The IEEE Wireless Communications and Networking Conference (WCNC'2003)
Panel session on Ultra-wideband (UWB) Technology
Ernest N. Memorial Convention Center, New Orleans, LA USA
11:05 am - 12:30 pm, Wednesday, March 19 2003

Research in Ultra Wide Band(UWB) Wireless Communications

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Communication Research Laboratory(CRL), Japan

Background of UWB R&D

Current Demands on Radio Systems → Higher Capacity and Better QoS

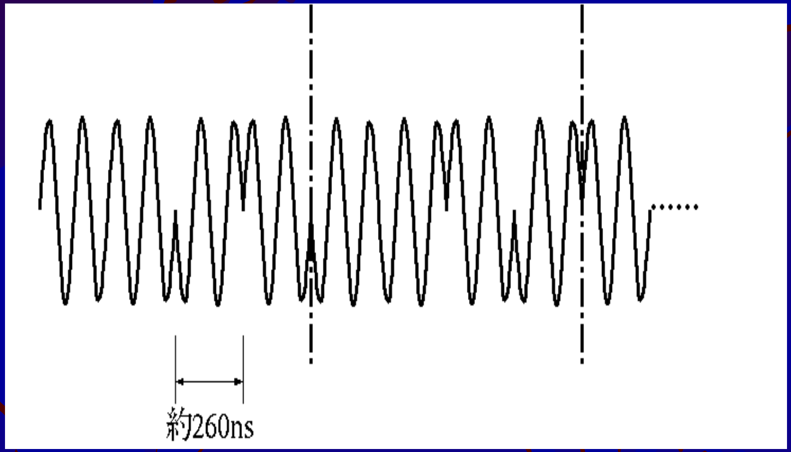
Wideband Radio Systems
(Wideband CDMA, SS, OFDM etc.)

The wider bandwidth radio system, the better performance will be obtained.

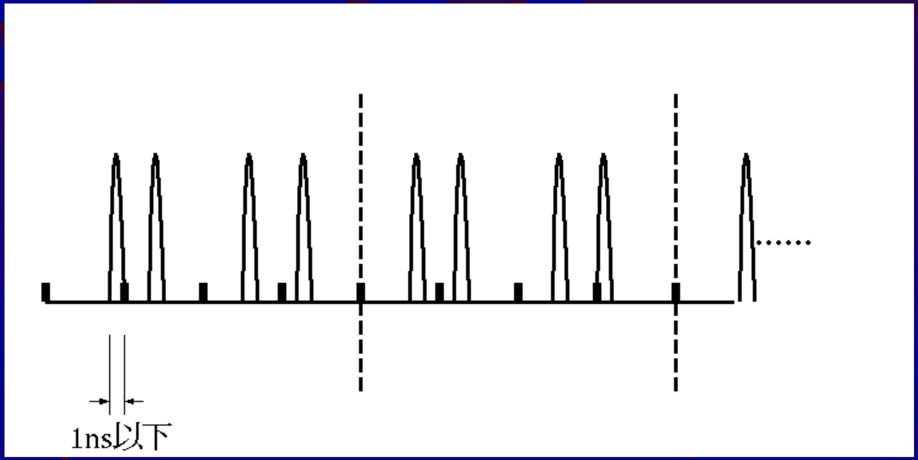
UWB (Ultra Wideband) based on Impulse Radio is attractive because

- Low Interference to Coexisting Systems
- Very Small Power Consumption
- Ultra High Speed Data Trasmission.
- High Multipath Resolution
- One-chip Implemention : SoC

What is UWB (Ultra Wideband)?



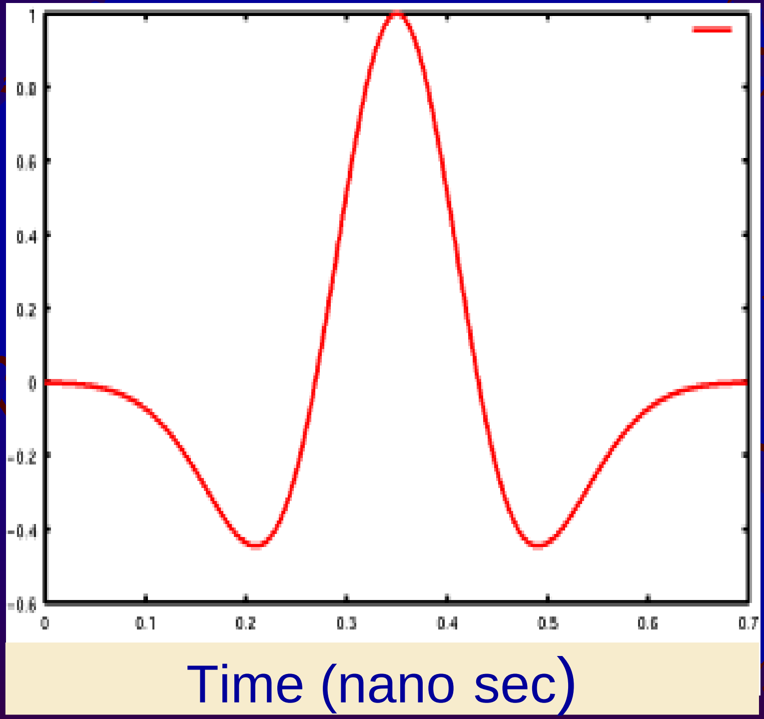
BPSK Signal with Sinusoidal Carrier



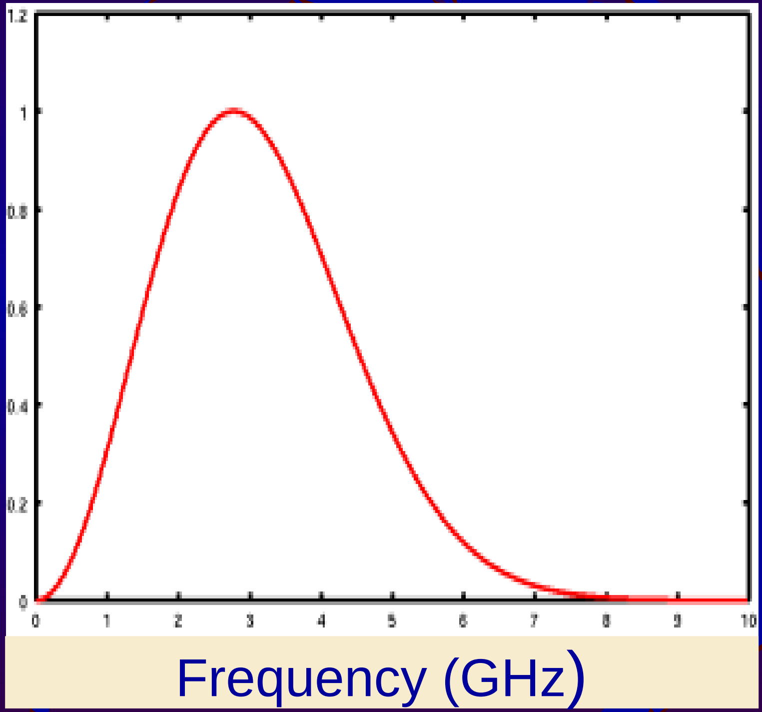
UWB Signal with Pulse Train

- UWB-IR (Ultra Wide Band based on Impulse Radio) is defined as a radio communication scheme using a train of pulses with duration of less than 1nsec.
- Its spectrum is ultra-widely spread over several GHz in width.

