Basics of UWB Technologies
- Utilization of Wide Spectrum Resource-

Ultra Low Power Transmission

Overlay Technique

Communication and Positioning

Content

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

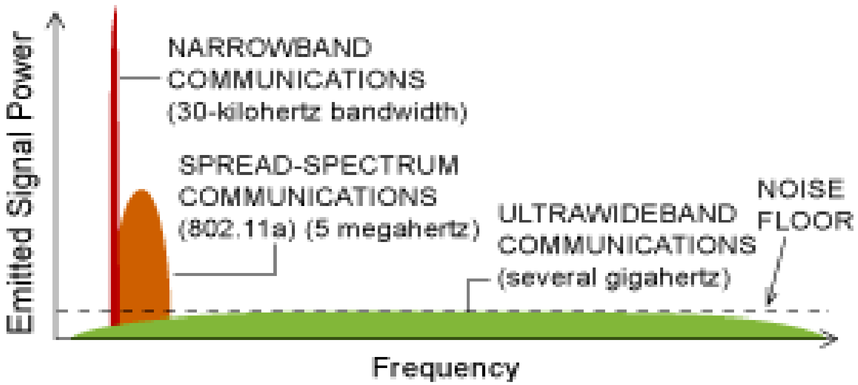
UWB

- 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

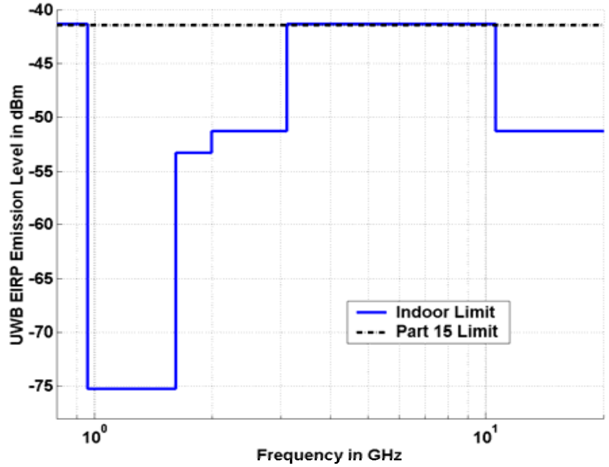
History and Recent Trend of UWB

- 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

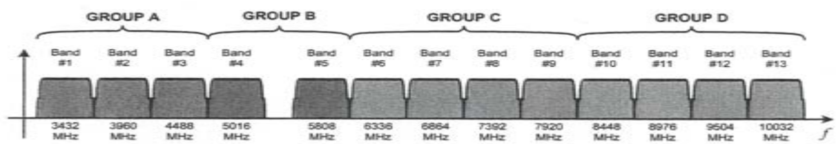


Equivalent Noise Temperature

- -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

- Group the 528 MHz bands into 4 distinct groups.

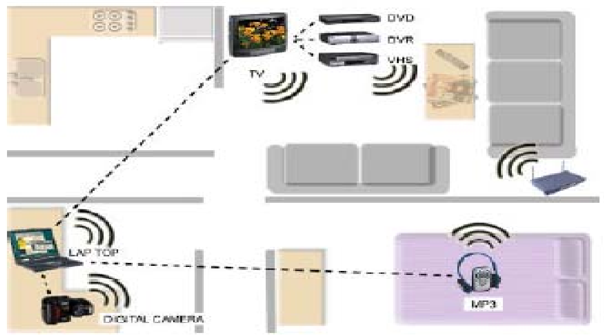


- Group A: Intended for 1st generation devices (3.1 – 4.9 GHz).
- Group B: Reserved for future use (4.9 – 6.0 GHz).
- Group C: Intended for devices with improved SOP performance (6.0 – 8.1 GHz).
- Group D: Reserved for future use (8.1 – 10.6 GHz).

