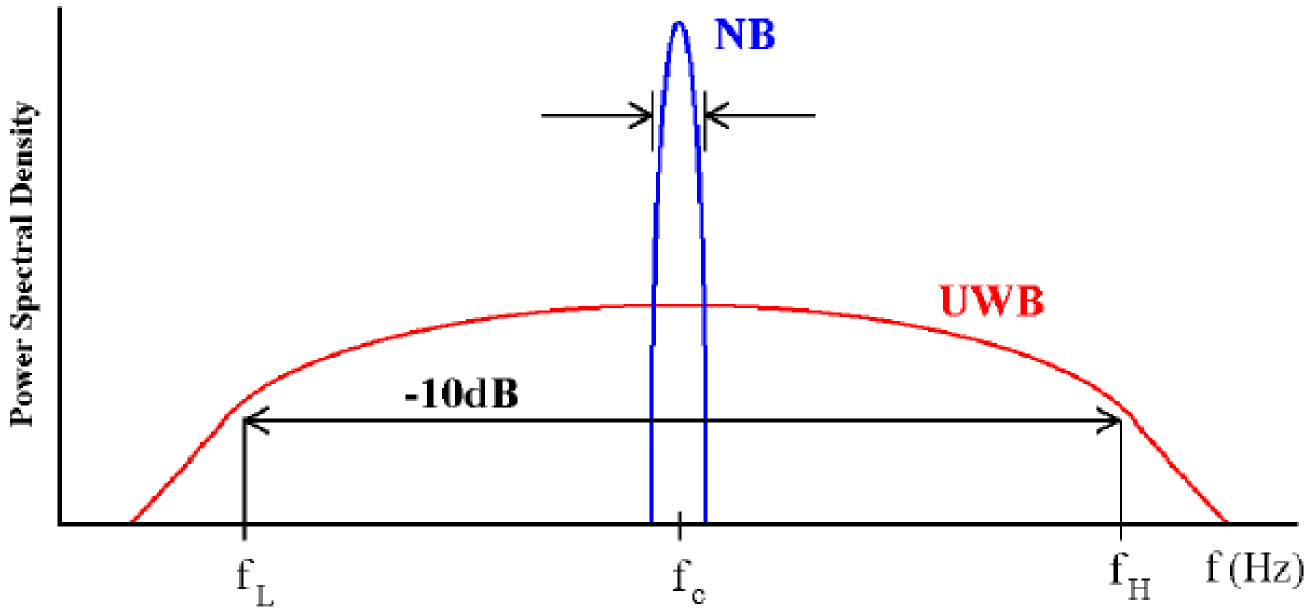
Introduction of UWB

UWB Definition

- Common Definitions
  - UWB: Fractional BW = $(f_H - f_L)/f_C > 25\%$ or total BW > 1.5 GHz.
  - Narrowband: $(f_H - f_L)/f_C < 1\%$.
- FCC Definition of UWB
  - Fractional bandwidth (measured at the -10dB points), $(f_H - f_L)/f_C > 20\%$ or total BW > 500 MHz.



FCC regulations regarding UWB

- In February of 2002, the FCC amended their Part 15 rules (concerning unlicensed radio devices) to include the operation of UWB devices without a license.