Typical Pulse Waveform *(duration = less than 1 nano sec)*
And Its Spectrum *(bandwidth = several GHz)*

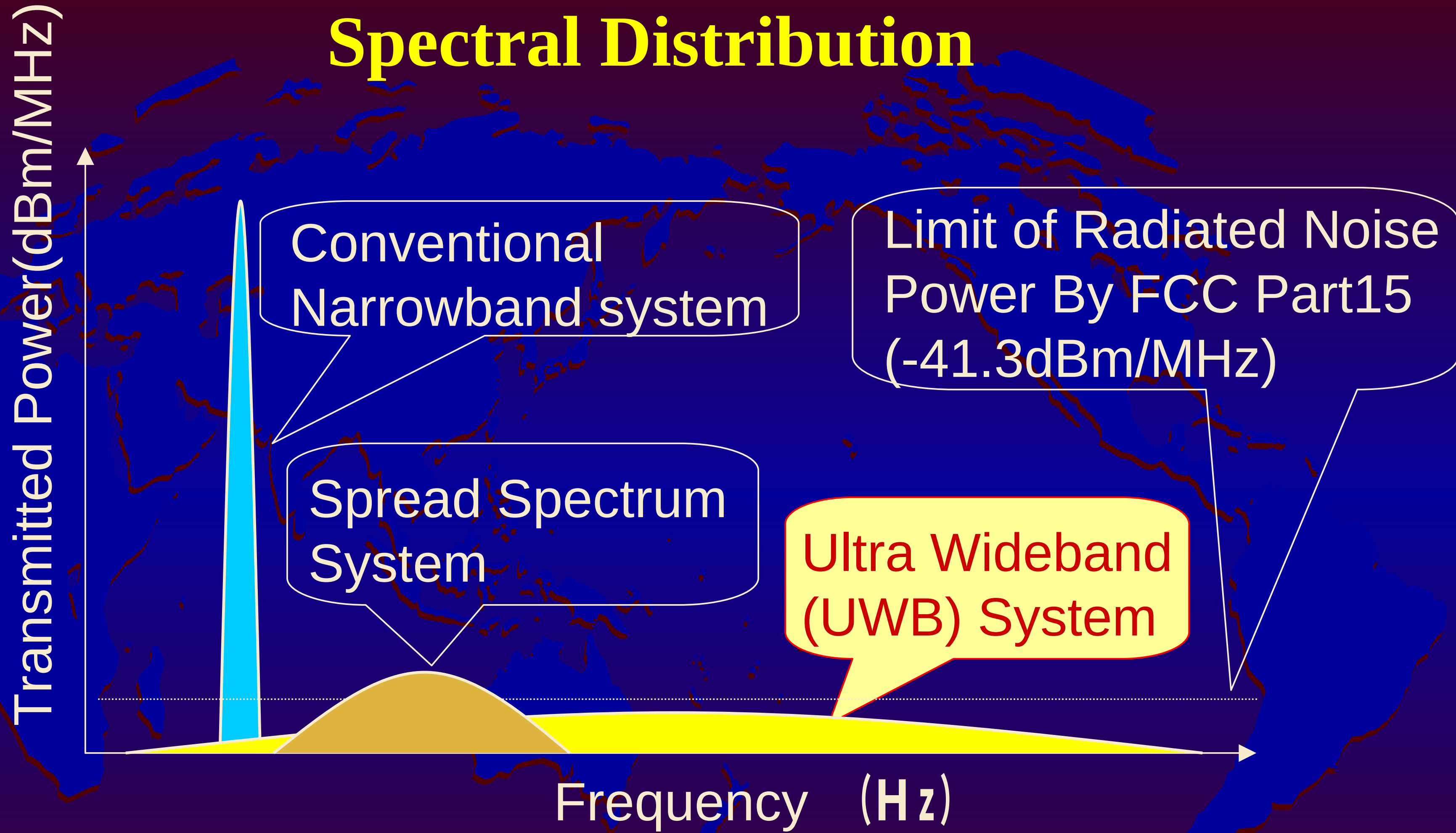


Time Waveform of
Gaussian Mono Cycle Pulse



Frequecy Spectrum of
Gaussian Mono Cycle Pulse

Spectral Distribution



- Ultra Wideband (GHz) is occupied by a pulse with ultra short time duration (1nsec～ 100psec)
- Transmitted power is extremely low (10nW/MHz)

Expected Benefits of UWB

1. Power Spectrum Density is extremely low (lower than noise)
   ⇒ Possible to coexist with other systems due to low interference (High immunity to interference due to large effective processing gain)
2. Time duration of a pulse is extremely short (a few nano sec)
   ⇒ Robust against multi-path distortion because of RAKE type of receiving with high path resolution
   ⇒ High resolution ranging and positioning (within a few cm)
   ⇒ Possible to achieve both communication and ranging
3. Carrier free, and extremely low duty cycle operation
   ⇒ Possible to implement low cost and compact systems with minimal RF, no mixer, and low power-consumption
4. Occupied frequency bandwidth is extremely wide (GHz)
   ⇒ Possible to achieve ultra-high capacity (many users) or high speed transmission (over 100 Mbps)

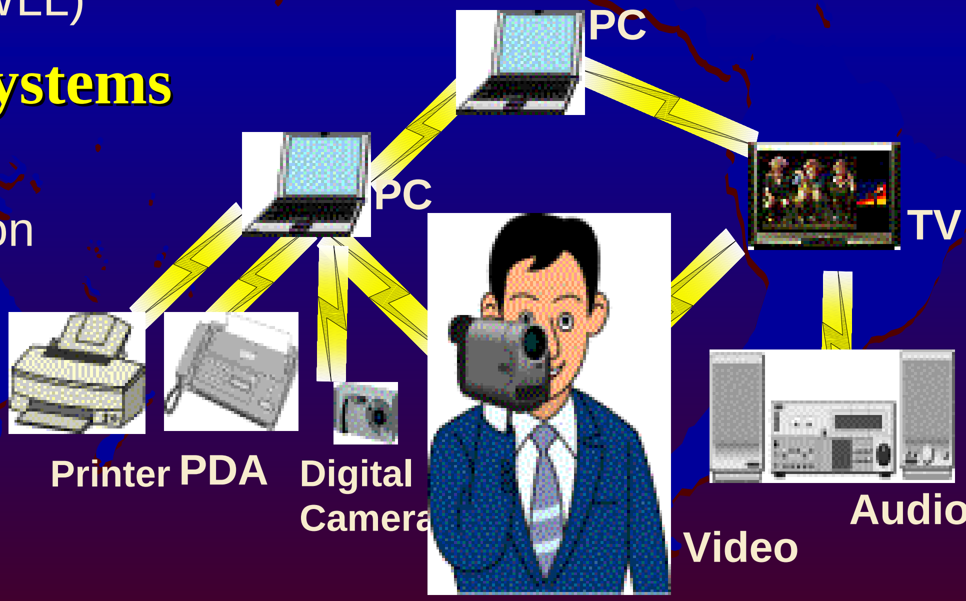
Potential Applications of UWB

- **Wireless communications**
  - High speed and user capacity: over 100 Mb/s
  - Short distance communication (e.g., a few km)
  - Indoor wireless (e.g., WLANs, wireless tags, WPAN) IEEE 802.15.3a

    Wireless USB(Universal serial bus) 2.0 (Intel): 480Mbps (USB 2.0)

  Ref. IEEE 802.15.1 Bluetooth 1Mb/s, IEEE 802.15.3 WiMedea 20 Mb/s
  - Outdoor communications (e.g., WLL)
- **ITS: Intelligent Transport Systems**
  - Colision avoidance radar
  - Realization of both communication

  and ranging with a single hardware
- **Imaging and sensors**
  - Medical imaging
  - Ground penetration
- **Security systems**
  - Intrusion detection and sensing



Problems of UWB

1. Design and Mass-Production of Pulse Generators, RF devises, Antennas etc for UWB
2. Detection of Accurate Pulse waveform in Receiver Inter-Pulse Symbol Interference in the Presence of Multipath
3. Multi-user Interference or Intra-system Interference
4. Inter-system Interference with Co-existing Overlaid Systems, e.g. GPS, Radio Astronomy, Medical Systems
5. Spectral Allocation for UWB Systems to Avoid Collision or Interference with Conventional Systems