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 Spectrum

- 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（1.38×10^-23) ,

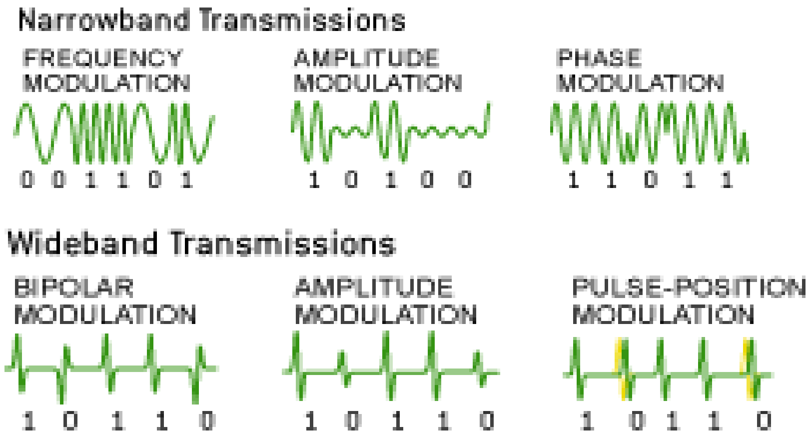
  T : Temperature
- At T=300 K N_0= -174dBm/Hz
- And for C=1Gbps S=-84dBm is enough

Principle of UWB Transmission

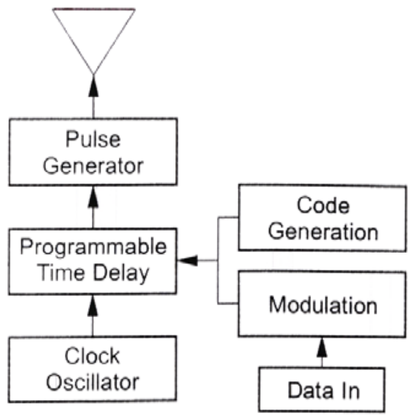
- Modulation
  - PAM (Amplitude)
  - OOK (ON／OFF)
  - PPM (Time Position)
  - Bi-Phase
- Carrier-less Transmission
- Broad banding
  - TM-UWB (Time-Modulated)
  - DS-UWB (Direct Sequence Phase Coding)

UWB Technology Basics:

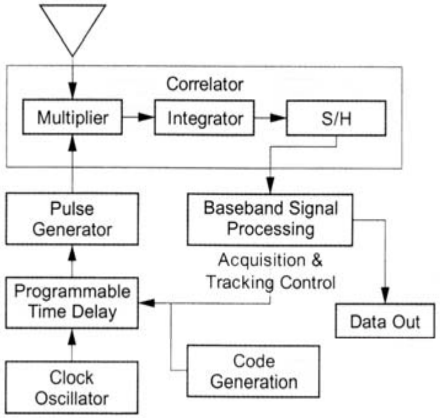
Transmitting Information



UWB Transmitter



UWB Receiver



Imbalance 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
- $H(\omega)=S(\omega)^*\exp(-j\omega Ts)$

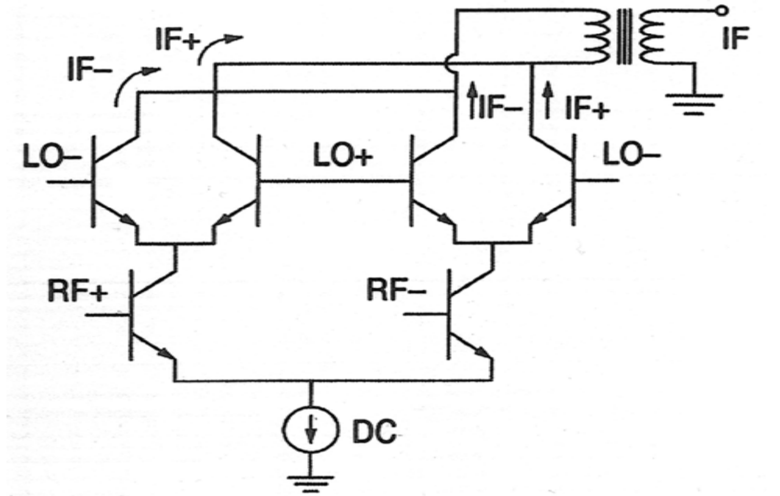
Technical Issues on Antenna and RF Circuit

