Huan-Bang Li, Kenichi Takizawa, Shigenobu Sasaki, Shinsuke Hara,
Makoto Itami, Tetsushi Ikegami, and Ryuji Kohno

National Institute of Information and Communications Technology (NICT), Japan

Toshiaki Sakane
Fujitsu Limited,

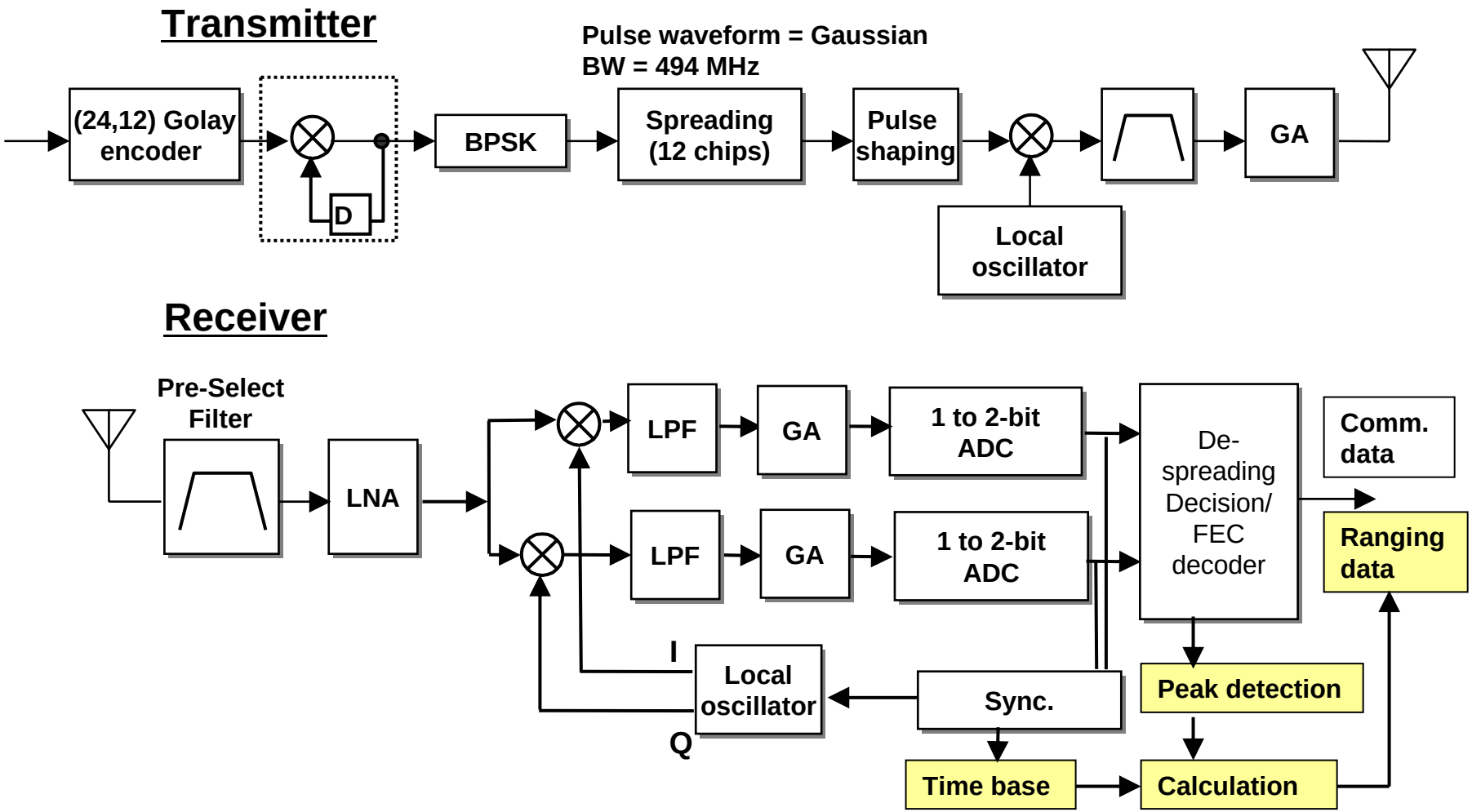
Kiyohito Tokuda
Oki Electric Industry Co. Ltd.

Motives and Contents

- **15.4a group had agreed to use impulse modulation based UWB while the code sequence and pulse shape are subjected to more discussions.**
- **Besides the mandatory mode, there is also agreement to include optional wave forms such as chirp to enhance performance.**
- **This document shows examples on**
  - **Basic results of the mandatory mode (DS-UWB) based on parameters agreed within the group.**
  - **Advantages that the optional CS-UWB can provide.**
  - **Feasibility of the optional CS-UWB**
- **Emphasis is laid on 'additional merits' of the optional CS-UWB to the mandatory DS-UWB.**

Mandatory DS-UWB

Block diagram of mandatory DS-UWB



DS-UWB Link Budget (BW=494MHz)

Parameter	Value	Notes
Data rate (Rb)	1083	(kbps)
Modulation	BPSK	Coherent detection
Coding rate（R)	1/2	(24,12)-Extended Golay Hard-decision decoding
Raw Symbol rate (Rs)	2167	Rs=Rb/R (ksymbol/second)
Pulse duration (Tp)	3.86	(ns)
Spreading code length (Ns)	12	
Chip rate (Rc)	26	=Rs*Ns (MHz)
Chip duration	38.5	=1/Rc (nsec)

Parameter	Value	Unit
Distance (d)	50	m
Peak payload bit rate (Rb)	1083	kbps
Average Tx power (Pt)	-16.9	dBm
Tx antenna gain (Gt)	0	dBi
Max Frequency	4.199	GHz
Min Frequency	3.705	GHz
Geometric center frequency (fc)	3.94	GHz
Path loss @ 1m (L1)	44.36	dB
Path loss @ d m (Ld)	33.98	dB
Rx antenna gain (Gr)	0	dBi
Rx power (Pr)	-95.24	dBm
Average noise power per bit (N)	-114	dBm
Rx Noise figure (Nf)	7.00	dB
Average noise power per bit (Pn)	-106.65372	dBm
Minimum Eb/N0 (S)	6.25	dB
Implementation loss (I)	3.00	dB
Link Margin	2.16	dB
Prposed Min. Rx Sensitivity Level	-97.40	dBm