Regulation Activities on Commercial UWB

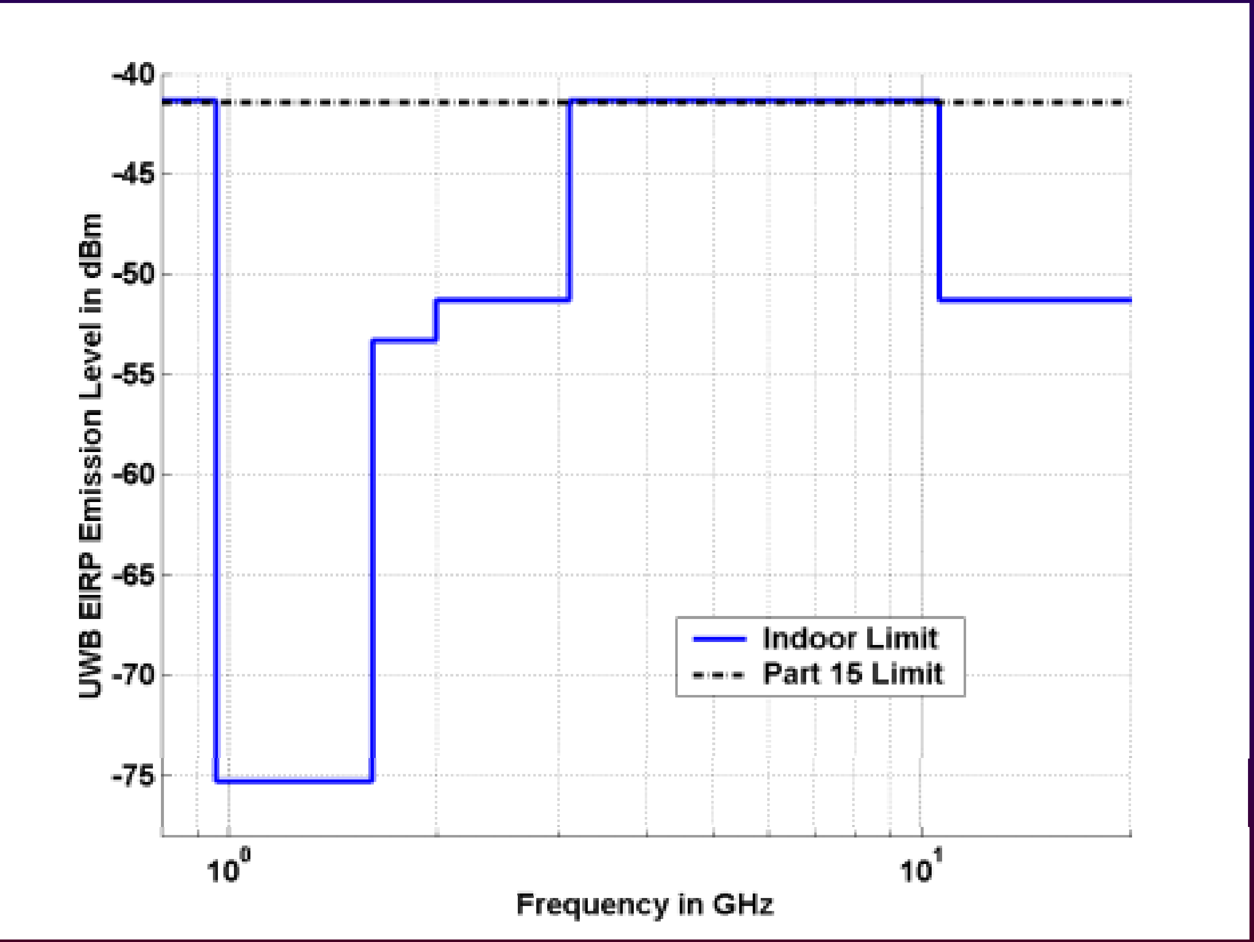
- In the USA, the FCC released the UWB regulations on February 14, 2002 with strict guidelines on transmitting power.
- In Japan, CRL established UWB technology Institute to promote R&D and improve radio regulation for commercial use of UWB.

FCC First Report and Order

Order establishes different technical standards and operating restrictions for three types of UWB devices based on their potential to cause interference

1. Imaging Systems
2. Vehicular Radar Systems
3. Communication Systems

UWB Emission Limit for Indoor Communication Systems defined by the FCC Feb 14, 02 [between 3.1-10.6 GHz.]



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Research in Ultra Wide Band(UWB) Wireless Communications in Japan

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UWB Technology Institute in CRL

- **Aim**

1. Promote R&D of UWB Commercial Systems and Its Related Technologies
2. Transfer the Technologies to Industry by Cooperation with Industry and Academia
3. Modify Radio Regulation and Establish Guidelines and Standard

- **Date**

May 1, 2002

- **Place**

CRL(Communication Research Laboratory) in YRP (Yokosuka Research Park)

- **Director**

Ryuji Kohno

UWB Consortium between Industry and Academia

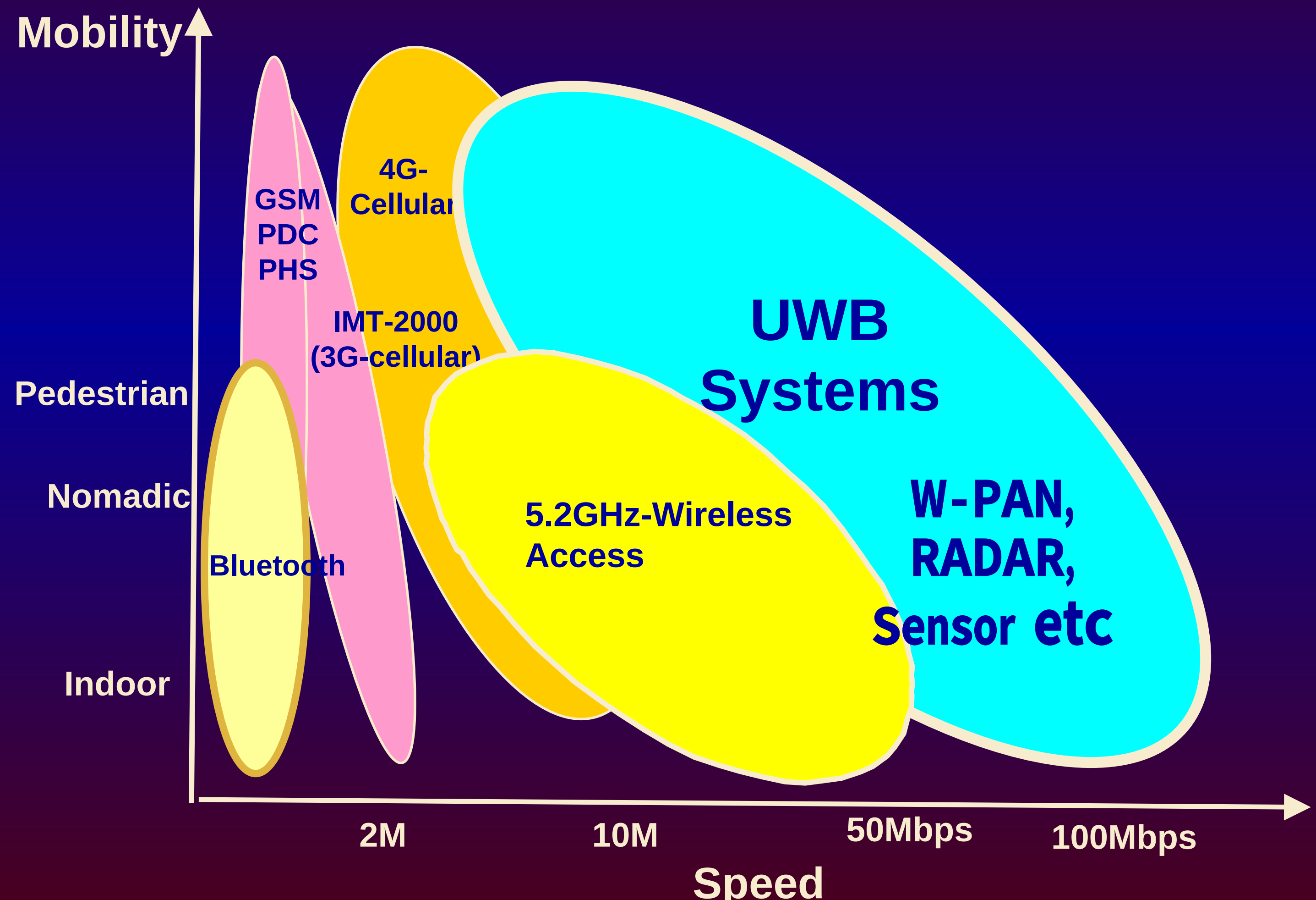
- **Organization:**

CRL UWB Technology Institute and associating Manufacturers and Academia

- **Aim:**

  - **R&D and Regulation of UWB Wireless Systems**
  - **Channel Measurement and Modeling with Experimental Analysis of UWB System Test-bed in band (960MHz, 3.1-10.6GHz, 22-29GHz, over 60GHz)**
  - **R&D of Low Cost Module with higher data rate over 100Mbps**
  - **Contribution in Standardization with ARIB and MMAC etc**

Targeting UWB Systems (Data rate vs. Mobility speed)



