Basics of UWB Technologies
- Utilization of Wide Spectrum -

Content

- What is UWB
- History and Recent Trend of UWB
- Principle of UWB
- Application of UWB
- Technical Issues for Antennas & RF Circuits
- Interference Problem
- Conclusion

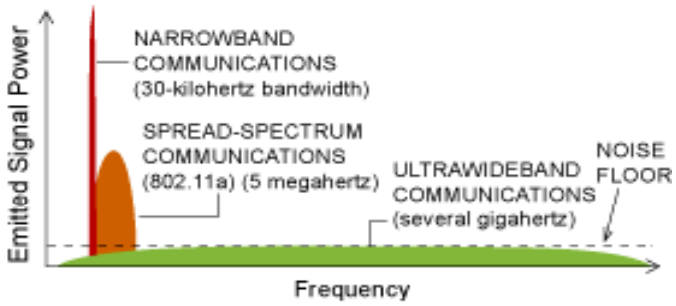
UWB

- Ultra Wide Band
  (more than 25% relative bandwidth transmission)
- By Using Short Impulse or Monocycle Signals,
  Communication／Sensing／ Imaging technologies
- In 2002 FCC allowed an use of UWB spectrum
- Physical Layer Technologies adopted for IEEE 801.15
- Carrier-less: IF Circuits, Mixer, etc are not required
- Originally, Military Radar/Communication Technology

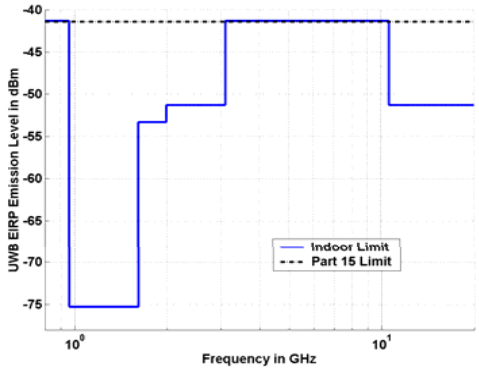
History and Recent Trend of UWB

- 1901 Marconi's frontier work on wireless communication is an Impulse transmission.
- 1998 Time Domain Inc. etc, asked FCC to use UWB.
- 1998 FCC started a technical review on UWB.
- 2002, 2 FCC allowed a commercial use for UWB.
- 2002, 5 First International Conference on UWB
- 2002, 9 UWB SG organized by MPT, Japan

UWB Technology Basics:
Wide Band & Low Power Density



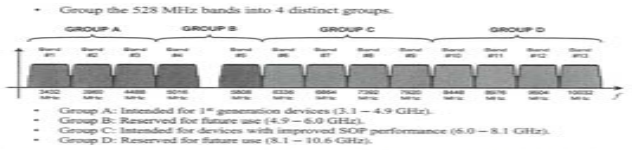
Spectrum Mask by FCC



Equivalent Noise Temperature

- -41.3dBm/MHz →0.742 ×10^-13 [Joule]
- kT：Power Spectrum Density
- T=5.38×10^9 [℃]
- Too High Temperature !!

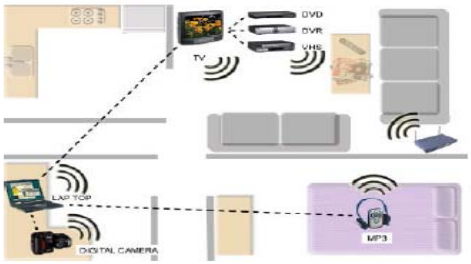
Multi-Band OFDM proposed by Intel



UWB's Application

- Imaging Systems
  - Ground Penetrating Radar
  - Wall-Imaging, Through-Wall Imaging
  - Medical-Imaging
- Vehicular Radar Systems
  - Collision Avoidance Radar
- Communication Systems
  - Short Range (～10m) Communications
  - WPAN (Wireless Personal Network)

Xtreme Spectrum's View of Home Networking



Nodes form a mesh to extend range throughout house

http://www.xtremespectrum.com/products/UWBWhitePaper.pdf

Prototypes by Venture Companies

- Time Domain (From 1989)
  - Pulse On 200
- Xtreme Spectrum Inc.
  - Data Rate 100Mbps (High Speed)
  - Transmission Power 200mW (Low Power)

- Broad Band Transmission

Channel Capacity

$$C = W\log_2\left(1+S/N\right) = W\log_2\left(1+S/WN_0\right)$$

where

S : signal power
N : noise power
W : bandwidth
N_0 : noise power spectrum density