Link Margins on 15.4a Channel Models

Link margin [dB]	single finger Rake @ 30 m	3-finger Rake @ 30m	single finger Rake @ 10 m	3-finger Rake @ 10m
AWGN	6.84	----	16.34	----
CM1	0.49	2.86	9.99	12.36
CM2	N/A	0.89	7.60	10.39
CM3	2.44	4.87	11.9	14.36
CM4	N/A	2.65	8.9	12.15
CM5	1.27	4.07	10.77	13.5
CM6	N/A	0.41	7.28	9.9
CM7	1.24	4.32	10.75	13.82
CM8	N/A	N/A	4.42	8.5

SOP Support

1. By FDM

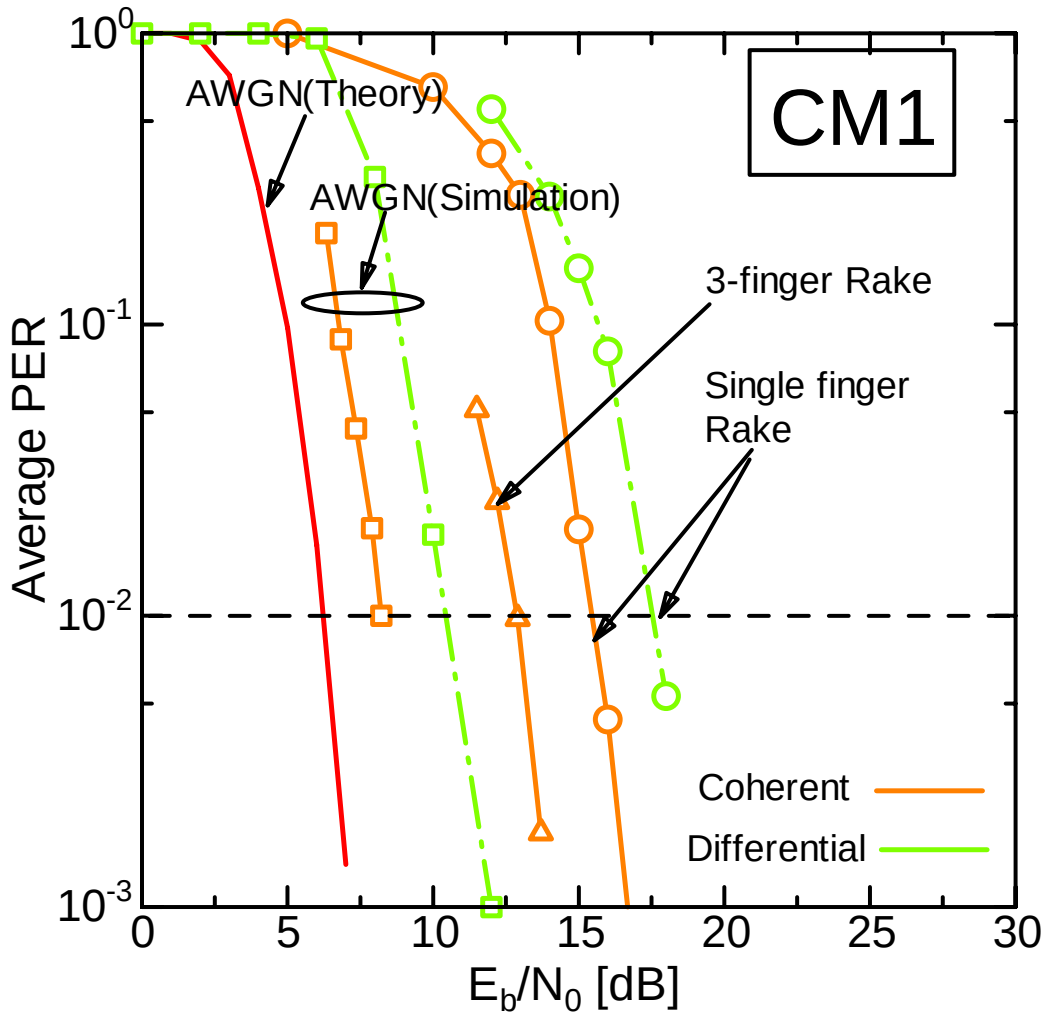
Band No.	3 dB BW (MHz)	Low Freq. (MHz)	Center Freq. (MHz)	High Freq. (MHz)
1	494	3211	3458	3705
2 (mandatory)	494	3705	3952	4199
3	494	4199	4446	4693
4	1482	3211	3952	4693