Comparison of System Specification

Specification	Targeted UWB System	Bluetooth	Bluetooth Ver.2	5.2GHz Mobile Access	License Free System in 60GHz
Data Rate	Over 100Mbps	Up to 721kbps	2Mbps	Up to 4Mbps	Home-link 1.6Gbps
Communication Range	10m	10〜100m	10〜100m	100m	10m
Drawback	Short range	Low rate		High power consumption	High Cost
Advantages	・Low Power Consumption ・Ad-Hoc ・Low Cost ・High Speed ・Ranging & Positioning	・Ad-Hoc ・Low Cost	・Ad-Hoc ・Low Cost	Indoor Only	High Transmission Rate

http://www.ericsson.co.jp/products/bluetooth_ip/faq/faq_02c.html#33

Ultra Wideband Impulse Radio Using Free-Verse Pulse Waveform Shaping, Soft-Spectrum Adaptation, and Local Sine Template Receiving

Ryuji Kohno, Honggang Zhang, Hiroyuki Nagasaka
UWB Technology Institute
Communications Research Laboratory (CRL)

Outline

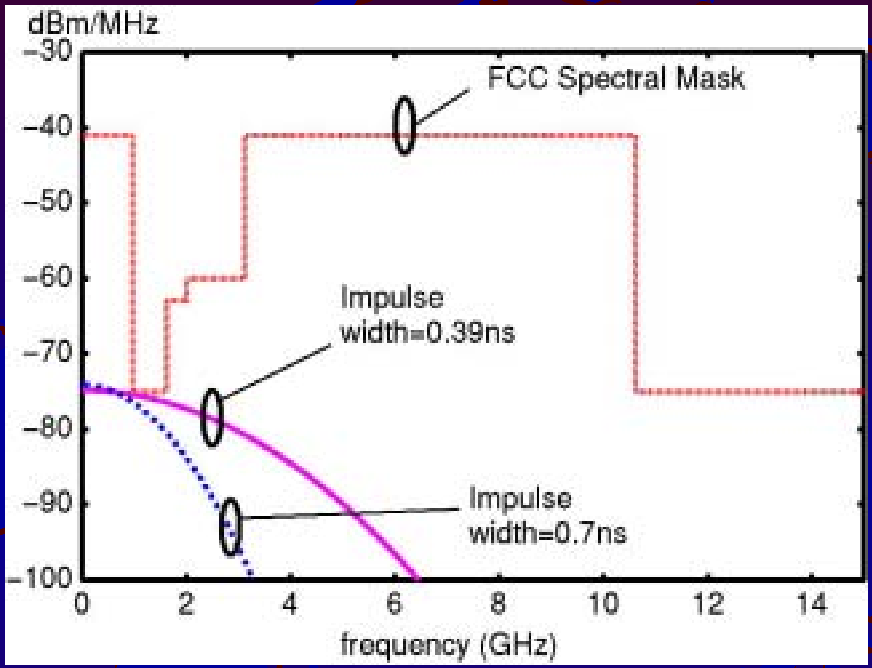
- Philosophy of ***Soft-Spectrum adaptation*** with flexible pulse waveform design

1. Soft-Spectrum adaptation based on *free-verse* pulse waveform shaping
2. Soft-Spectrum adaptation based on *geometric* pulse waveform shaping

→ *Interference avoidance and co-existence*

→ *Scalable, adaptive performance improvement*

- Local *sine* template receiving
- Summary



- Considering the whole frequency bands from DC to 15 GHz, in regard of the FCC Spectrum Mask

- The maximum emission power is limited to –80dBm/MHz (whole bands)
- Frequency efficiency is extremely worse

What's the solution?

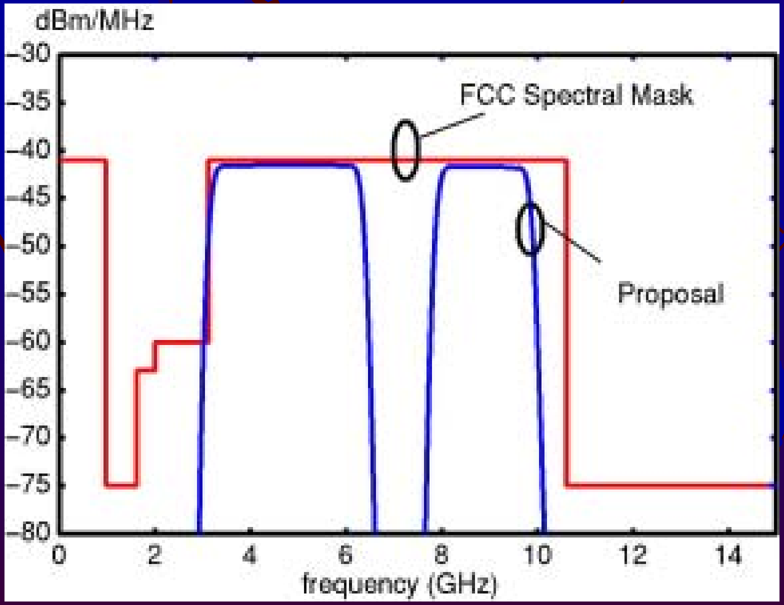
(I) Pulse domain (II) Spectrum domain

What we want to do ?

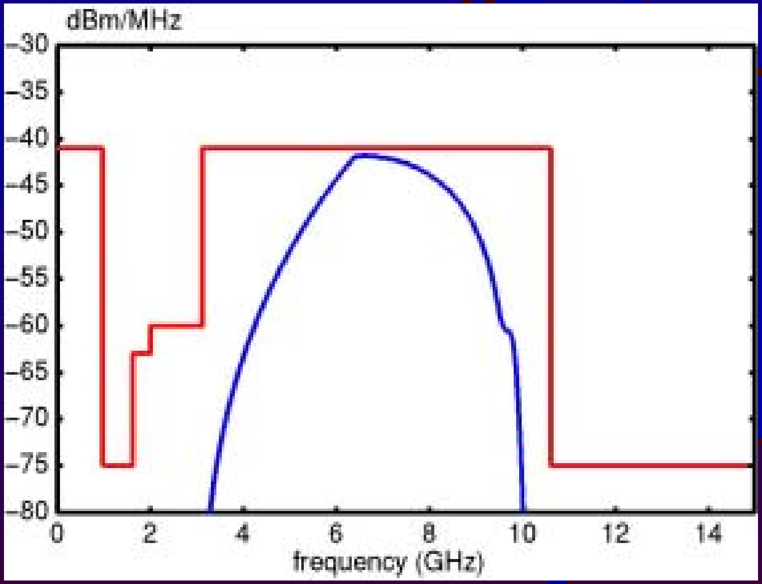
- Giving spectrum freedom → flexible pulse design
- Maintaining exchangeability with existing UWB systems
- Still keeping the pulse width in the order of *ns* for high data rate

Basic philosophy

- Pulse design corresponding to the required bandwidths
- Flexible and adaptive spectrum (***Soft-Spectrum***), even if the Spectrum Mask were changed



EX(1): some bands are restrained

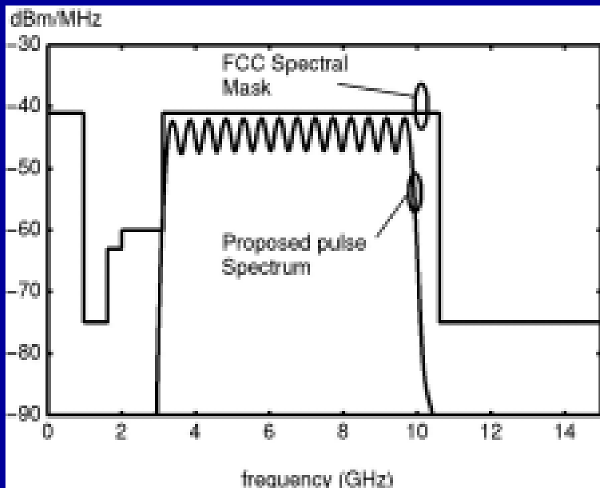


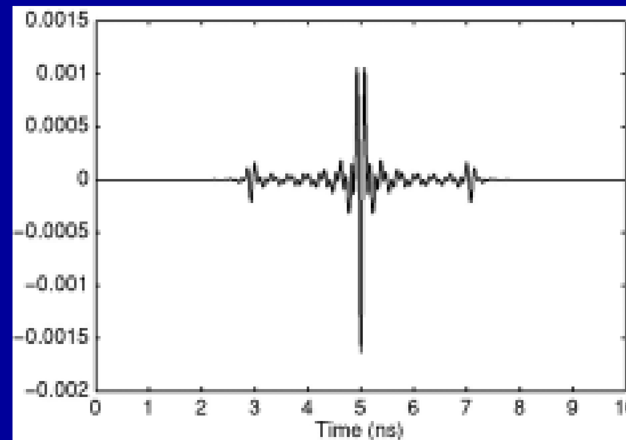
EX(2): free-verse spectrum design

Section (I)