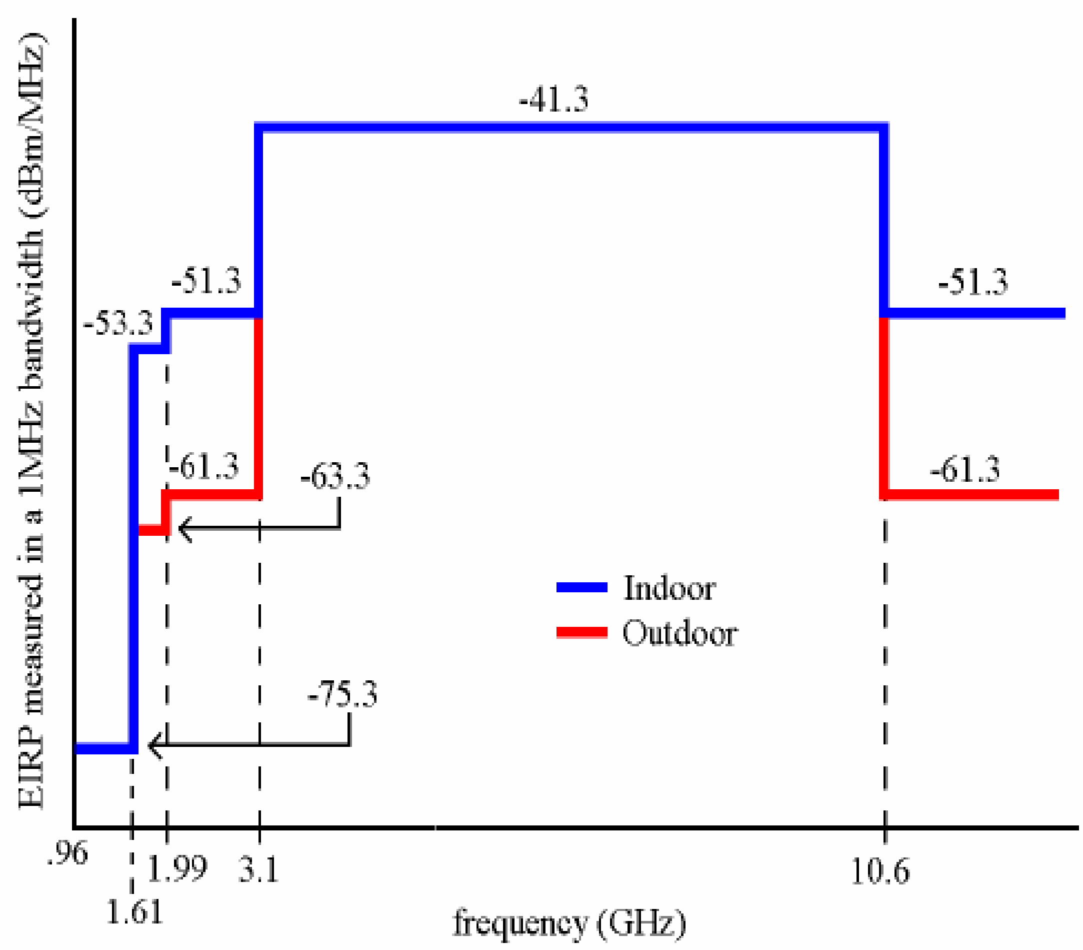
- Defined 3 types of UWB devices
  - Imaging Systems.
  - Communications and Measurement Systems.
  - Vehicular Radar.

- Below 960 MHz, all types must meet FCC §15.209 limits.

FCC Mask for Communications

- Indoor
  - Must show that they will not operate when taken outside (ex: require AC power).

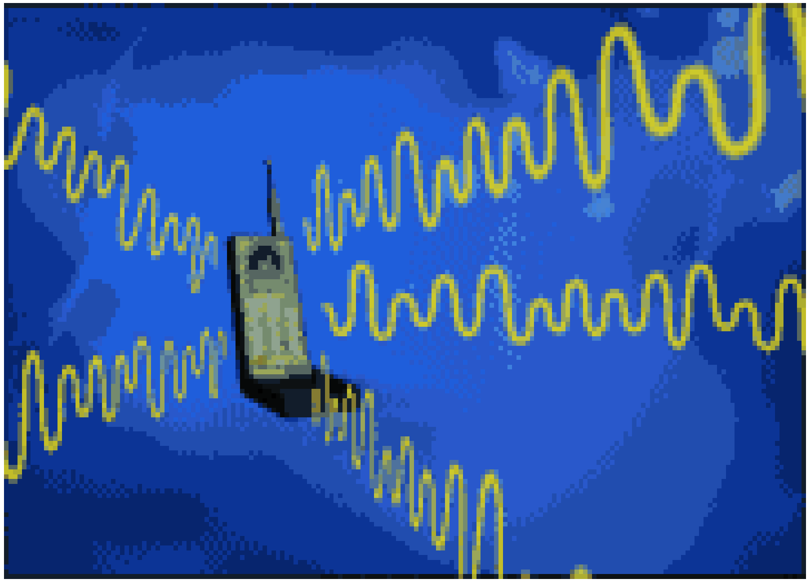
- Handheld (outdoor)
  - Operate in a peer-to-peer mode without location restriction.