Upper Bound

$$C \le \frac{S}{\ln 2\, N_0}$$

$$\lim_{W\to\infty} C = \frac{S}{\ln 2\, N_0}$$

Low Power Transmission by Wide Band

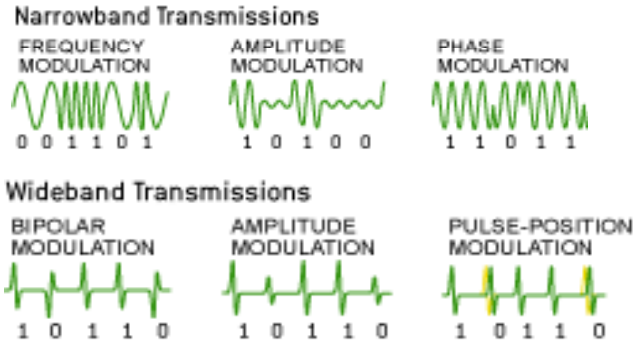
- Channel Capacity C is a monotonic increasing function of bandwidth W for given S and N_0
- But there is an upper bound
- For thermal noise N_0 (Power spectrum density) = kT
- k : Boltzmann constant ,T : Temperature
- For T=300 K N_0= -174dBm/Hz
- And for C=1Gbps S=-84dBm is enough

Principle of UWB Transmission

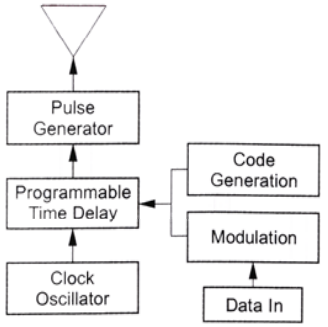
- Modulation
  - PAM (Amplitude)
  - OOK (ON／OFF)
  - PPM (Time Position)
  - Bi-Phase
- Carrier-less Transmission
- Broad banding
  - TM-UWB (Time-Modulated)
  - DS-UWB (Direct Sequence Phase Coding)

UWB Technology Basics:

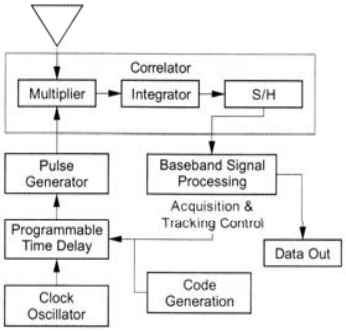
Transmitting Information



UWB Transmitter



UWB Receiver



Unbalance in TX and RX

- TX is simple, and low-cost.
- RX is complicated due to high-speed time domain processing.
- Template pulse waveform should be adaptively modified including channel characteristics for Matched Filtering.
- Frequency Domain Processing → Time Domain Processing
- Amplitude/Phase Control → Amplitude/Delay Control

Matched Filter Concept

- Transmitting Pulse Waveform : s(t)
- Receiving Pulse Waveform : r(t)=s(t)+n(t)
- Filtering :
- Sampling and decision
- Optimum Filtering for Maximizing SNR
- $H(\omega)=S(\omega)*\exp(-j\omega Ts)$

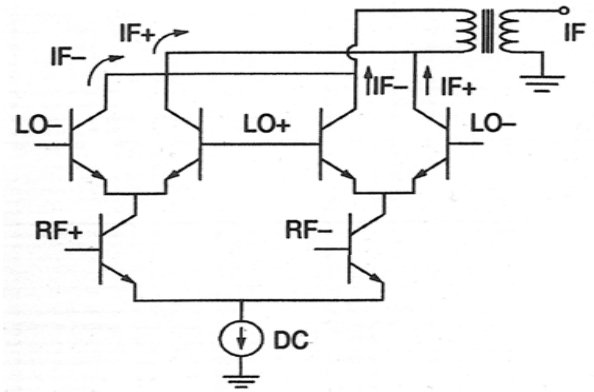
Technical Issues on Antenna and RF Circuit

- Wide Band Antenna → Low Efficiency, Diamond Dipole, COTAB
- High Precision Timer (Pico second order)
- High Speed Multipliers, Correlators
- Variable Delay Line
- Wide Band Front-end LNA, RF BPF

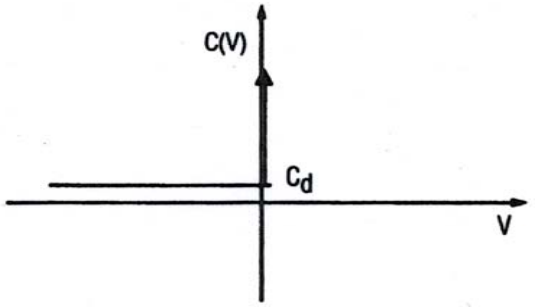
Broadband Multipliers/Amplifiers

- Si-Ge or CMOS Devices are suitable for this application.
- Front-end Multipliers/Amplifiers are key components.