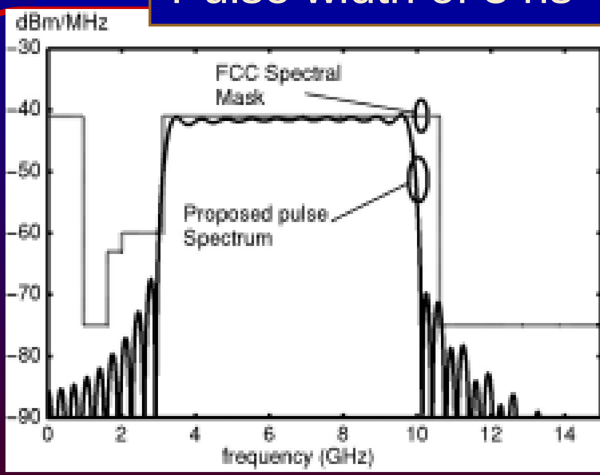
Soft-Spectrum (*Soft-Bands*) Adaptation with *Free-Verse* Pulse Waveform Shaping

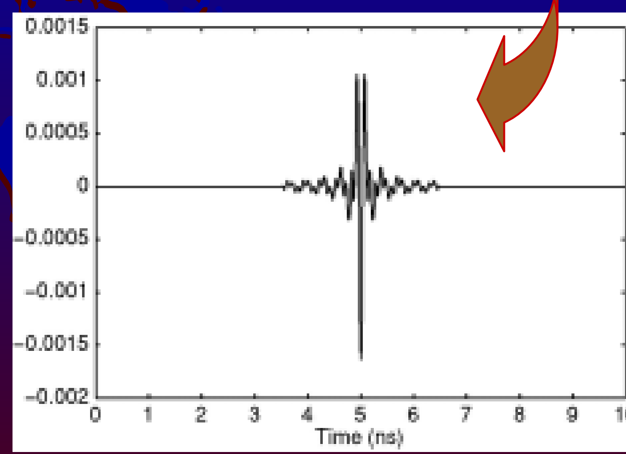
Pulse width of 10 ns





Pulse width of 3 ns





Frequency characteristics

Tread-off

Pulse width

Robustness to MAI

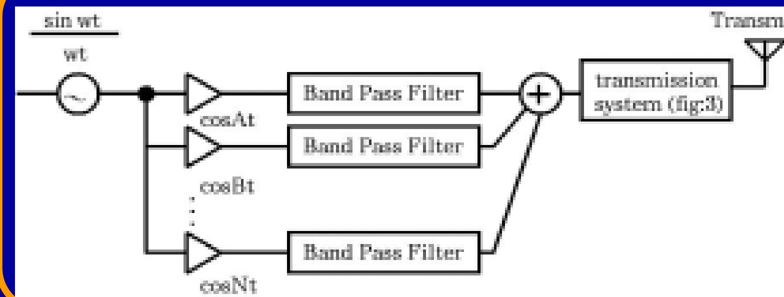
Basic Formulation

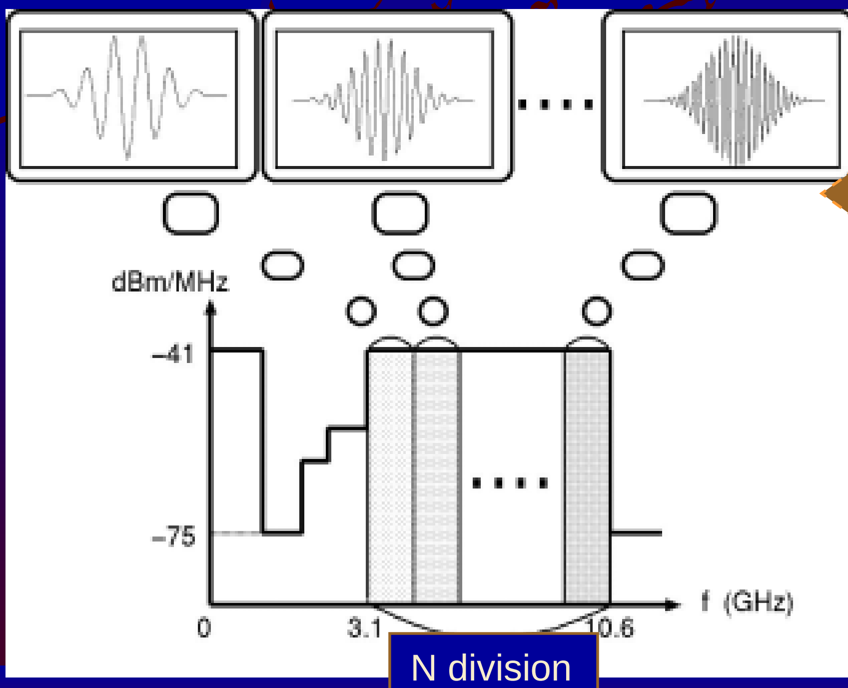
$$f(t) = \sum_{k=1}^{N} f_k(t)$$

$$f_k(t) = \cos[2\pi(f_L + \frac{(1+2k)B}{2N})] \times \frac{\sin(B\pi t)}{N\pi t}$$

B:bandwidth [f $_H$ ~f $_L$]