Transmitted Power

- The FCC ruling allows UWB communication devices to
  operate at low power (an EIRP of -41.3 dBm/MHz) in an
  unlicensed spectrum from 3.1 to 10.6 GHz.
- 7.5 GHz equivalent bandwidth :
  550 microWatts EIRP (-2.5 dBm)
- Allow 3 dB margin to the limit
- NET Transmitted Power = -5.5 dBm
- True Low Power Radio!

Impulse Radio UWB



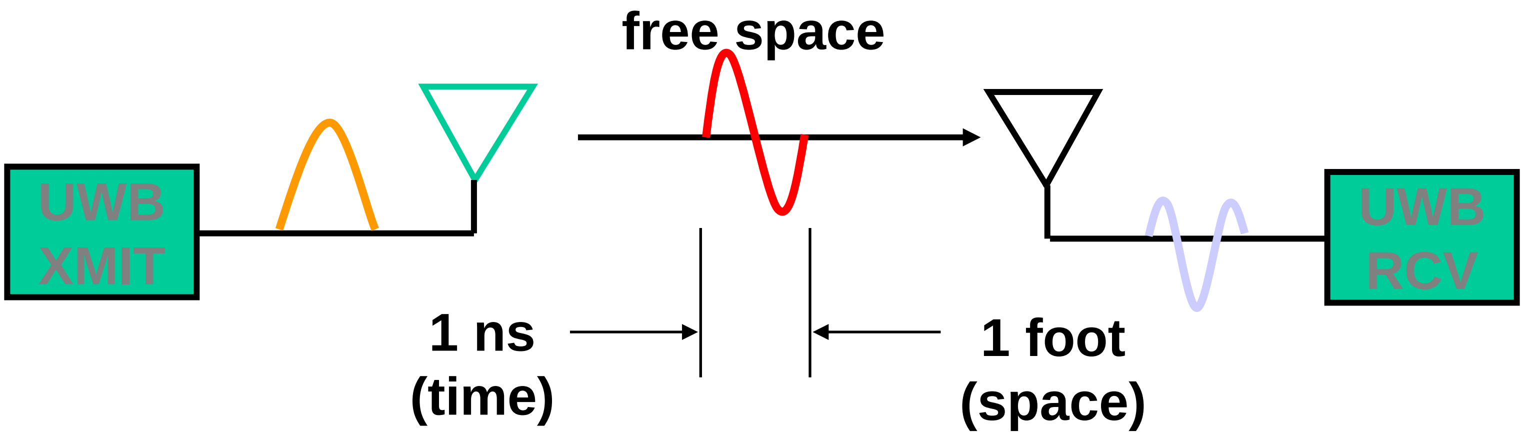
Continuous Sine Waves

- Carrier System
- Phase, Frequency, Amplitude
- PSK, FSK, ASK, Hybrids

Impulse Radio

- Carrierless System
- Pulse with width 0.2ns ~ 1.5ns
- PPM + THSS or DSSS

Impulse Radio UWB (Transmission)



A Gaussian function

1st derivation of a Gaussian function

2nd derivation of a Gaussian function

Impulse Radio Modulation

- Pulse position modulation (PPM)
  - Binary/M-ary
- Bipolar Signaling (BPSK)
- Pulse Amplitude Modulation (PAM)
- On/Off Keying (OOK)
- Orthogonal pulse shapes
  - Hermite Polynomials
- Combinations of the above

Impulse Radio UWB Techniques (1)

- Time-Modulated (Hopping) UWB (TM(H)-UWB) ：

  — low duty cycle (Impulse radio)