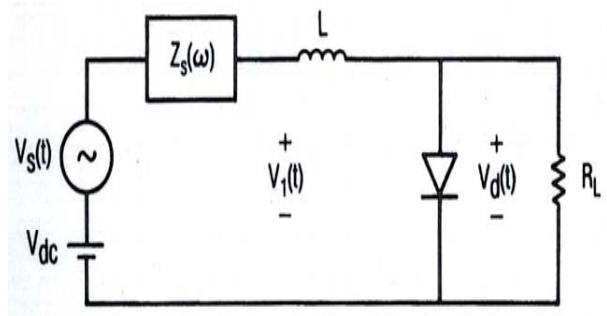
Gilbert Cell （Differential Multiplier)



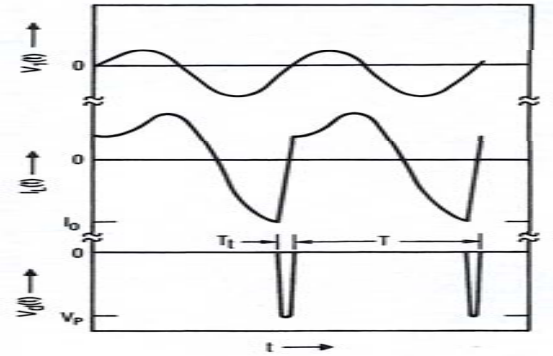
C-V Characteristics of Step Recovery Diode



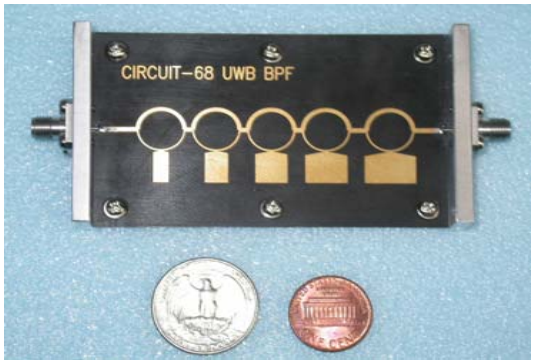
Pulse Generator Circuit



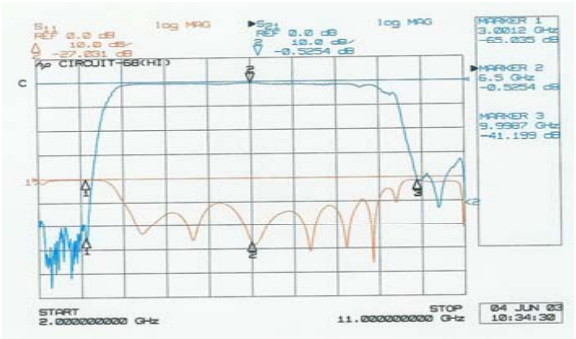
Pulse Waveform



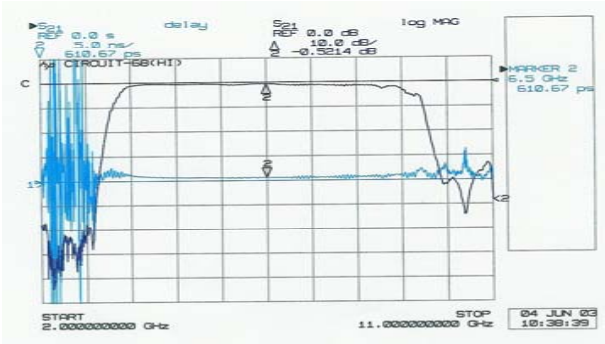
Broad Band BPF



Transmission/Reflection Characteristics



Group Delay Characteristics



COTAB

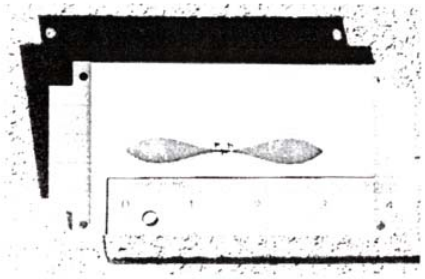


Figure 1. A COTAB UWB magnetic slot antenna

Diamond Dipole (2001, APS)