Pulse Generator

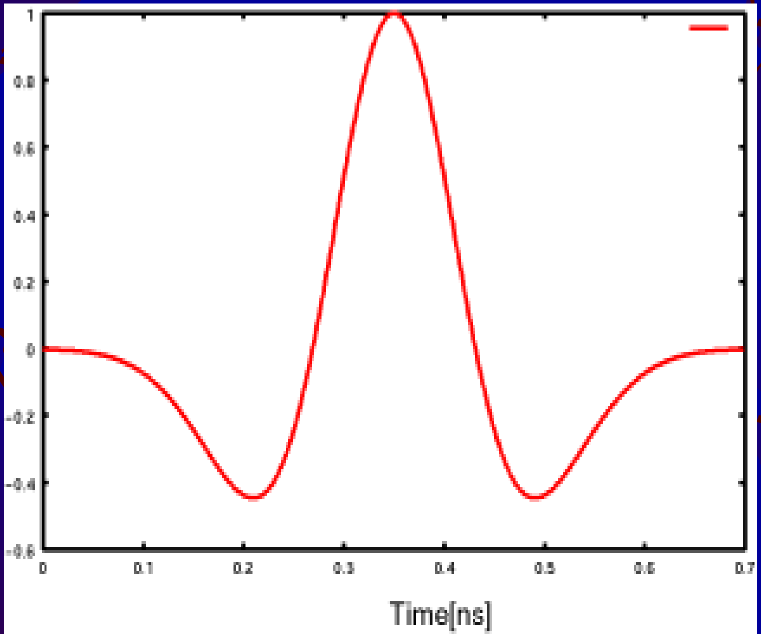


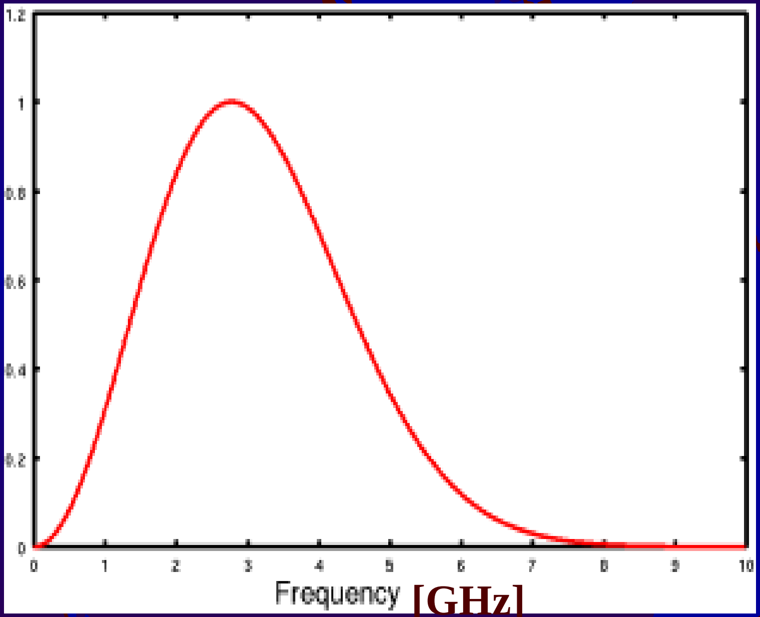


Feasible Solution: Pulse design satisfying Spectrum Mask

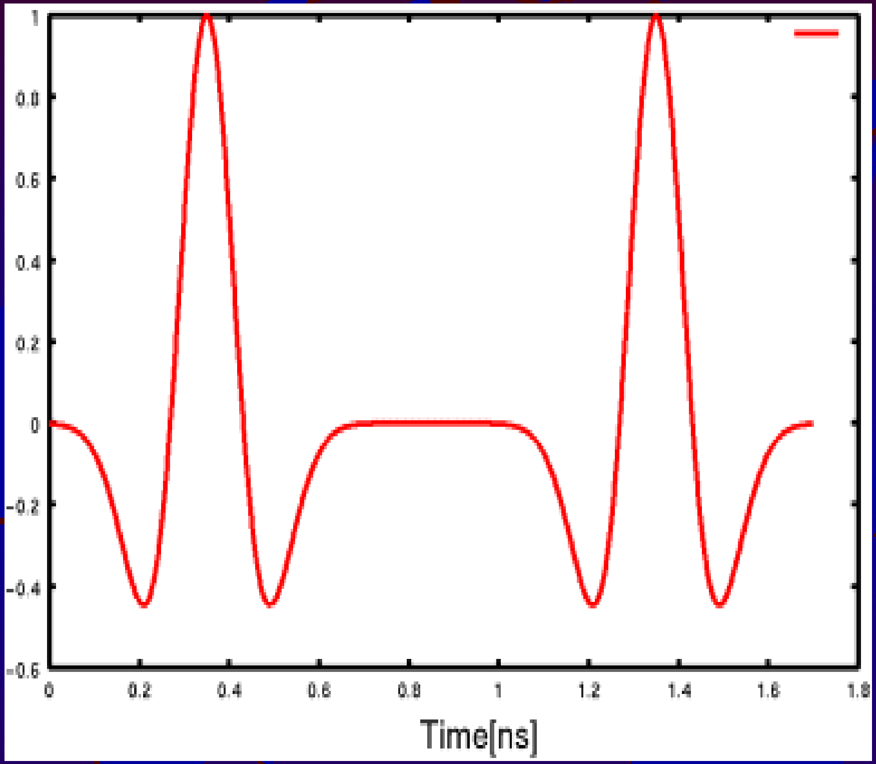
- Divide the whole bandwidth into several sub-bands → *Soft Spectrum* (spectrum matching)
- Pulse synthesis → *M*-ary signaling

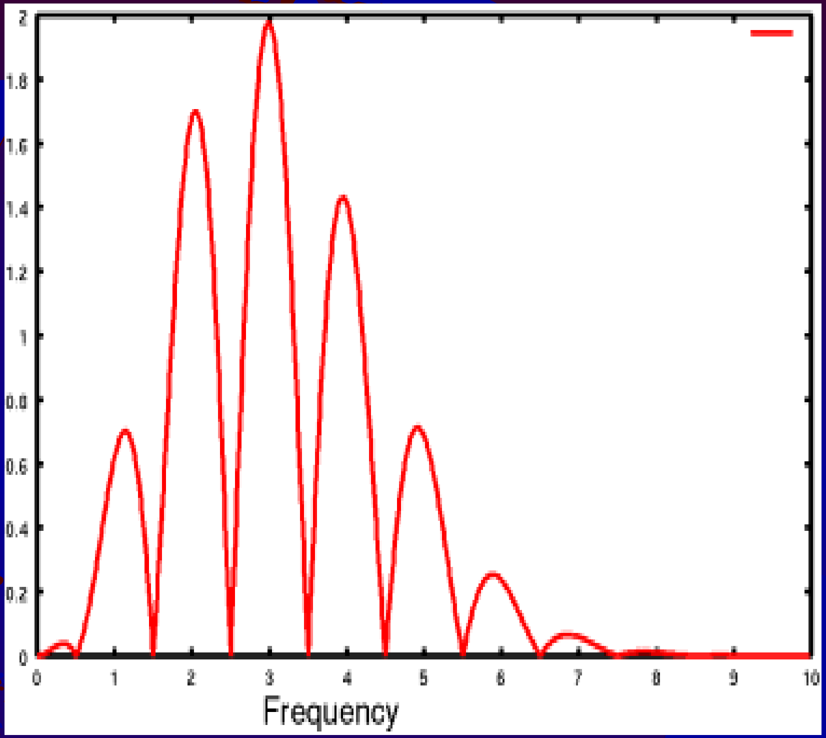
Feasible Solution: Pulse design satisfying coexistence and interference avoidance with existing narrowband systems



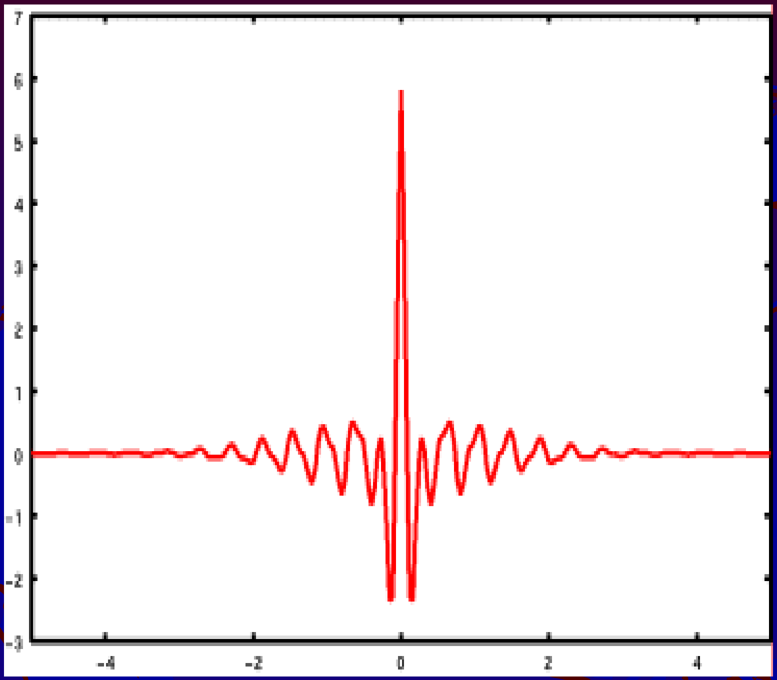


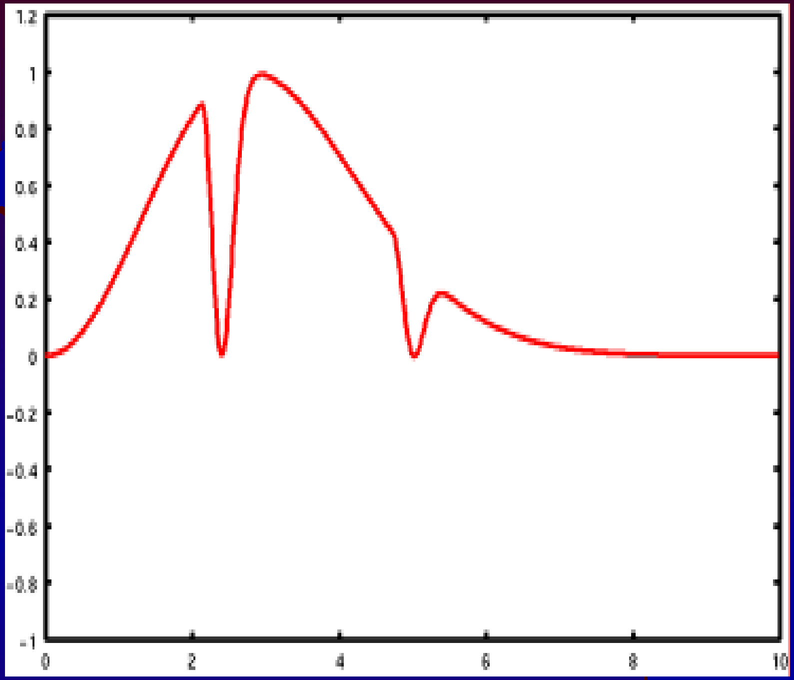
Time and frequency domain characteristics of the conventional Gaussian-type pulse