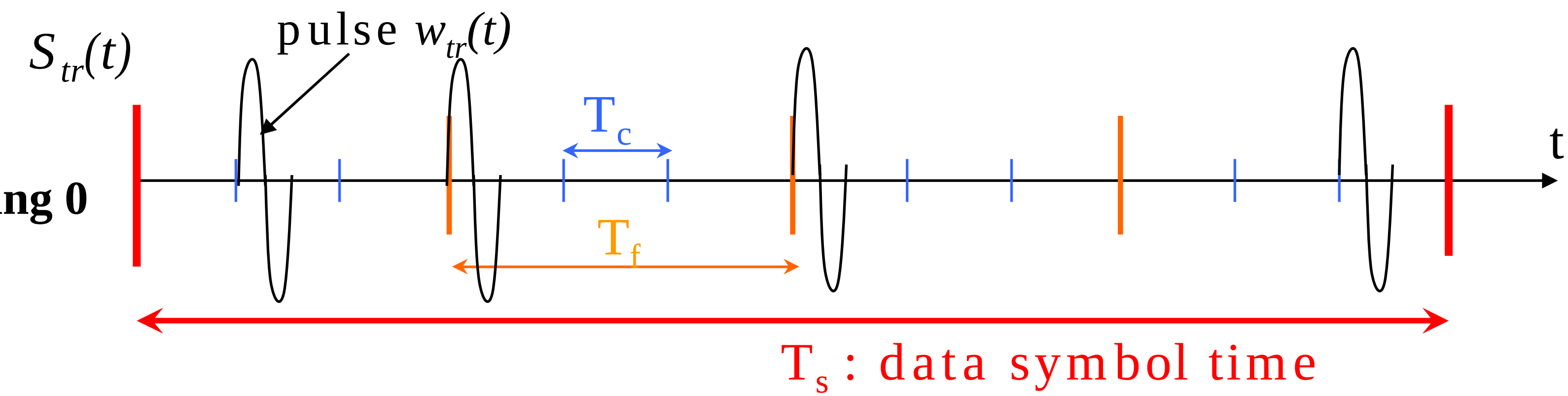
  — data modulation by pulse position (time dithering) or signal polarity

  — multiaccess channelization by time coding (Time- Hopping, TH)

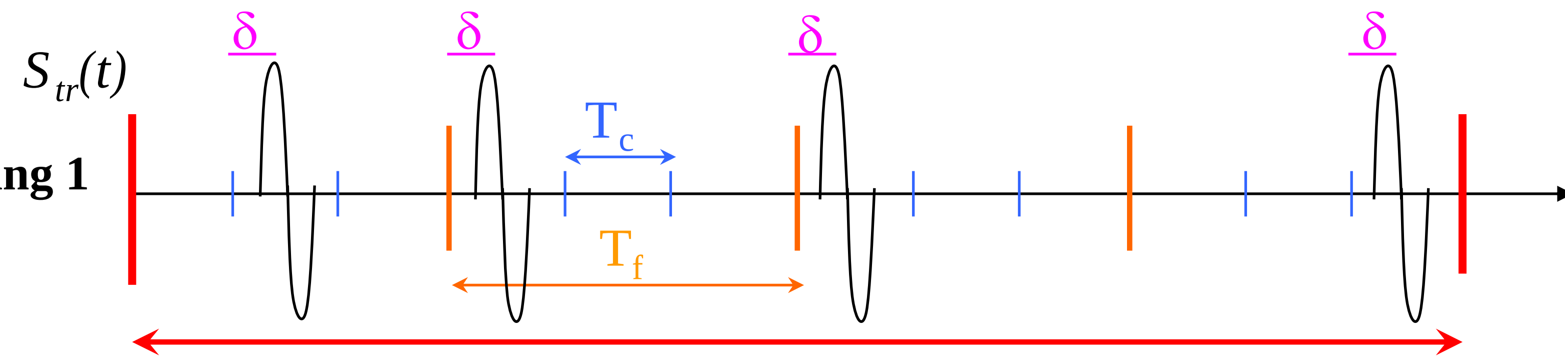
  — for precise location, tracking, radar sensing (through wall), data communications