2. By 12-chip DS codes

Code												
1	1	-1	1	-1	1	1	1	-1	-1	-1	1	-1
2	1	-1	-1	1	-1	1	1	1	-1	-1	-1	1

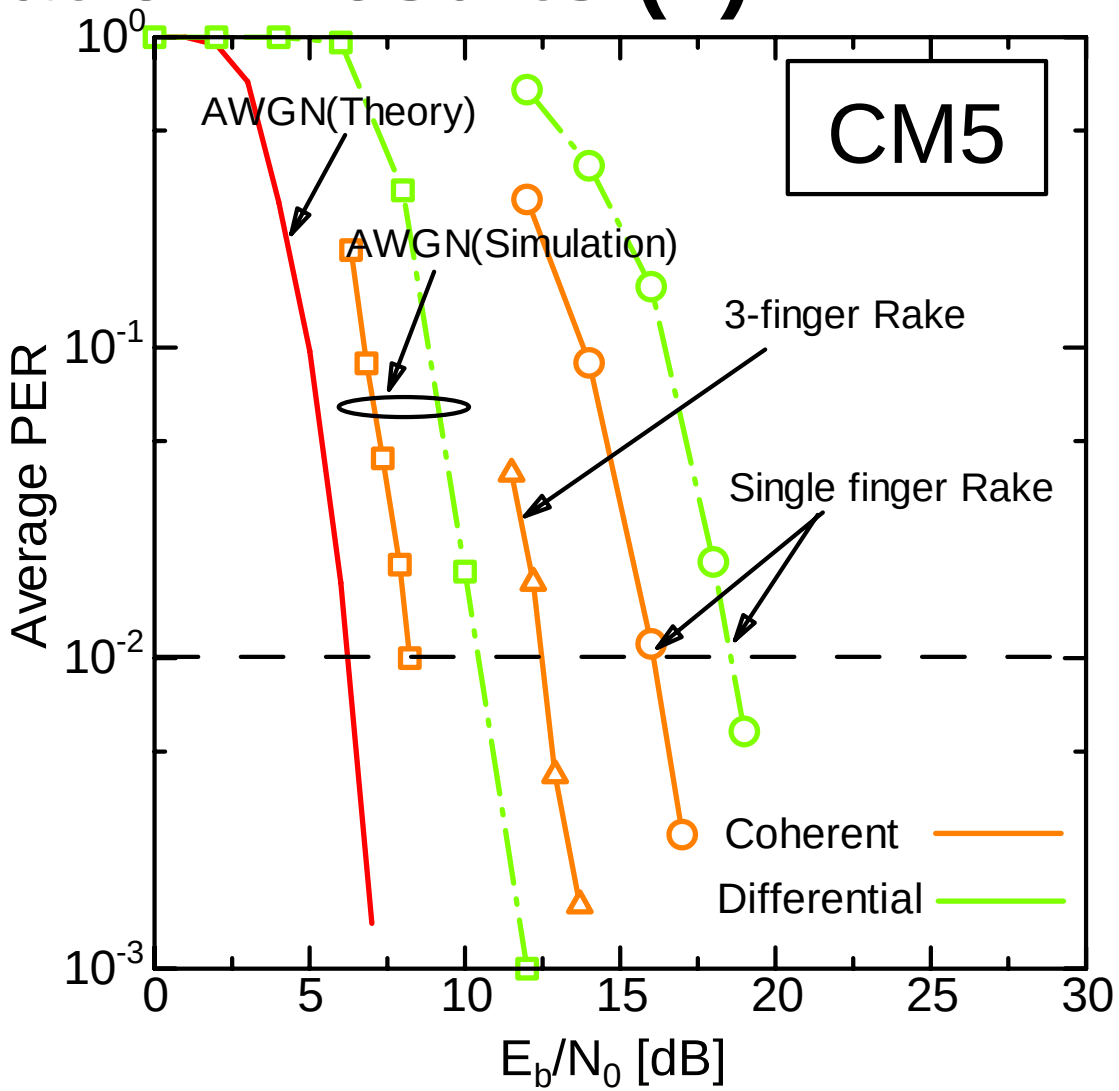
Simulation Results (1)

- 15.4a CM1 channel
- Coherent and differential detection
- Single-finger and 3-finger RAKE
- 1-bit ADC
- Mandatory band



Simulation Results (2)

- 15.4a CM5 channel
- Coherent and differential detection
- Single-finger and 3-finger RAKE
- 1-bit ADC
- Mandatory band



Optional chirp

+ Additional dimensions for SOP
+ Robustness against interference
+ High precision ranging

← Better correlation

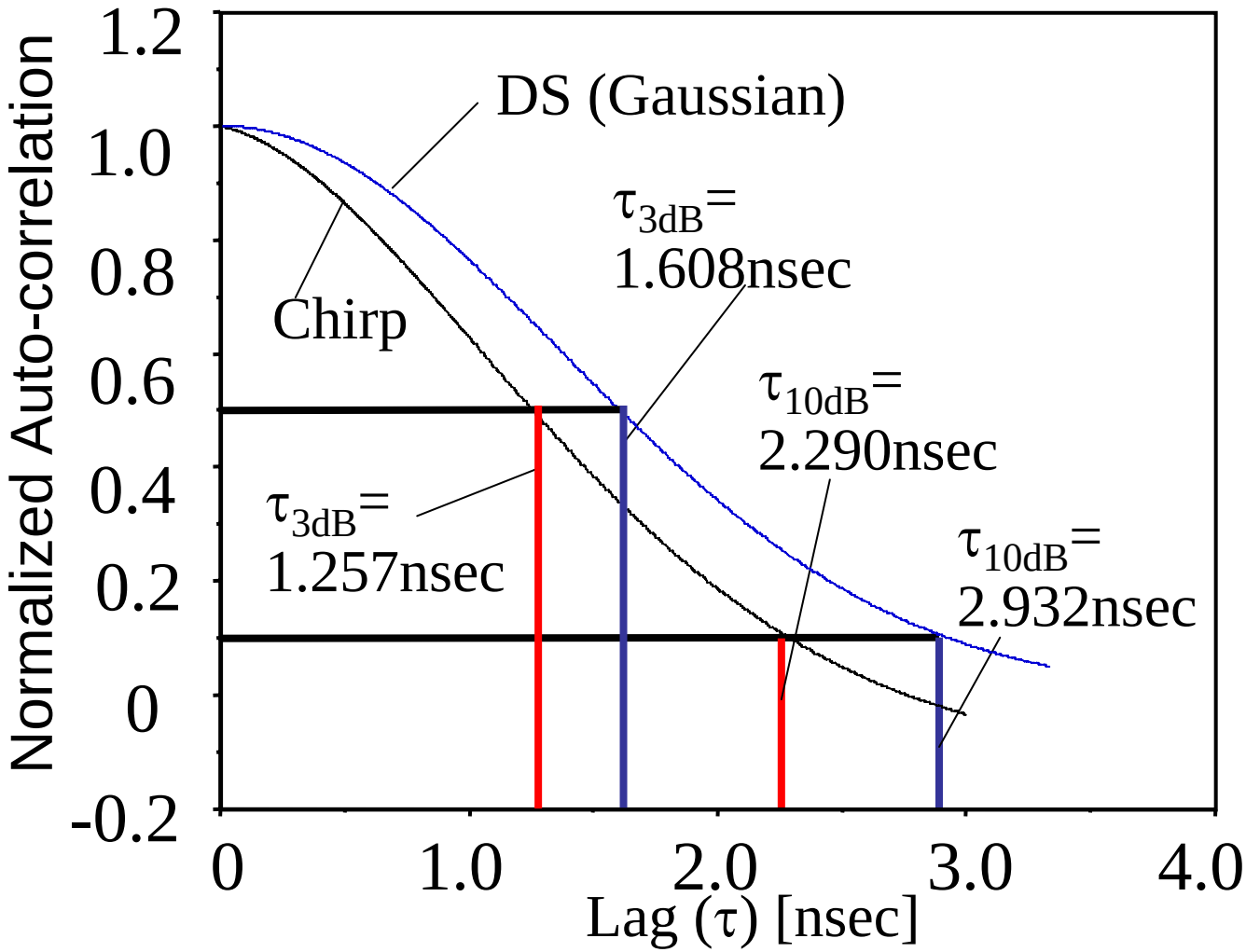
+ Additional link margins ← More average power

- Feasibility
- Compliance with FCC rule

Assumption on Correlation Calculation

- The same band width (500MHz) for both DS-UWB and Optional CS-UWB
- Gaussian pulse for DS-UWB
- Linear chirp for optional CS-UWB
- Chirp rate = 100 MHz
- Carrier frequency = 4 GHz

Advantages --- Better Correlation



The auto-correlation main lobe

	Gaussian pulse	Chirp Pulse	Ratio
Lag at -3dB	1.608 nsec	1.257 nsec	78%
Lag at -10dB	2.932 nsec	2.290 nsec	78%

The auto-correlation main lobe of chirp pulse is much narrower (22% reduction) than that of Gaussian pulse. This will benefit SOP, anti-multipath,and ranging operation.