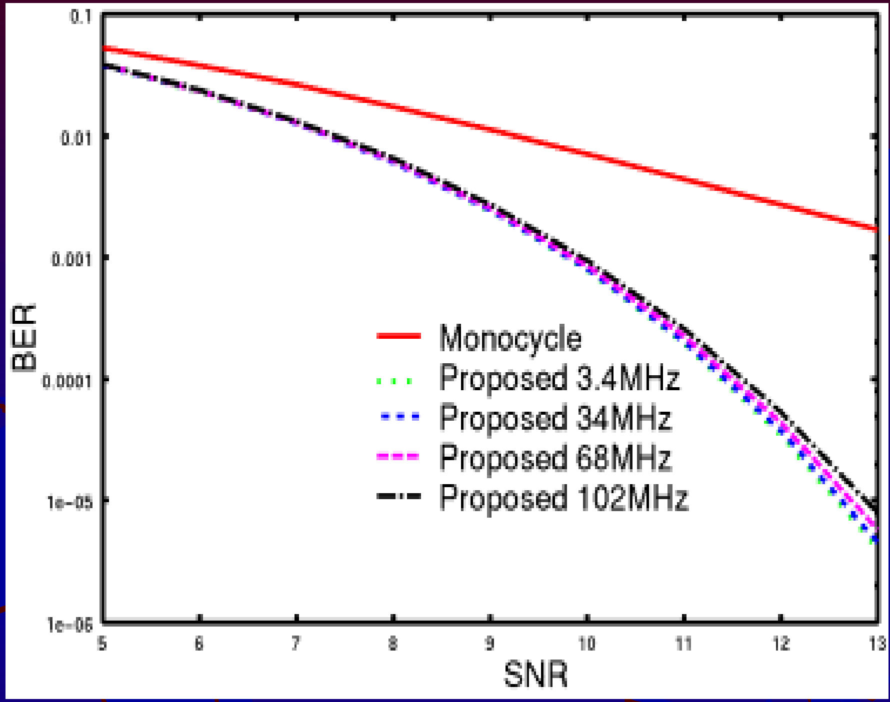


Time and frequency domain characteristics of the **proposed Dual-cycle pulse** (*K-2*)
(Note: several band notches happen)

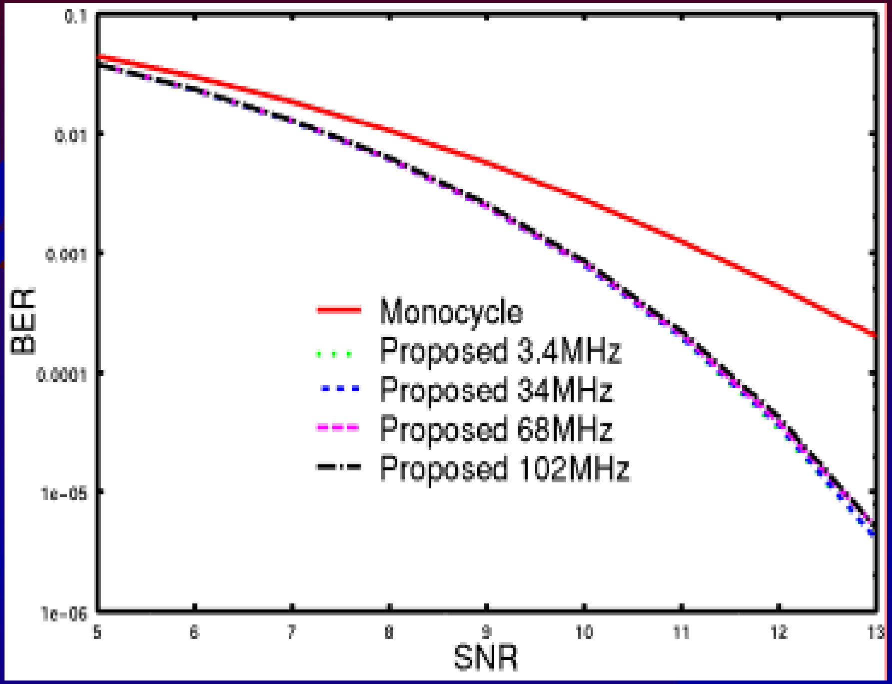




Time and frequency domain characteristics of another proposed pulse waveform (*K-4*) generated by different Gaussain pulses overlapping
(Note: band notches *clearly* happen at 2.4 and 5 GHz as well)

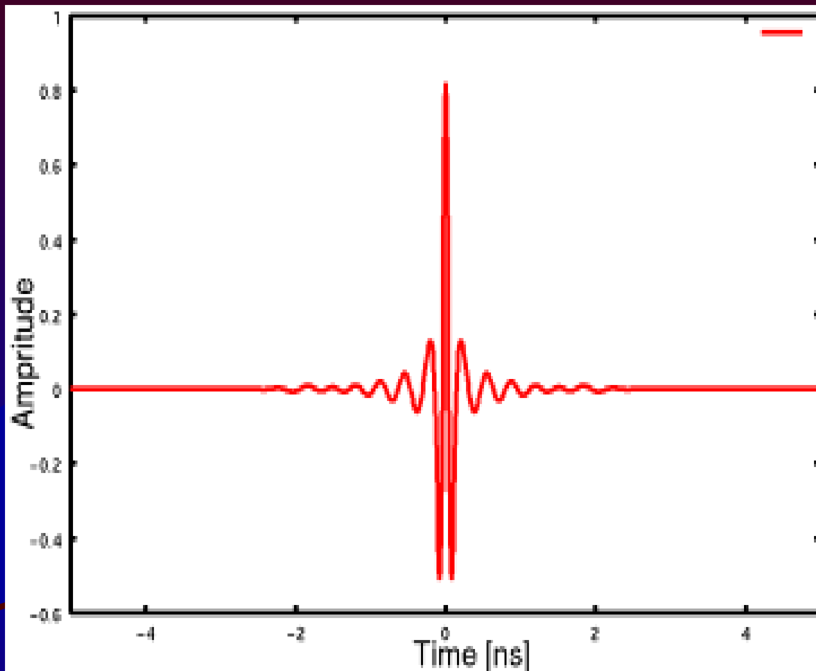


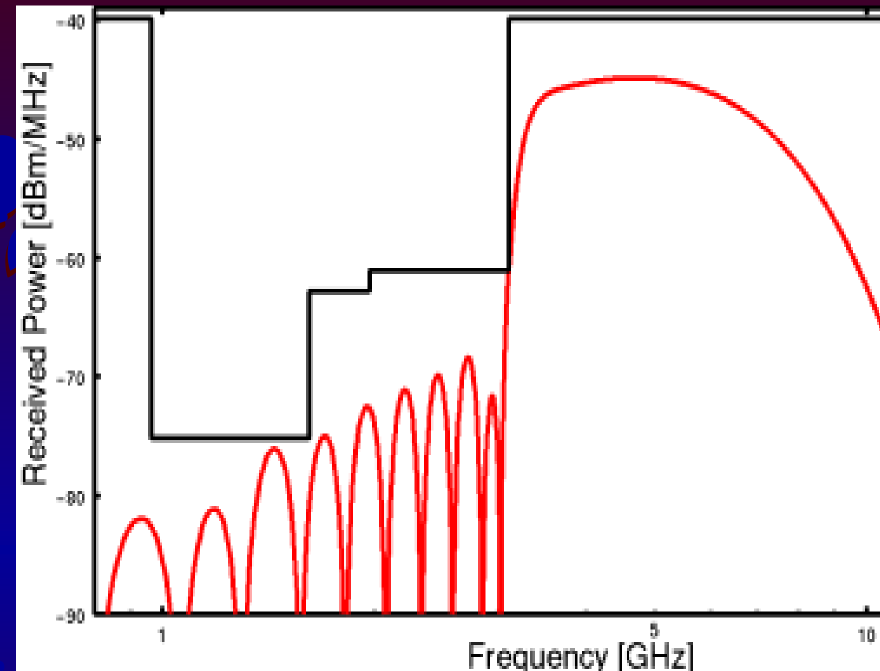
(1) BER of DS-SS system while *K-4* UWB system causing interference



(2) BER of *K-4* UWB system while DS-SS system causing interference

Performance comparisons of the coexistence of the DS-SS and UWB systems (*K-4*)
(Note: DS-SS system uses carrier frequency of 2.5 GHz, i.e. notch band for the proposed UWB system)