PPM + THSS

- **transmitting 0**



- **transmitting 1**



codeword $C = [1\ 0\ 0\ 2]$, $N_h = 3$

code period $N_p = 4$

$T_s = N_s \cdot T_f$ i.e., $T_s = 4 \cdot T_f$

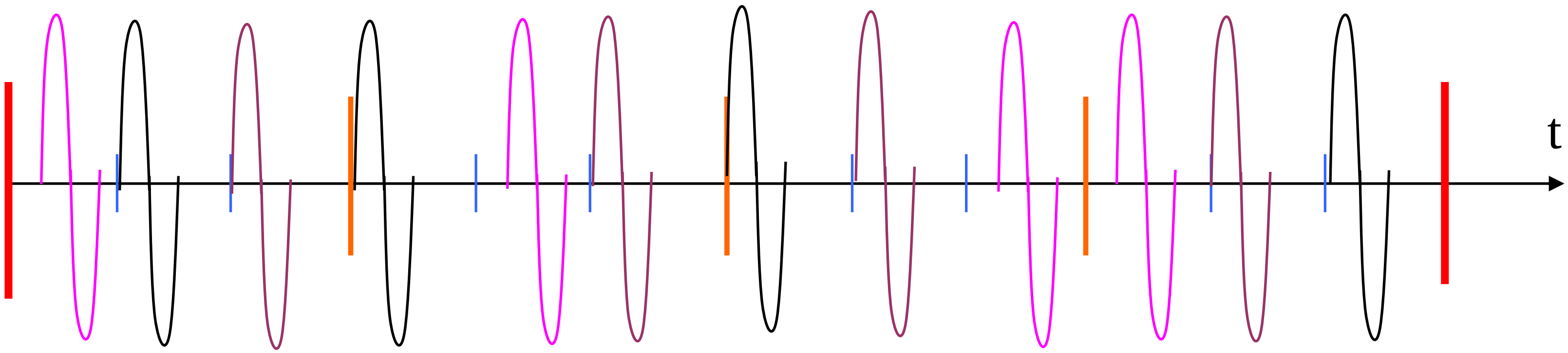
N_s : number of pulses per data symbol

$T_f \geq N_h \cdot T_c$ i.e., $T_f = 3 \cdot T_c$

$$S_{tr}(t) = \sum_{i} \sum_{j=0}^{Ns-1} w_{tr}\left(t - iT_s - jT_f - c_j T_c - d_i \delta\right)$$