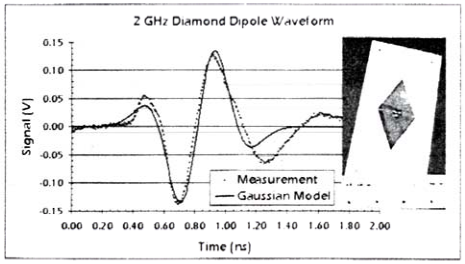
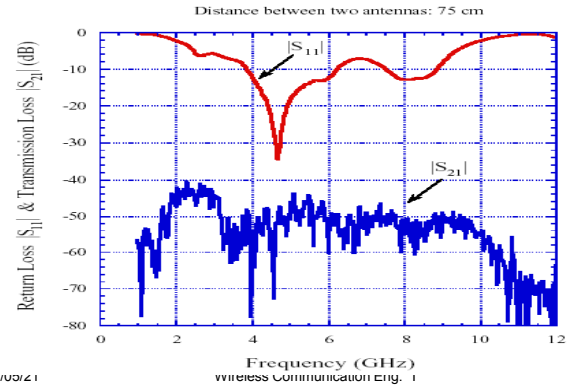
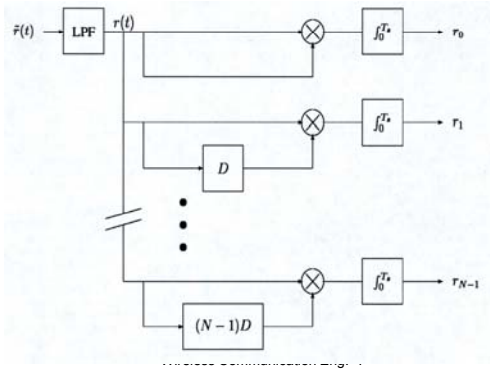


Figure 1: Measured waveform of a diamond dipole compared to a Gaussian model where $f_c \cong 1.85GHz$. A standard 2 GHz diamond dipole is shown to the right.

Small-size Broad Band Antenna



TR Receivers



Square (Power) Detector → Multiplier ?

$$a(t) * b(t) = \frac{[a(t)+b(t)]^2 - [a(t)-b(t)]^2}{4}$$

$[\ \ ]^2$: Square Detection

$\pm$: Linear Processing

Interference Problem

- UWB → Narrow Band Communication Systems (including GPS)
  - 41.3dBm／MHz Allowable Radiation Power from Electronics Equipments, e.g. PC
- Narrow Band Communication Systems → UWB ?
  - Coding Technique over Frequency Domain

Channel Modeling for UWB

- CLEAN Algorithm for Clustering and Modeling
- Measured propagation characteristics are to be de-convolved into antennas and channel characteristics.
- Broad band/ High speed measurement systems are also to be developed in Frequency/ Time Domain.

Channel characteristics

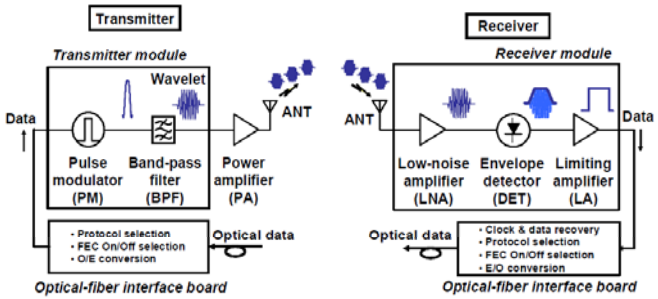
- Fading or Shadowing ?
- Not Frequency Flat but Frequency Selective
- Pulse distortion ⇒ Increase of BER

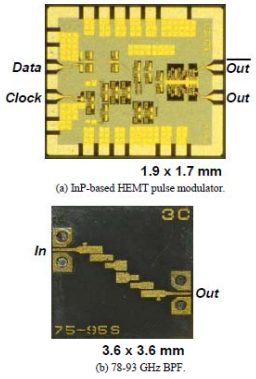
MIMO for UWB

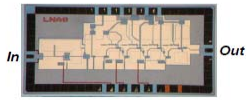
- Time Domain beam/null forming should be developed for UWB-MIMO. → Delay Control
- Conventional beam/null forming has been done in Frequency Domain. → Phase Control

Prototype of IR UWB

- Millimeter-wave Region
- 10 Gps Data Rate
- OOK Modulation

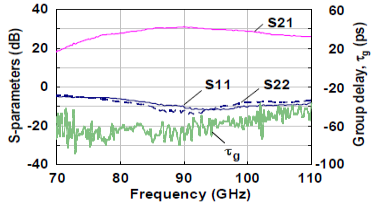




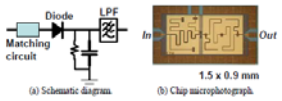


2.6 x 1.4 mm

(a) Chip micro photograph.