- 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

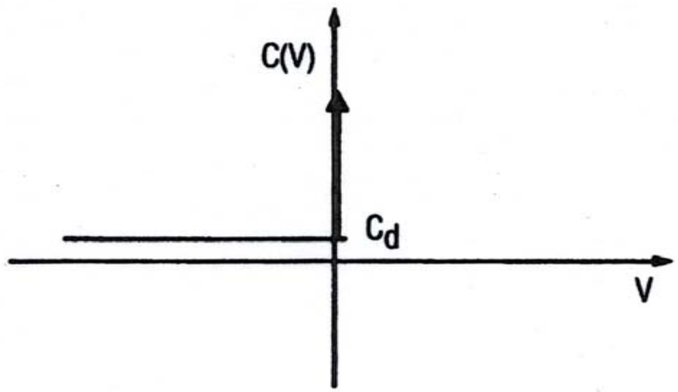
Broadband Multipliers/Amplifiers

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

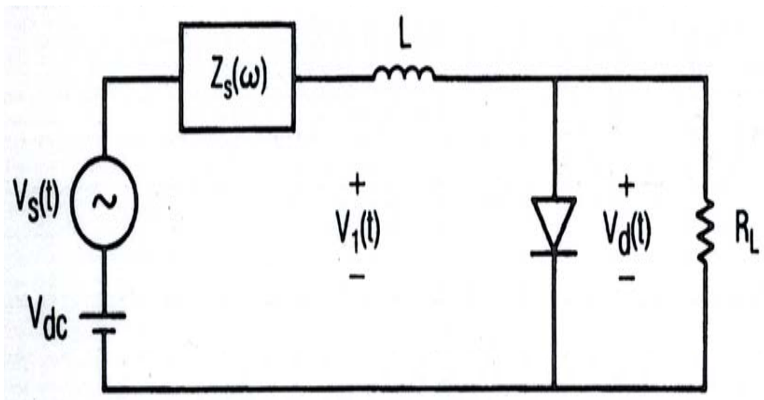
Gilbert Cell （Differential Multiplier)



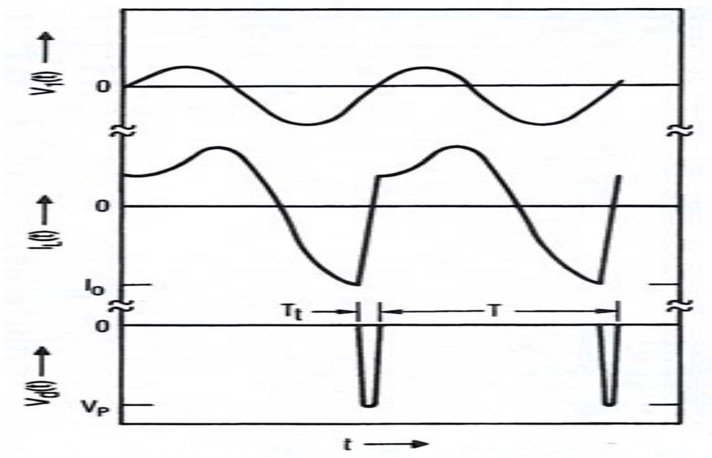
C-V Characteristics of Step Recovery Diode