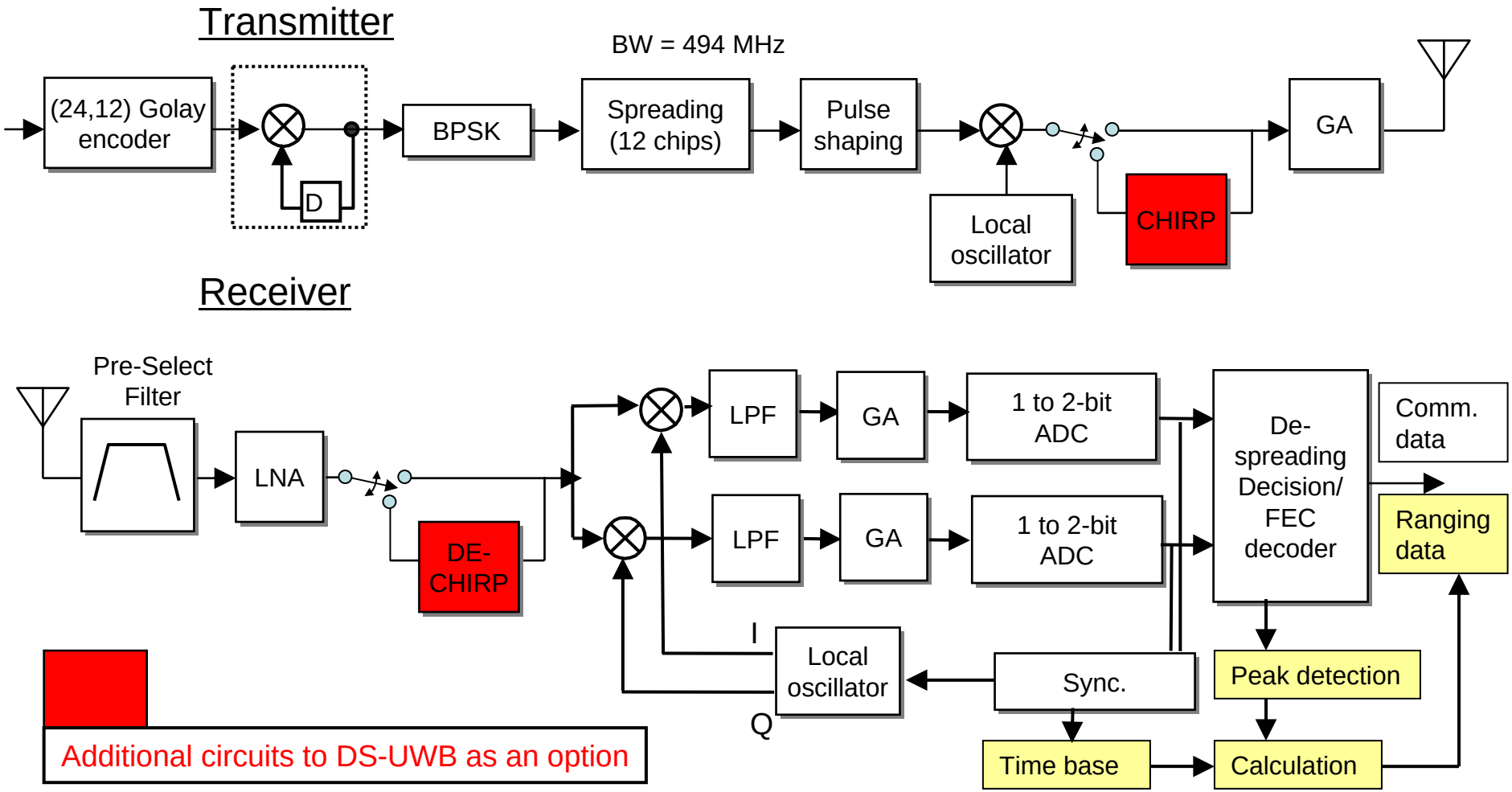
CS-UWB Link Budget (BW=494MHz)

Parameter	Value	Notes
Data rate (Rb)	1083	(kbps)
Modulation	BPSK	Coherent detection
Coding rate（R)	1/2	(24,12)-Extended Golay Hard-decision decoding
Raw Symbol rate (Rs)	2167	Rs=Rb/R (ksymbol/s)
Chirp signal duration (Tc)	3.86	(ns)
Spreading code length (Ns)	12	
Chip rate (Rc)	26	=Rs*Ns (MHz)
Chip duration	38.5	=1/Rc (nsec)

1 dB more gains than DS-UWB.
(Different items from DS-UWB are given in red color)