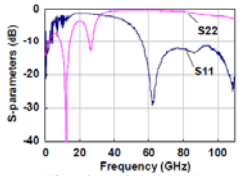


(b) Frequency response.

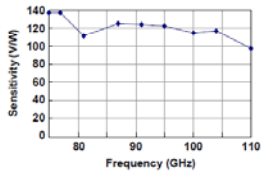


1.5 x 0.9 mm

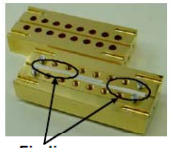
(a) Schematic diagram (b) Chip microphotograph.



(c) Input and output reflection characteristics.

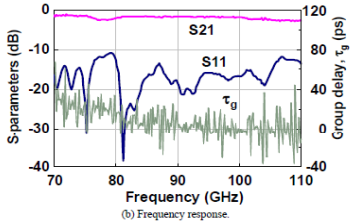


(d) Sensitivity characteristics.



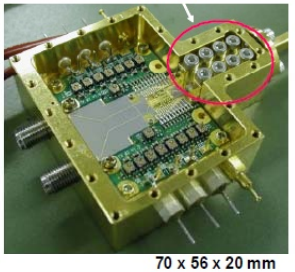
Fin line

(a) Test fixture.

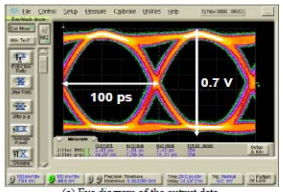


(b) Frequency response.

Fin-line WG-to-MSL transition

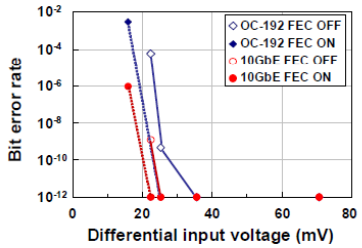


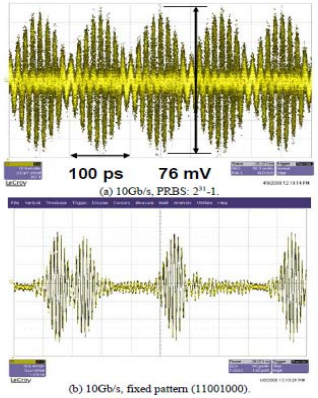
70 x 56 x 20 mm



(a) Eye diagram of the output data.

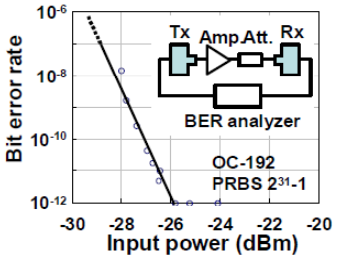
(b) Output clock waveform.

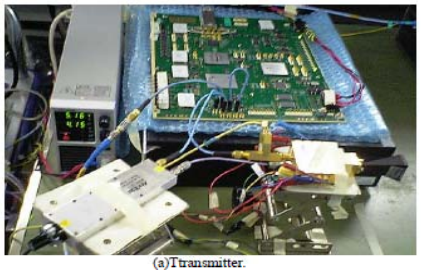




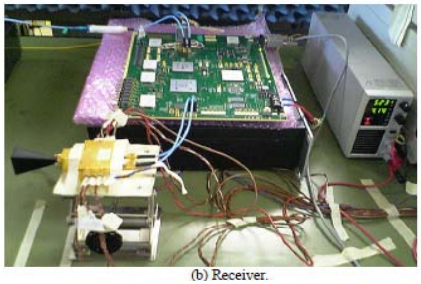
(a) 10Gb/s, PRBS: 2^{31}-1.

(b) 10Gb/s, fixed pattern (11001000).





(a)Ttransmitter.



(b) Receiver.