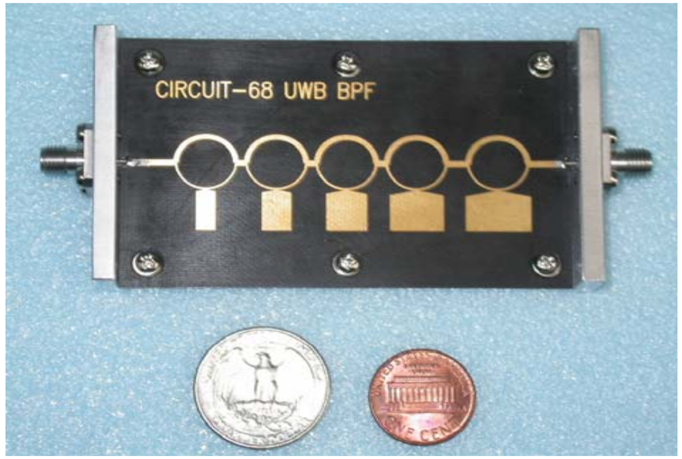
Pulse Generator Circuit



Pulse Waveform

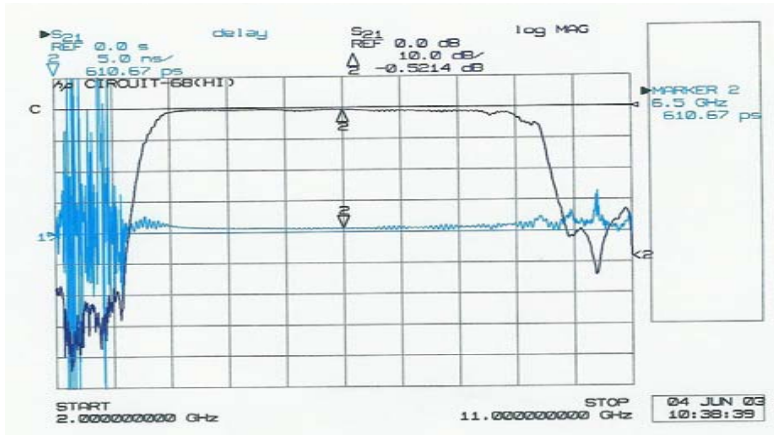


Broad Band BPF



Transmission/Reflection Characteristics

Group Delay Characteristics



COTAB

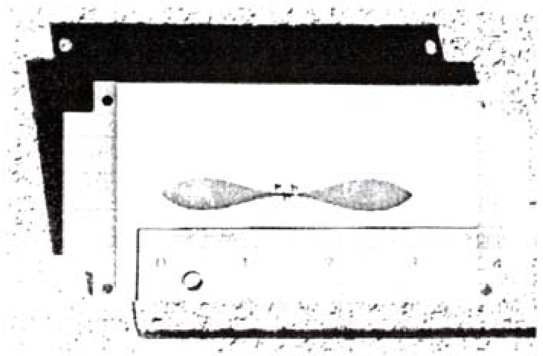


Figure 1. A COTAB UWB magnetic slot antenna

Diamond Dipole (2001, APS)

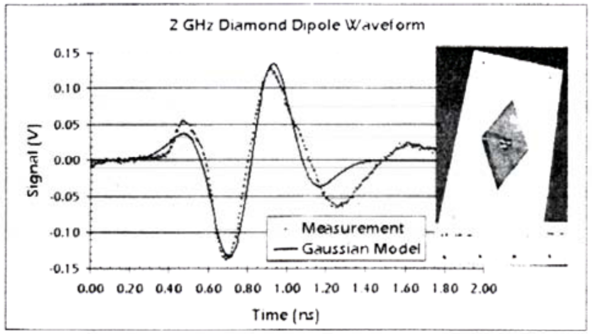
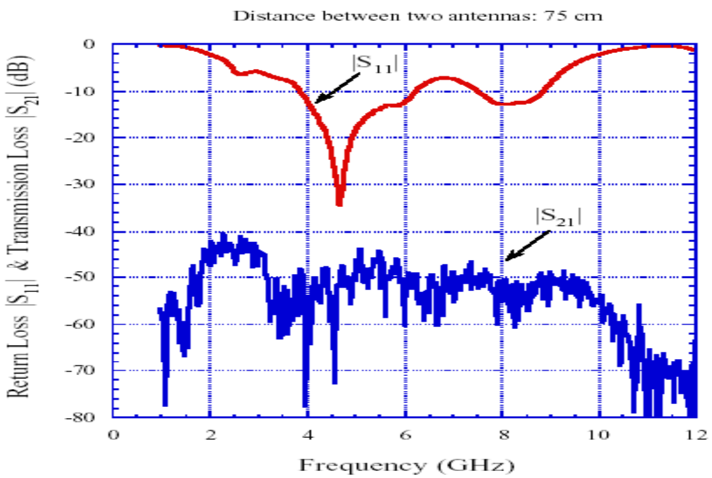
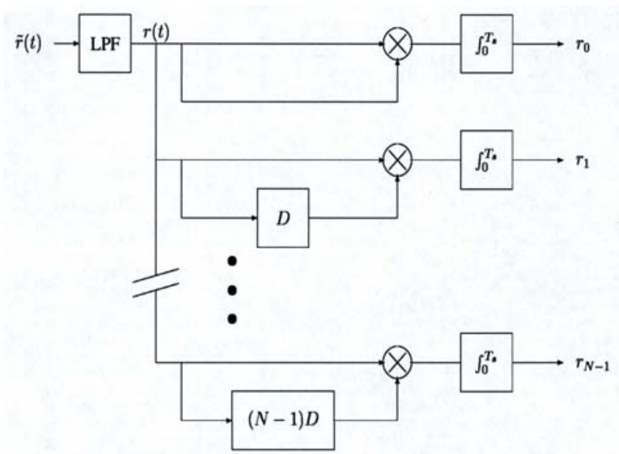


Figure 1: Measured waveform of a diamond dipole compared to a Gaussian model where $f_c \cong 1.85GHz$. A standard 2 GHz diamond dipole is shown to the right

Small-size Broad Band Antenna



TR Receivers



Square (Power) Detector → Multiplier ?