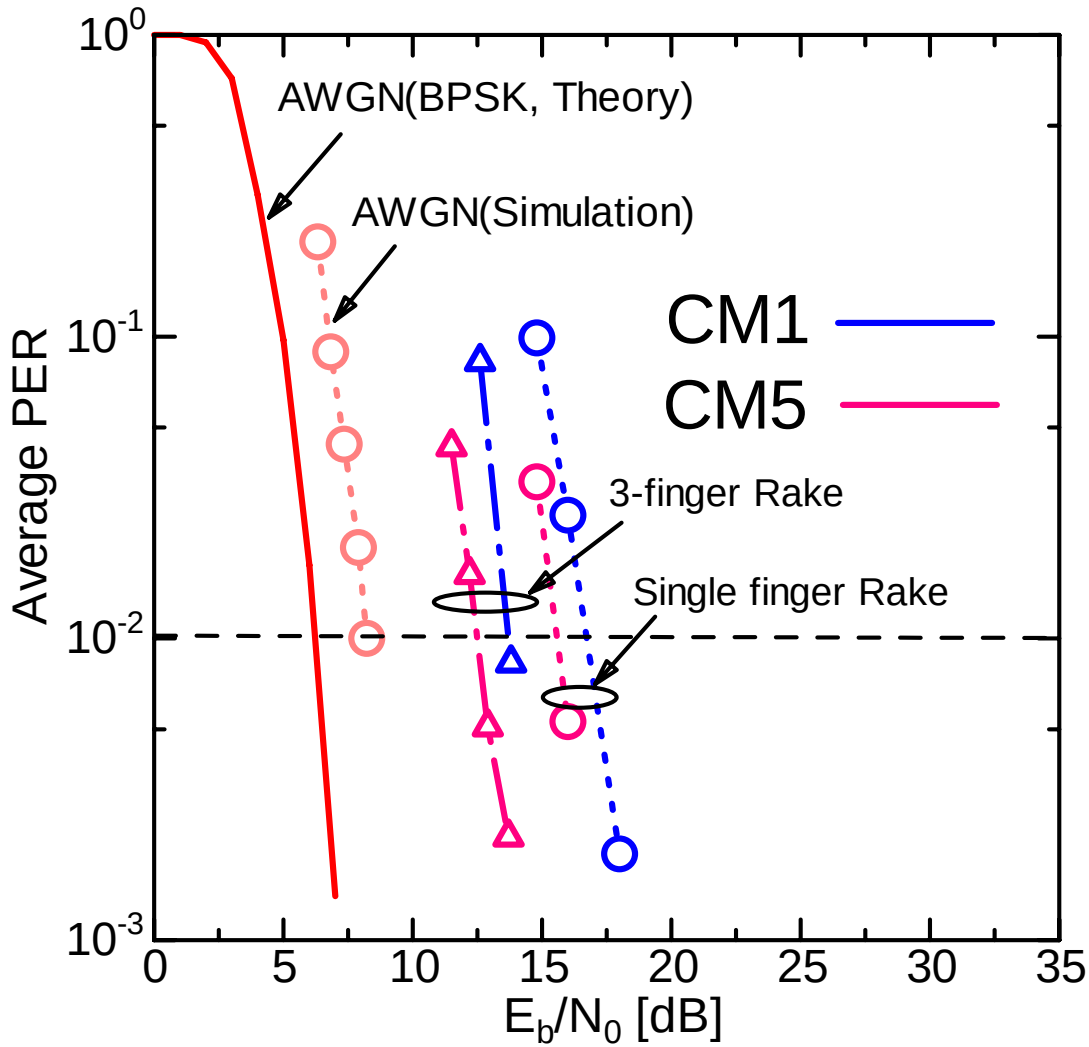
Parameter	Value	Unit
Distance (d)	50	m
Peak payload bit rate (Rb)	1083	kbps
Average Tx power (Pt)	-15.38	dBm
Tx antenna gain (Gt)	0	dBi
Max Frequency	4.199	GHz
Min Frequency	3.705	GHz
Geometric center frequency (fc)	3.94	GHz
Path loss @ 1m (L1)	44.36	dB
Path loss @ d m (Ld)	33.98	dB
Rx antenna gain (Gr)	0	dBi
Rx power (Pr)	-93.72	dBm
Average noise power per bit (N)	-114	dBm
Rx Noise figure (Nf)	7.00	dB
Average noise power per bit (Pn)	-106.65372	dBm
Minimum Eb/N0 (S)	6.25	dB
Implementation loss (I)	3.50	dB
Link Margin	3.18	dB
Prposed Min. Rx Sensitivity Level	-96.90	dBm

Overall Block Diagram With Optional CS



Simulation Results (3)

- 15.4a CM1 and CM5 channels
- Coherent detection
- Single-finger and 3-finger RAKE
- 1-bit ADC
- Mandatory band



Simulation Results

- **SOP performance** (The allowable minimum distance for PER=10^{-2})

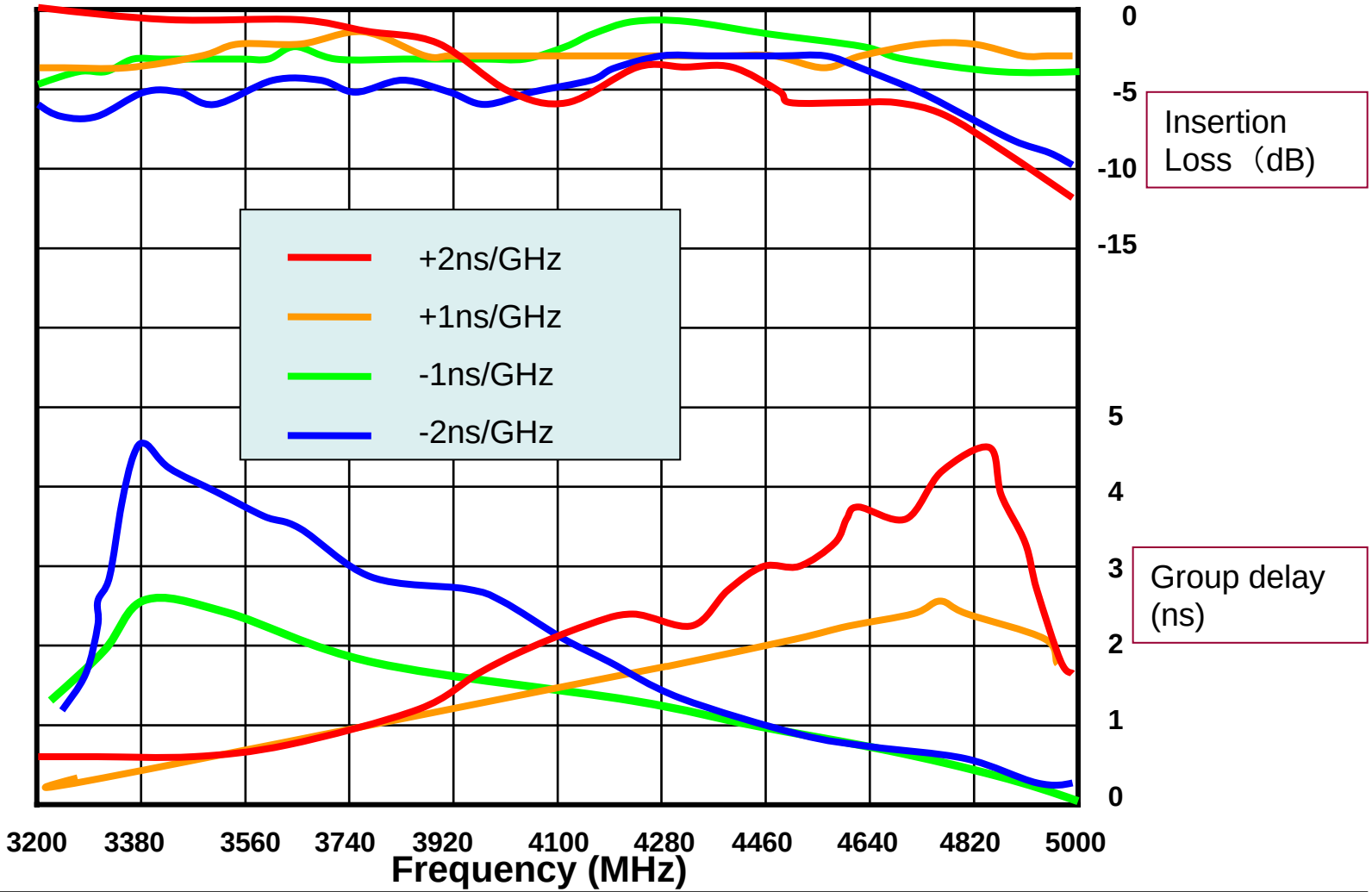
1. **DS-UWB (coherent detection, d_ref=15m)**