Conclusion

- UWB is a challenging theme for device/communication/signal processing researchers and engineers.
- High-speed and precise signal processing devices and algorithms are necessary in time domain.
- Nonlinearity due to large peak value should be considered.
- Narrow Band transmission → Carrier-less transmission.
- Frequency Domain → Time Domain Processing

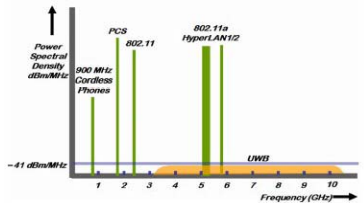
Multiple Access Performance of TR-UWB System Using a Combined PPM and DMPM

Content

- Background
- Motivation
- Multi-user system for PPM-DMPM TR-UWB
- Receiver
- Simulation result and Discussion
- Conclusion

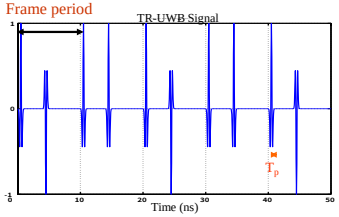
Background

- Ultra wide-band (UWB) technology has recently emerged as a promising candidate for high throughput short range wireless communication system.
- UWB system is characterized by low emission, high data rates and spectrum reuse.



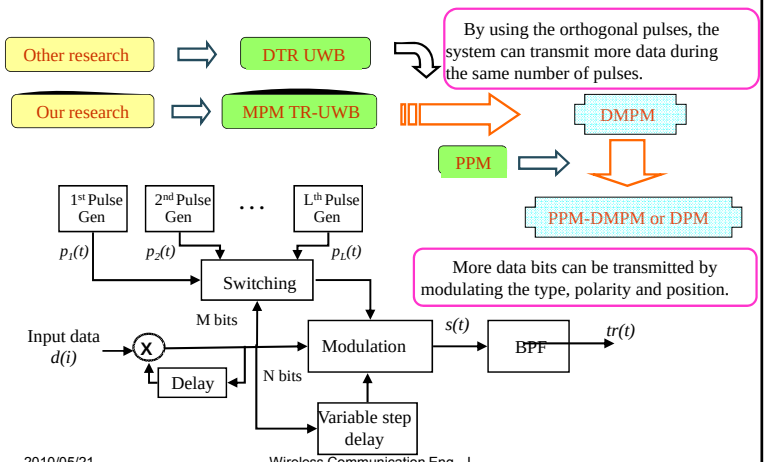
"Wireless Design" Microwave engineering, March 2005

Frame period



- Later, Transmit-Reference UWB (TR-UWB) approach has been envisioned as a promising effective method to avoid channel estimation.
- However, at least two pulses are necessary for transmitting one data bit that lead to decrease data rate of the system.

Motivation

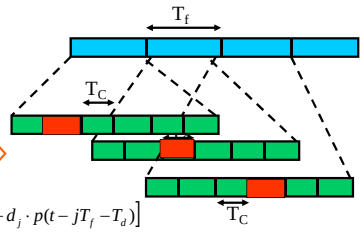


Multi-user system for TR-UWB

Time Hopping (TH) is one technique to randomizing the pulse train of UWB system.

Each element of the hopping sequence $\{C_j^{(k)}\}$ is uniformly distributed on $\{0,1,2,\ldots,N_u\text{-}1\}$ in order to provide the multiple access capability

$C_j^{(k)} = \{2, 3, 4, 1, \ldots\}$



Single user

$$s_{TR}(t) = \sum_{j=-\infty}^{\infty} \left[p(t - jT_f) + d_j \cdot p(t - jT_f - T_d) \right]$$

Multiple access

$$s_{TR}^{(k)}(t) = \sum_{j=-\infty}^{\infty} \left[p(t - jT_f - c_j^{(k)} T_c) + d_j^{(k)} \cdot p(t - jT_f - c_j^{(k)} T_c - T_d^{(k)}) \right]$$

Where $c_j^{(k)}$ is the hopping sequence

T_c is the chip period

Multiple access for TH-PPM-DMPM TR-UWB system

$$s_{TR}^{(k)}(t) = \sum_{j=-\infty}^{\infty}\left[p(t - jT_f - c_j^{(k)}T_c) + d_j^{(k)} \cdot p(t - jT_f - c_j^{(k)}T_c - T_d^{(k)})\right]$$

$$s_{DMPM}^{(k)}(t) = \sum_{j=-\infty}^{\infty}\left[dd_{j,1}^{(k)} \cdot p_{(dd_{j,2}^{(k)}, dd_{j,3}^{(k)}, \ldots, dd_{j,m+1}^{(k)})}(t - jT_f - c_j^{(k)}T_c)\right]$$

$$s_{DPM}^{(k)}(t) = \sum_{j=-\infty}^{\infty}\left[dd_{j,1} \cdot p_{(dd_{j,2}^{(k)}, dd_{j,3}^{(k)}, \ldots, dd_{j,m+1}^{(k)})}(t - jT_f - c_j^{(k)}T_c - \delta(dd_{j,m+2}^{(k)}, \ldots, dd_{j,m+n+1}^{(k)}))\right]$$