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

$$[\quad]^2 : \text{Square Detection}$$

$$\pm : \text{Linear Processing}$$

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. ⇒ De-embedding
- Broad band/ High speed measurement systems are also to be developed in Frequency/ Time Domain.

Channel characteristics

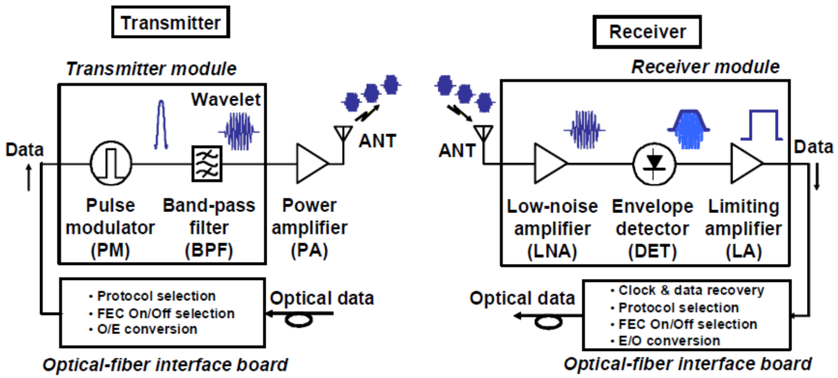
- Fading or Shadowing ?
- Not Frequency Flat but Frequency Selective
- Pulse distortion ⇒ Increase of BER

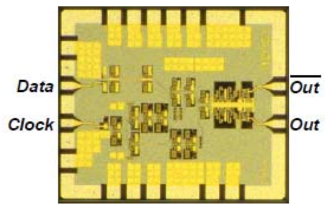
MIMO for UWB

- 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

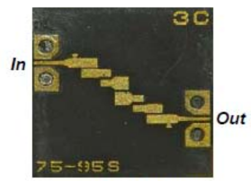
- Millimeter-wave Region
- 10 Gps Data Rate
- OOK Modulation





1.9 x 1.7 mm

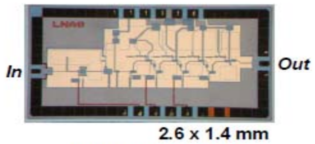
(a) InP-based HEMT pulse modulator.



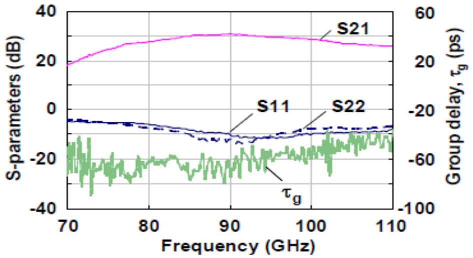
3.6 x 3.6 mm

(b) 78-93 GHz BPF.

Pulse modulator and BPF

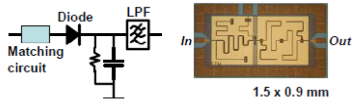


(a) Chip micro photograph.

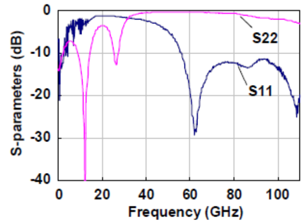


(b) Frequency response.

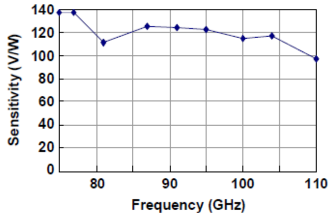
Wideband Amplifier



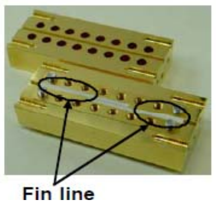
(a) Schematic diagram. (b) Chip microphotograph.



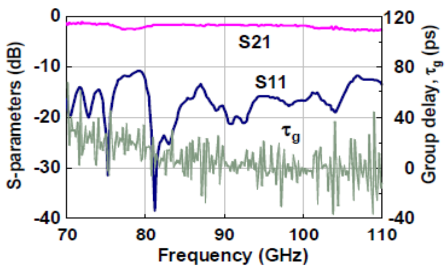
(c) Input and output reflection characteristics.