	Co-channel (CM1)	Co-channel (CM5)	Adjacent Ch. (2SOPs, CM1)	Adjacent Ch. (2SOPs, CM5)
d_int [m]	8.3	9.0	12.4	9.8

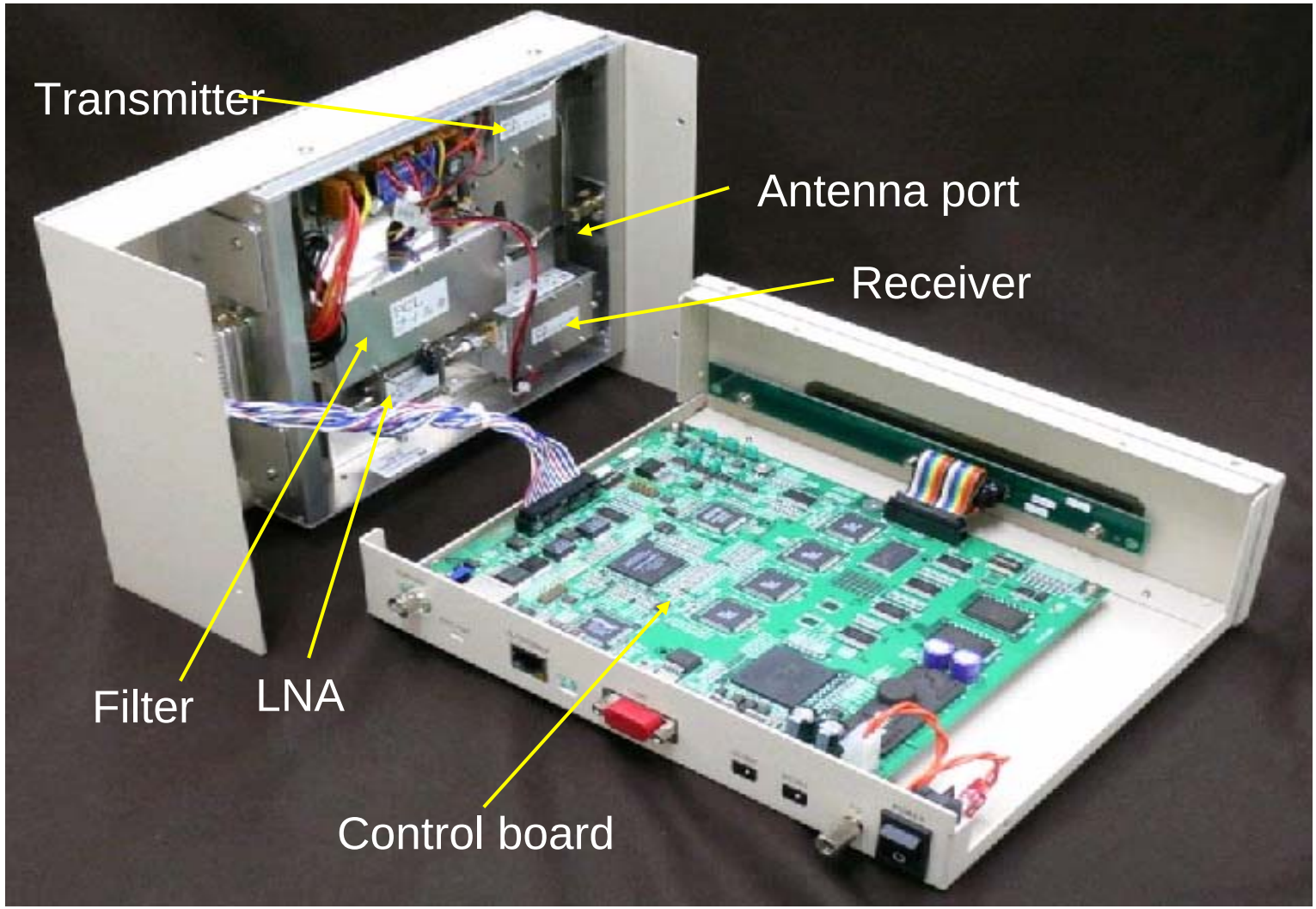
2. **CS-UWB (coherent detection, d_ref=15m)**

	Co-channel (CM1)	Co-channel (CM5)	Adjacent Ch. (2SOPs, CM1)	Adjacent Ch. (2SOPs, CM5)
d_int [m]	7.4	8.4	7.9	5.5