THSS Multiple Access

$$\sum_{k=1}^{3} S_{tr}^{(k)}(t)$$



User1 : $C^{(1)}$=[1 0 0 2] $d^1=0$

User2 : $C^{(2)}$=[0 1 2 0] $d^2=1$

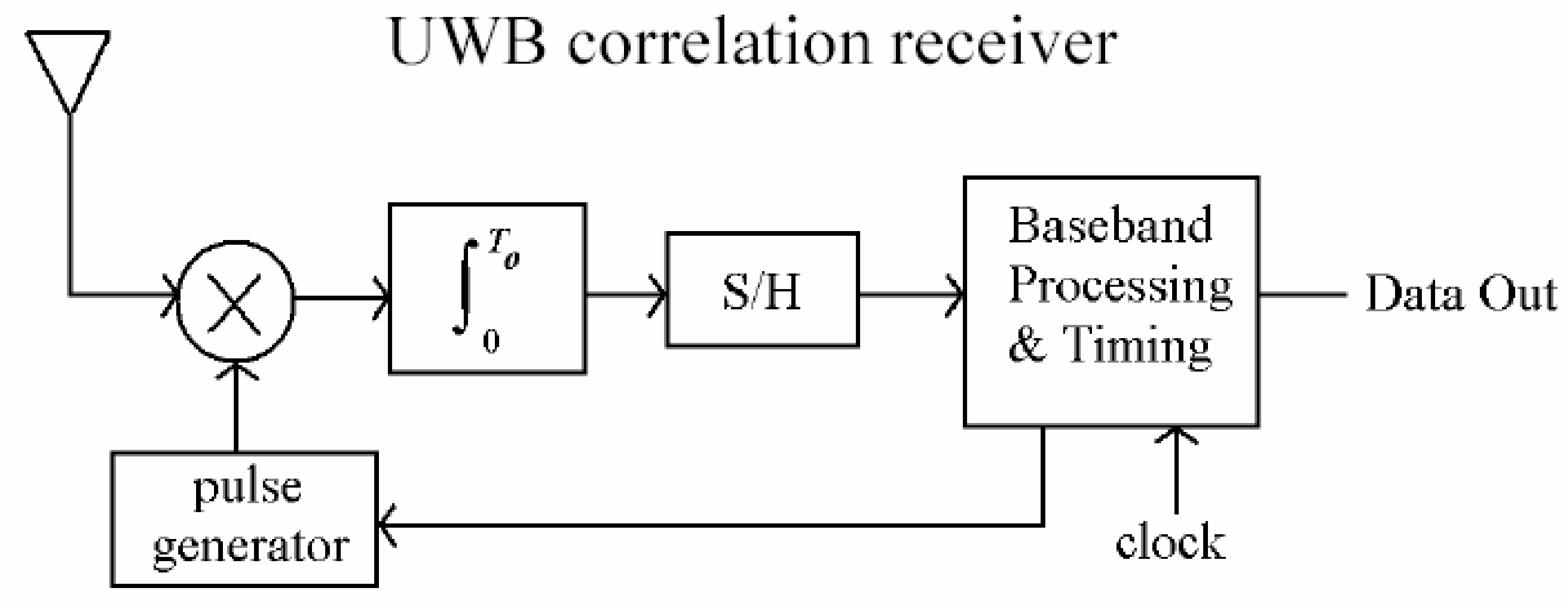
User3 : $C^{(3)}$=[2 2 1 1] $d^3=0$

Impulse Radio UWB Techniques (2)

- Direction-Sequence Phase Coded UWB (DS-UWB)：
  - — high duty cycle
  - — data modulation by pulse polarity
  - — multiaccess channelization by PN coding (DS)
  - — suitable mostly for data-communication applications

Impulse Radio Correlation Receiver

- The received signal is correlated with the expected received pulse (may differ from the transmitted pulse due to distortion by the antennas and channel).
- Simple design, less RF hardware than narrowband receivers.



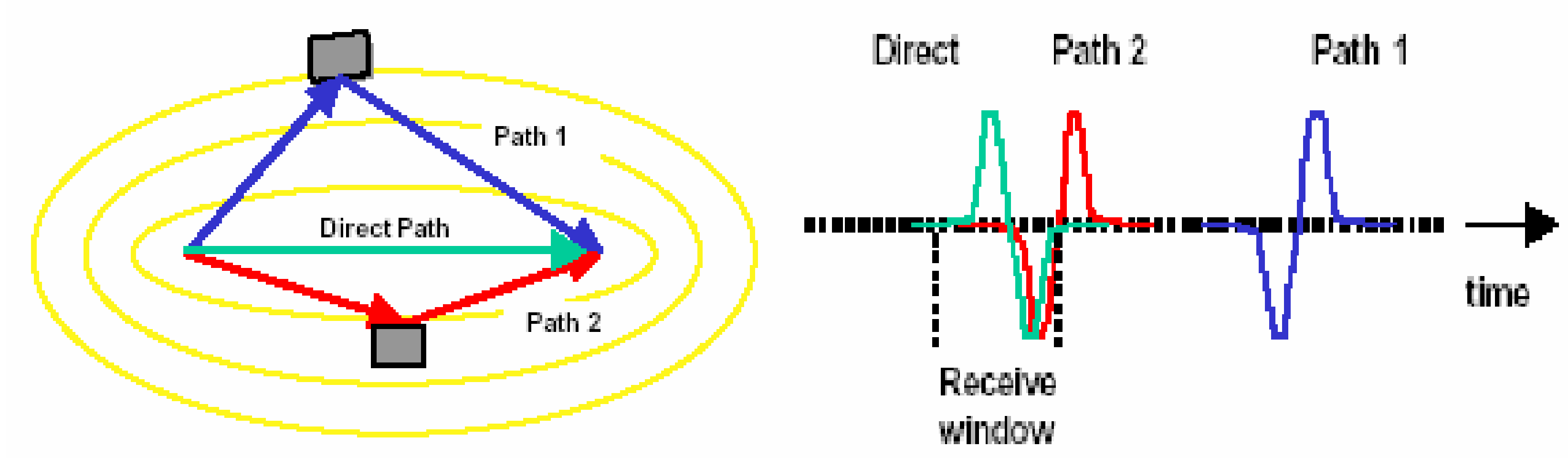
Characteristics of Impulse Radio UWB (1)

- Since the BW ranges from near dc to GHz, this impulse radio signal undergoes distortions in the propagation process.
- It has the best chance of penetrating materials that tend to be more opaque at higher frequencies.
- Multipath is resolvable down to the order of a nsec or less(a foot or less)

  $\rightarrow$ reduce fading effects (low fading margin and low transmission power) in indoor environments.