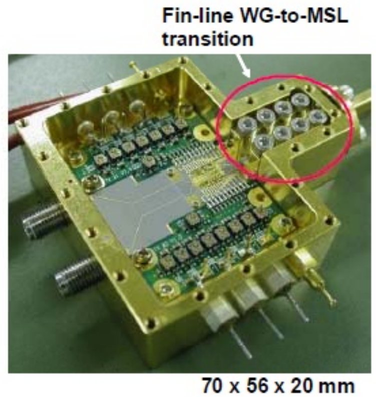
(d) Sensitivity characteristics.

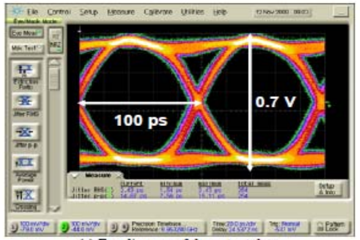


(a) Test fixture.

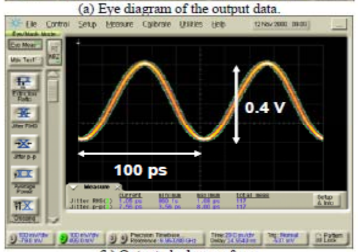


(b) Frequency response.

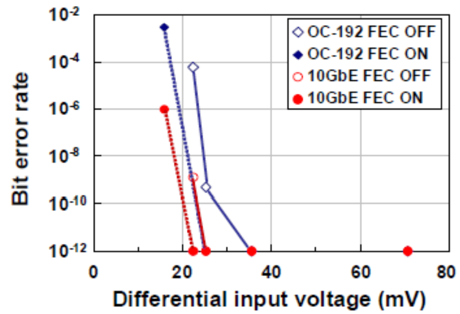




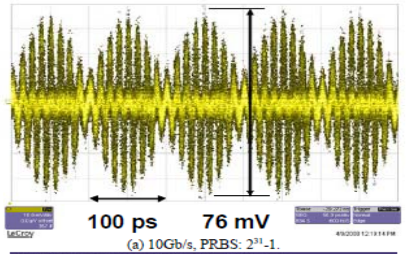
(a) Eye diagram of the output data.



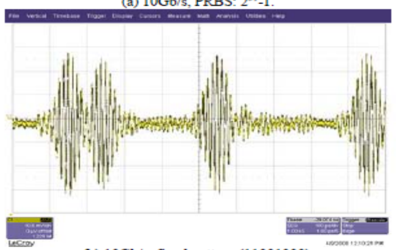
(b) Output clock waveform.

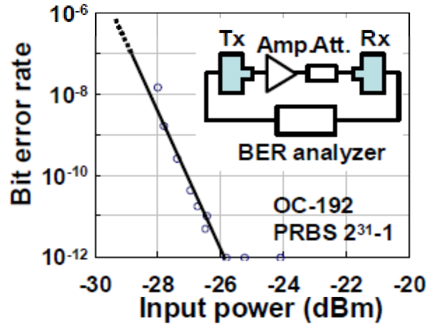


FEC RS(255,239)



(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

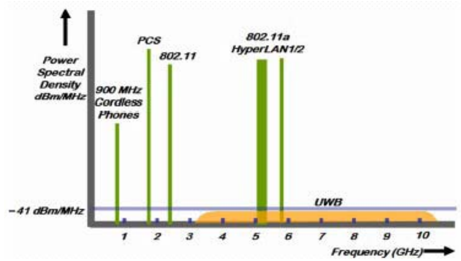
Multiple Access Performance of TR-UWB System Using a Combined PPM and DMPM

Content

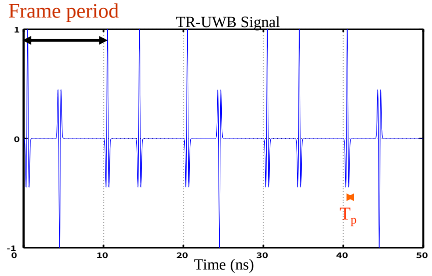
- Background
- Motivation
- Multi-user system for PPM-DMPM TR-UWB
- Receiver
- Simulation result and Discussion
- Conclusion

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.