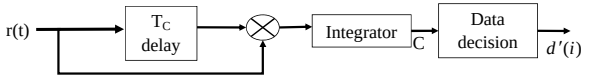
In order to prevent interframe interference and inter chip interference

	TH-TR UWB	TH-DMPM	TH-PPM-DMPM
T_f	$> (N_u - 1)T_C + T_P + \max\{T_d^{(k)}\} + T_{mds}$	$> (N_u - 1)T_C + T_P + T_{mds}$	$> (N_u - 1)T_C + T_P + \max\{\delta^{(k)}\} + T_{mds}$
T_C	$> T_P + \max\{T_d^{(k)}\} + T_{mds}$	$> T_{mds}$	$> \max\{\delta^{(k)}\} + T_{mds}$

Receiver

$$r(t) = s(t) * h(t) + n(t)$$

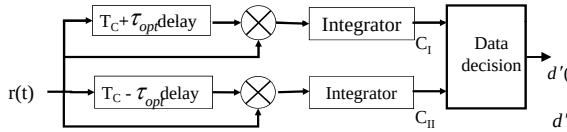
Auto-correlation Receiver — For TR and PPM DTR-UWB



$$C(i) = \int_{iT_f}^{iT_f + T_c} r(t - T_c)r(t)dt$$

$$d'(i) = sign(C(i))$$

Shift Correlation Receiver — For MPM and DMPM TR-UWB



$$C_I(i) = \int_{iT_f}^{iT_f + T_c} r(t - T_c - \tau_{opt})r(t)dt$$

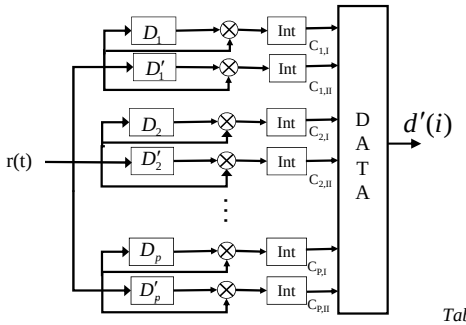
$$C_{II}(i) = \int_{iT_f}^{iT_f + T_c} r(t - T_c + \tau_{opt})r(t)dt$$

$$d'(i) = Table(C_I, C_{II})$$

Receiver (2)

For DPM TR-UWB

The number of shift correlation receiver have been used as the number of position (P) that used for modulation.



$$C_{1,I}(i) = \int_{iT_f}^{iT_f + T_c} r(t - T_c - \delta_1 - \tau_{opt})r(t)dt$$

$$C_{1,II}(i) = \int_{iT_f}^{iT_f + T_c} r(t - T_c - \delta_1 + \tau_{opt})r(t)dt$$

$$\vdots$$

$$C_{p,I}(i) = \int_{iT_f}^{iT_f + T_c} r(t - T_c - \delta_p - \tau_{opt})r(t)dt$$

$$C_{p,II}(i) = \int_{iT_f}^{iT_f + T_c} r(t - T_c - \delta_p + \tau_{opt})r(t)dt$$

$$d'(i,1,\ldots,N+M+1) = Table(C_{1,I}, C_{1,II}, \ldots, C_{p,I}, C_{p,II})$$

Multi-user system for PPM-DMPM

The hopping sequence and chip period have to be considered in the receiver.

Auto-correlation Receiver

$$C(i) = \int_{iT_f}^{iT_f + T_{corr}} r(t - T_d)r(t)dt$$

Multi-user

$$C^{(k)}(i) = \int_{iT_f + c_i^{(k)}T_c + T_d^{(k)}}^{iT_f + c_i^{(k)}T_c + T_d^{(k)} + T_{corr}} r(t - T_d^{(k)})r(t)dt$$

$$d'^{(k)}(i) = sign(C^{(k)}(i))$$

Shift correlation Receiver

$$C_I(i,\tau) = \int_{iT_f}^{iT_f + T_{corr}} r(t + \tau) \cdot r(t - T_f)dt,$$

$$C_{II}(i,\tau) = \int_{iT_f}^{iT_f + T_{corr}} r(t) \cdot r(t - T_f + \tau)dt$$

Multi-user

$$C_i^{(k)}(i,\tau) = \int_{iT_f + c_i^{(k)}T_c}^{iT_f + c_i^{(k)}T_c + T_{corr}} r(t + \tau) \cdot r(t - T_f - \left[c_{i-1}^{(k)} + c_i^{(k)}\right]T_C)dt$$