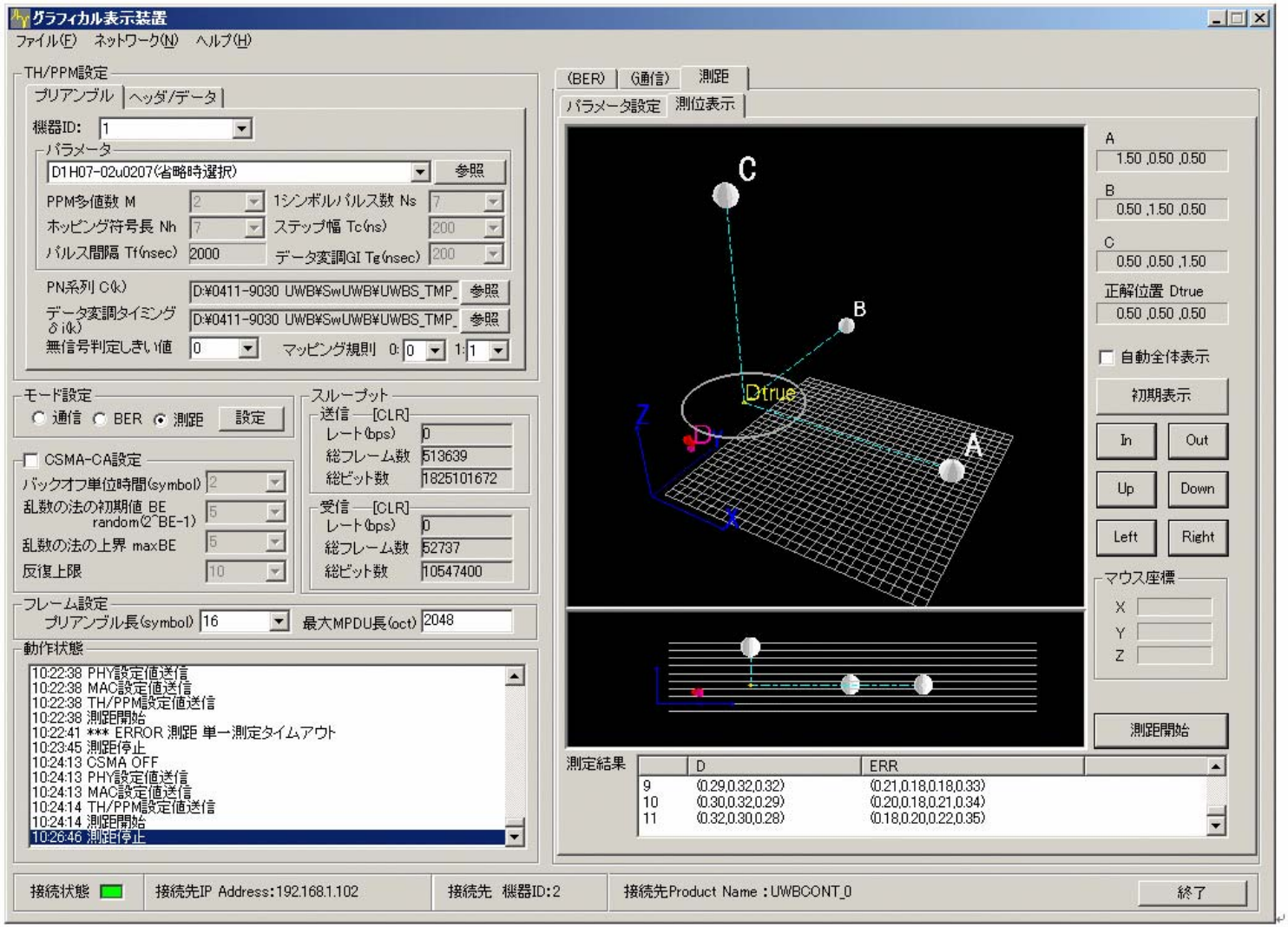
Characteristics of Chirp Filter



Prototype Device



Graphically View for the Sensor Position



Compliance with FCC rule

Why chirp UWB has not been approved by FCC

- **FCC Regulation on UWB (1st R&O)**
  - **When measuring the emission power, Frequency sweep, and Frequency hopping must be stopped.**
  - **If sweep of a pure chirp UWB is stopped, it becomes nothing more than a single carrier signal. Consequently, it will not satisfy the FCC definition of UWB.**
  - **For MB-OFDM even hopping is stopped, it still satisfies the UWB definition.**
- **FCC Waiver for MB-OFDM**
  - **If it is in ordinary operation, hopping may not be stopped for measurement.**
  - **Frequency sweep or chirp are not included in the FCC waiver.**

Approach for Compliance

- The chirp signal should occupy a bandwidth larger than 500MHz. This requires a chirp signal duration at an order of 2ns.
  - Up to 4nsec/1GHz chirp realization had been shown. By combining with DS-UWB, the FCC definition can be met.

- When sweep is stopped, the signal BW should still meet the FCC definition.
  - Yes. The signal turns out to a DS-UWB signal when the chirp filter is switched out.

Concluding Remarks

- DS-UWB with optional CS-UWB was illustrated with some primitive results.
- For the mandatory DS-UWB, results of performance for both coherent and differential coherent detections were presented.
- For the optional CS-UWB, additional advantages and feasibility to DS-UWB were shown. With better correlation characteristics, CS-UWB has superiority on system performance and ranging. It also provide additional dimensions for SOP.
  - Techniques to realize CS-UWB are ready.
  - Approach for compliance with FCC regulation looks less challenging.