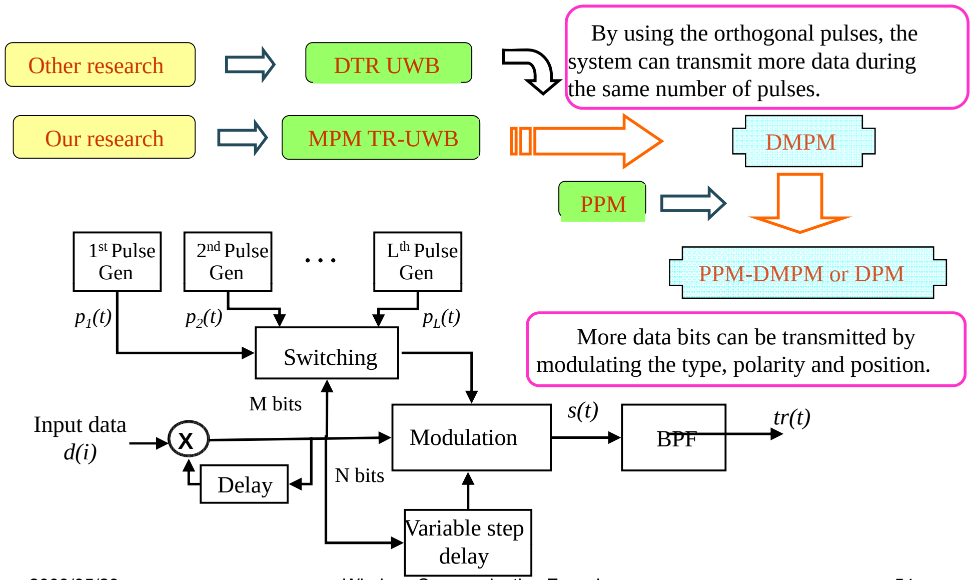


"Wireless Design" Microwave engineering, March 2005



- 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

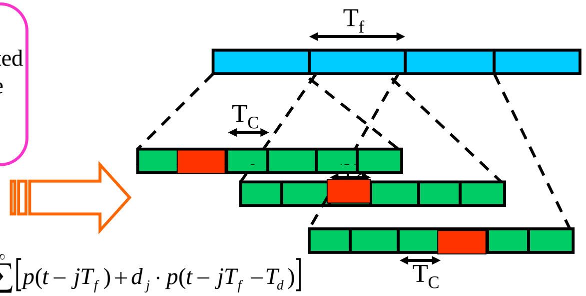


Multi-user system for TR-UWB

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 $\{0,1,2,\ldots,N_u-1\}$ 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

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

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

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

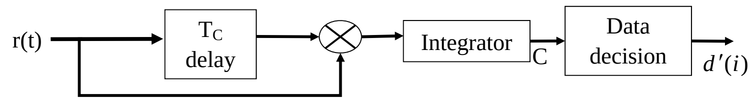
In order to prevent interframe interference and inter chip interference

	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

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

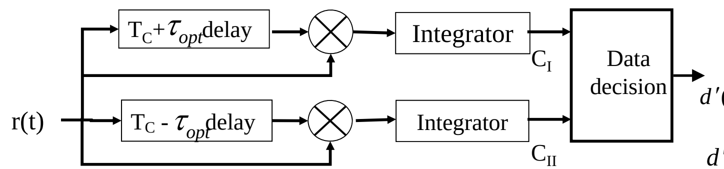
Auto-correlation Receiver — For TR and PPM DTR-UWB



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

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

Shift Correlation Receiver — For MPM and DMPM TR-UWB



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

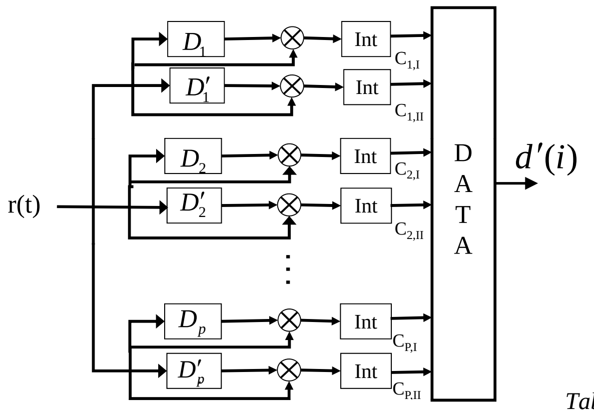
$$C_{II}(i) = \int_{iT_f}^{iT_f+T_c} r(t - T_c + \tau_{opt}) r(t) dt$$

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

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.