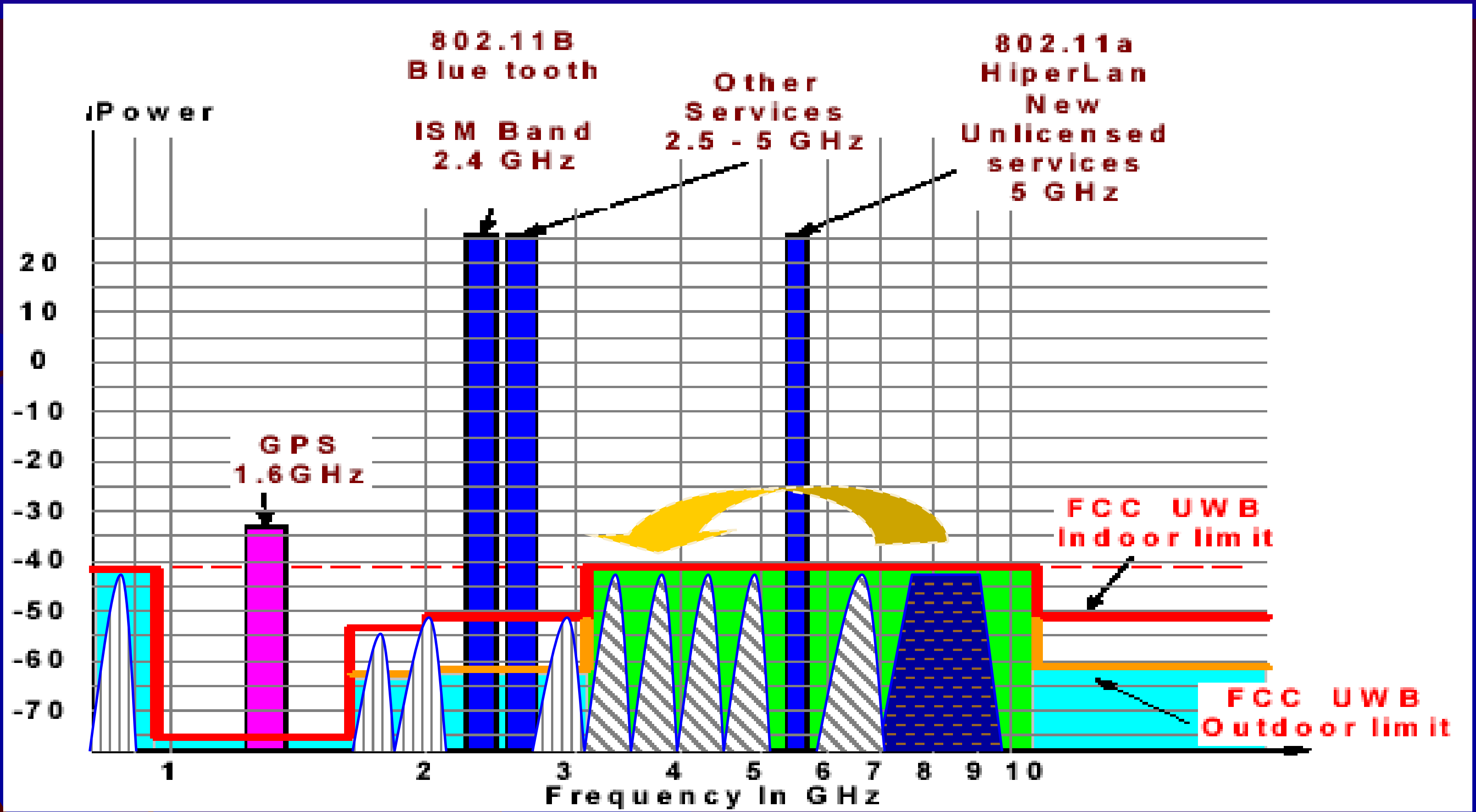




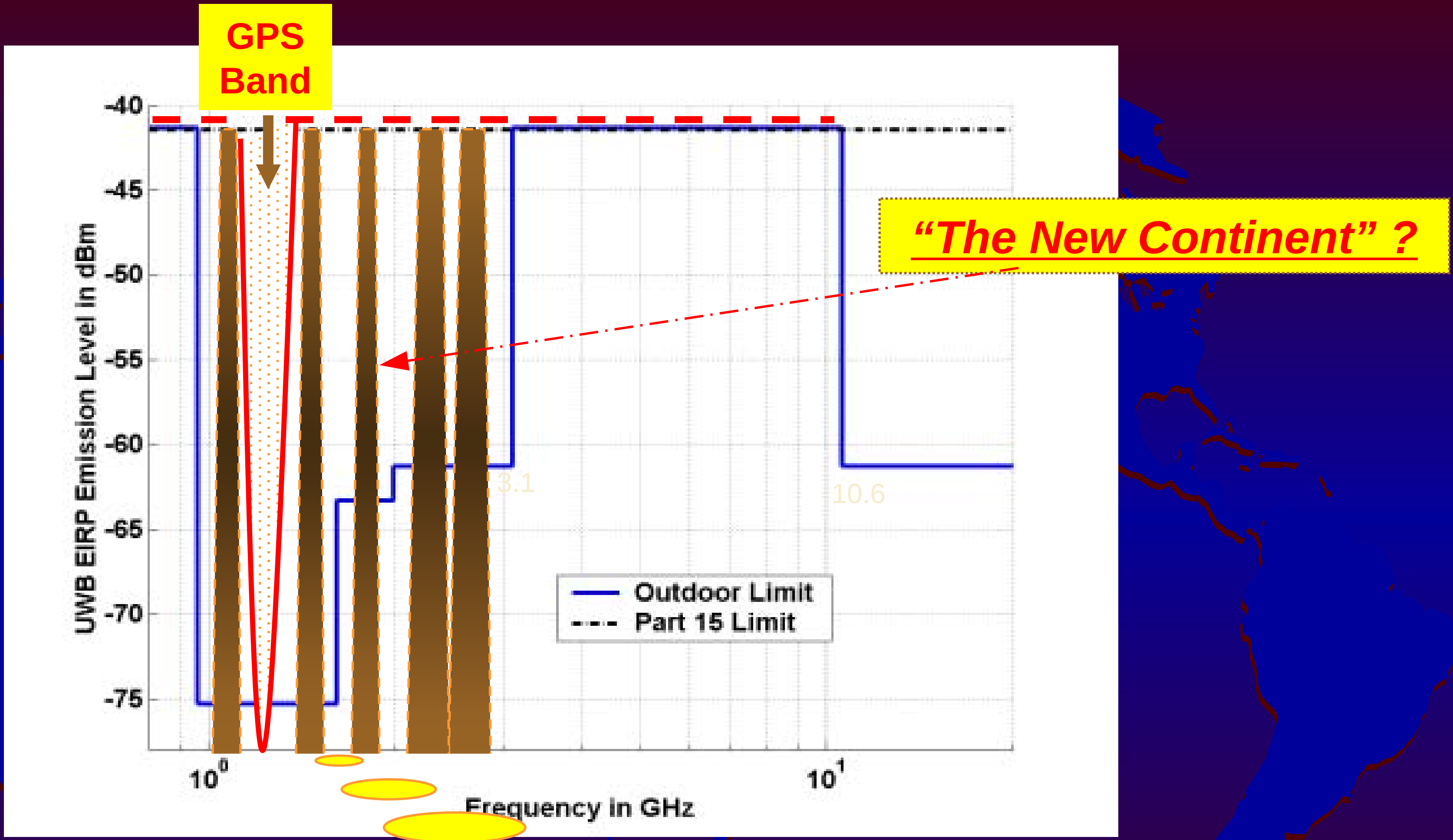
$$\exp\left(-2\pi\frac{t^2}{(\alpha\tau_m)^2}\right)\cos\omega_0 t$$

Giving Spectrum Freedom

→ Flexible pulse waveform and spectrum design



Geometric Soft-Spectrum Adaptation (*Spread-and-Shrink*) and pulse waveform shaping provide new dimension, frontier, and challenge (seeing FCC UWB Emission Limit: FCC 02-48, UWB Report & Order)



Just a dream-world?

Summary of Soft-Spectrum Adaptation

- ***Soft-Spectrum adaptation*** can satisfy the FCC Spectrum Mask and any Mask adaptively.
- ***Soft-Spectrum adaptation*** can be applied to avoid possible interferences with other existing narrowband wireless systems.
- Scalable and adaptive performance improvement can be achieved by utilizing pulse waveform shaping **even in multi-user and multipath fading environment.**