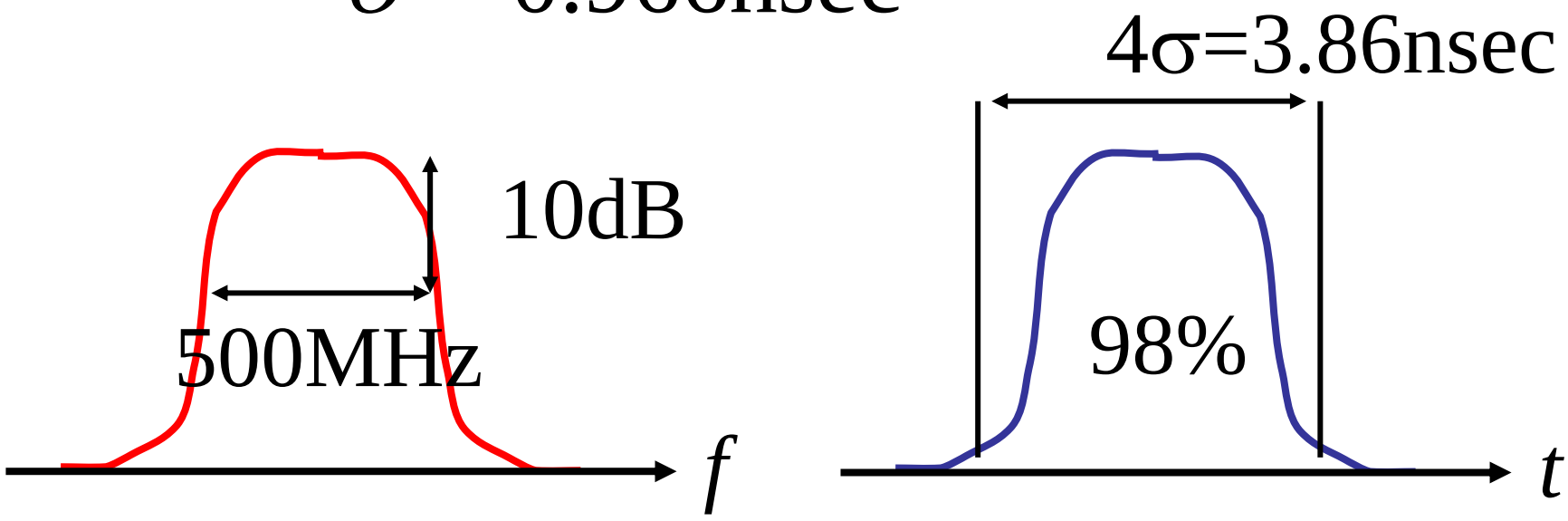
Appendix

Comparison of auto-correlation properties between DS-UWB and Optional CS-UWB

DS-UWB (Gaussian Pulse)

$$f_{10dB} = 500\text{MHz}$$

$$\sigma = 0.966\text{nsec}$$

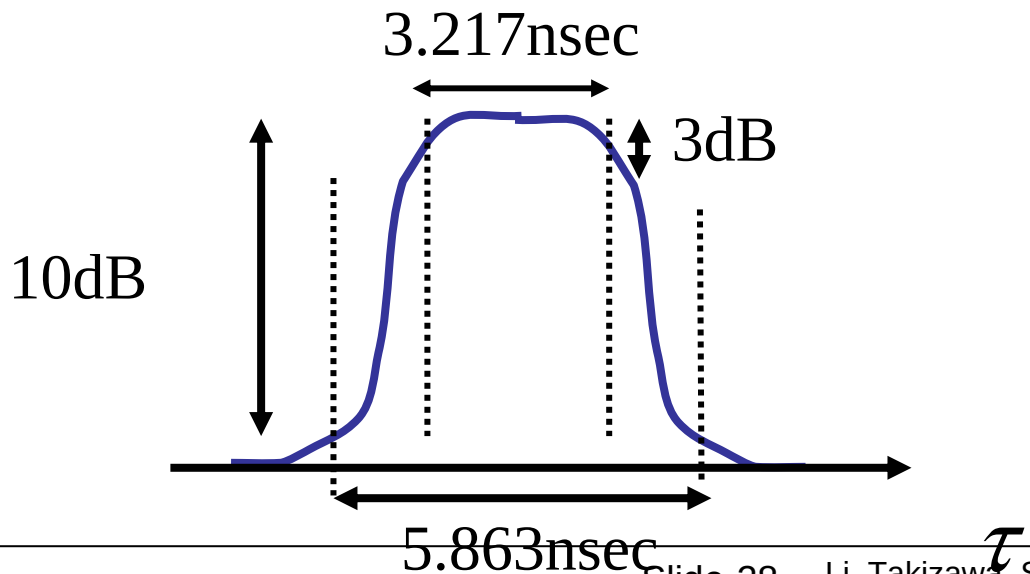


Calculation of Autocorrelation (DS-UWB)

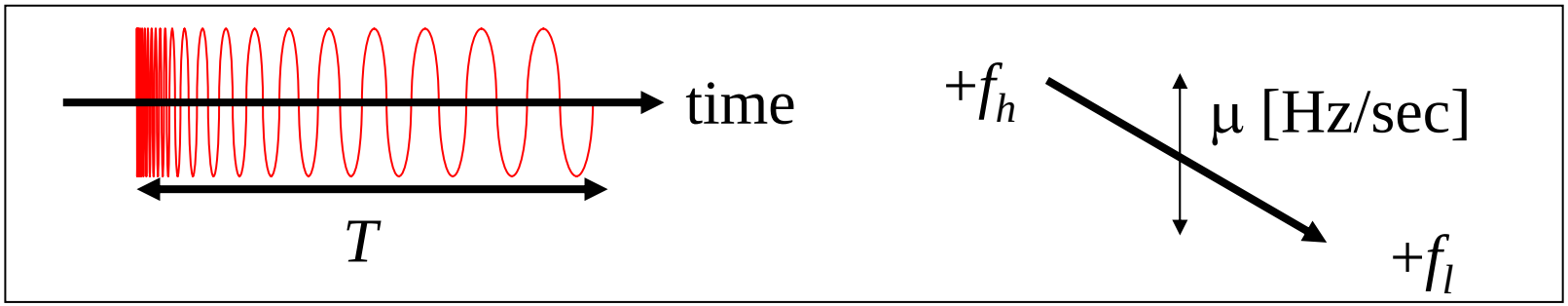
$$r_{gauss}(\tau) = \frac{1}{2\sqrt{2\pi}\sigma} e^{-\frac{\tau^2}{4\sigma^2}}$$

$$\tau_{3dB} = 2\sigma\sqrt{\log_e 2} = 1.608\text{nsec}$$

$$\tau_{10dB} = 2\sigma\sqrt{\log_e 10} = 2.932\text{nsec}$$



CS-UWB (Linear Down Chirp)



Chirping pulse

$$p_{chirp}(t) = \begin{cases} \cos(2\pi f t_c - \pi\mu_1 t^2) & ;(-\frac{T}{2} \le t \le \frac{T}{2}) \\ 0 & ;(otherwise) \end{cases}$$

Impulse response of correlator

$$h(t) = \begin{cases} \cos(2\pi f_c t + \pi\mu_1 t^2) & ;(-\frac{T}{2} \le t \le \frac{T}{2}) \\ 0 & ;(otherwise) \end{cases}$$

Calculation of Autocorrelation (CS-UWB)

$$r_{chirp}(\tau) = \begin{cases} \dfrac{A}{2\pi\mu_1\tau}\sin\left[\pi\mu_1(T-\tau)\tau\right]\cos(2\pi f_c t) & ;(-T \le \tau \le 0) \\ 0 & ;(\tau \le -T) \\ \dfrac{A}{2\pi\mu_1\tau}\sin\left[\pi\mu_1(T-\tau)\tau\right]\cos(2\pi f_c t) & ;(\tau \le T) \\ 0 & ;(T \le \tau) \end{cases}$$