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

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

$$\vdots$$

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

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

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

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

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

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

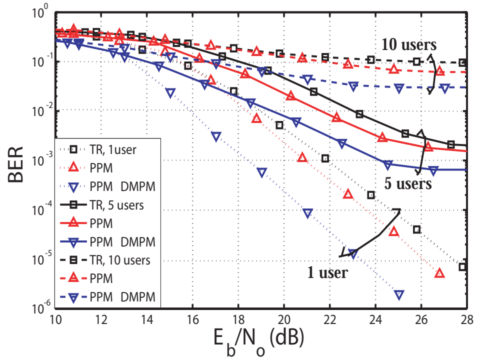
$$d'^{(k)}(i) = Table(C_I^{(k)}, C_{II}^{(k)})$$

Simulation Specification

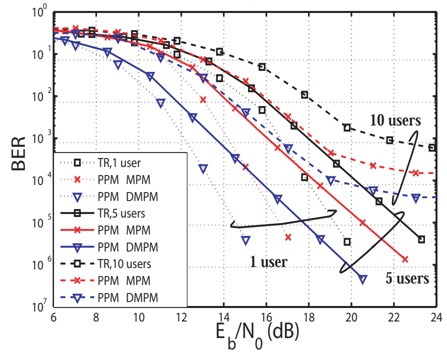
Pulse	Gaussian and Rayleigh monocycle
Modulation	PPM and DPM
Pulse period	0.5 ns
Chip period	1-20 ns
Frame period	10-400 ns
Number chips per frame (Nc)	10, 20
Filter	Bandpass (3.1-10.3 GHz)
Channel	S-V model with NLOS 1-4 m (CM2)

Simulation result and Discussion (1)

BER when frame period = 100 ns



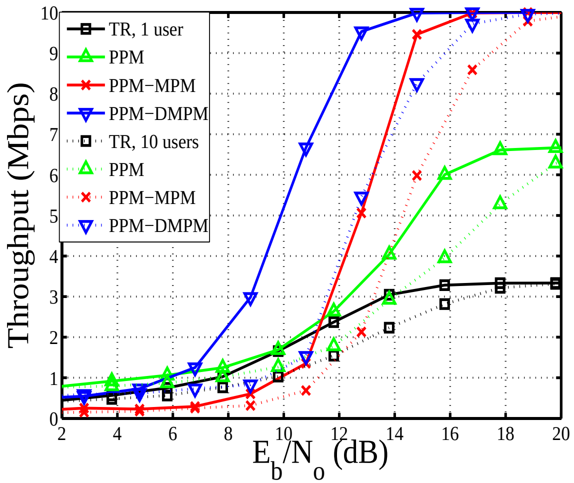
BER when frame period = 300 ns



- 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.

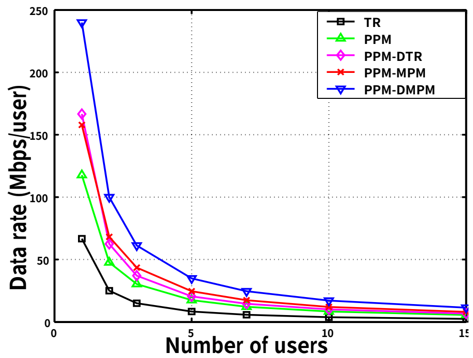
Simulation result and Discussion (2)

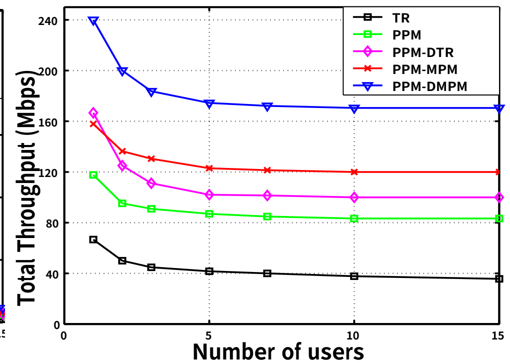
Throughput performance when frame period = 300 ns



- 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