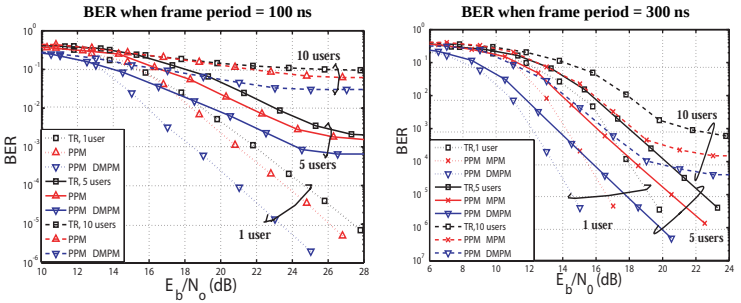
$$C_{ii}^{(k)}(i,\tau) = \int_{iT_f + c_i^{(k)}T_c}^{iT_f + c_i^{(k)}T_c + T_{corr}} r(t) \cdot r(t - T_f - \left[c_{i-1}^{(k)} + c_i^{(k)}\right]T_C + \tau)dt$$

$$d'^{(k)}(i) = Table(C_I^{(k)}, C_{II}^{(k)})$$

Simulation Specification

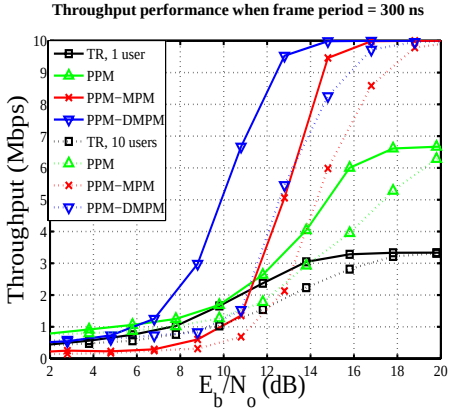
Pulse	Gaussian and Rayleigh monocycle
Modulation	PPM and DPM
Pulse period	0.5 ns
Chip period	1-20 ns
Frame period	10-400 ns
Number chips per frame (Nc)	10, 20
Filter	Bandpass (3.1-10.3 GHz)
Channel	S-V model with NLOS 1-4 m (CM2)

Simulation result and Discussion (1)



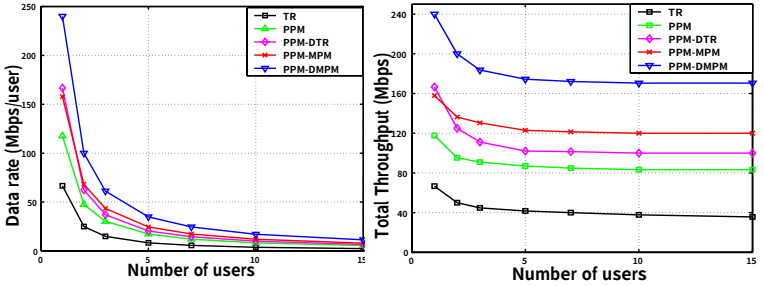
- By using PPM-DMPM, the system decrease the required E_b/N_0 by 4-6 dB.
- For 5 users case, the error floor has occurred in case of short frame period, 100 ns (left graph).
- The error floor has occurred in all of the system when the number of user increased.
- MAI (Multiple Access Interference) dominates the performance as the number of user increase.

Simulation result and Discussion (2)



- PPM-MPM and PPM-DMPM can achieve its maximum throughput at E_b/N_0 of about 16-18 dB.
- PPM-MPM and PPM-DMPM can provide better throughput performance than conventional system.
- Especially, PPM-DMPM needs the lower required E_b/N_0 than PPM-MPM about 2 dB.

Simulation result and Discussion (3)



This result shows the system capacity with BER (error floor) = 10^{-3} .

- PPM-DMPM can provide more system capacity than other TR-UWB in both of single user and multiple access system because of more transmitted data bits per frame.
- Total throughput performance in both case of proposed systems are better than conventional system.
- Throughput characteristic of all system are similar to each other because of using the same multiple access.

Conclusion

• By using SCR, the proposed system can achieve the excellent error and total throughput performance of the system.

• When frame period has become longer, although the error performance has been improved, the maximum data rate of the system will be decreased.

• By using the proposed system, PPM-DMPM TR-UWB, more total throughput has been achieved, e.g.

	TR-UWB	PPM	PPM-DMPM
For single user	70 Mbps	115 Mbps	240 Mbps
For multi-users	40 Mbps	85 Mbps	185 Mbps