Characteristics of Impulse Radio -UWB (2)

- Resolvable multipaths → RAKE receiver
- Path overlap < half of the pulse length
  → positive contribution

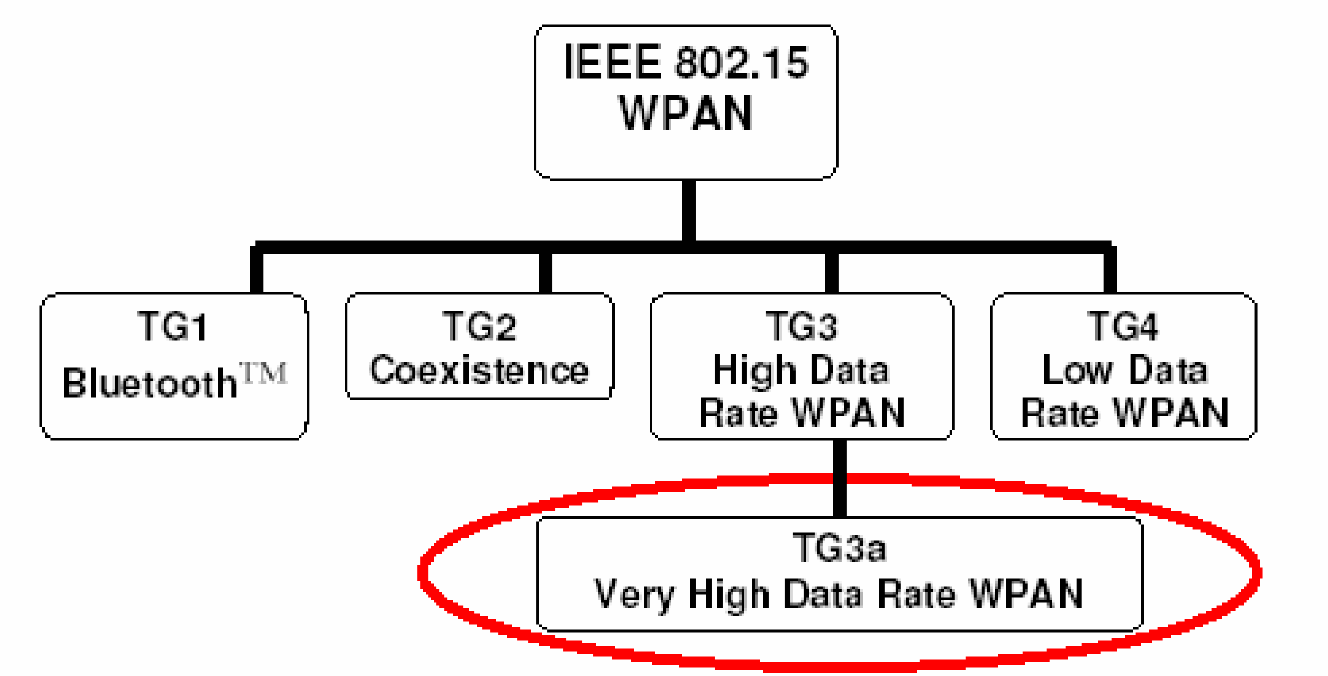


Impulse Radio UWB Potential Applications

- Advanced Radar Sensing
  - — through wall radar capability of detection, ranging, motion sensing
  - — effective vehicular anti-collision radar
  - — ground penetrating radar
- Precision Location and Tracking
  - — PLT(Position, Location, Tracking) systems.
- Communications
  - — especially for high quality, fully mobile short-range indoor radio systems

UWB and IEEE 802.15.3a

- IEEE 802.15, of which we are concerned with, is responsible for Wireless Personal Area Network (WPAN) standards.
- TG3a was created to investigate physical layer alternatives for high data rate WPAN systems



The efforts of IEEE 802.15 are divided up into four main areas

IEEE 802.15.3a Technical Requirements and Selection Criteria (1)

Parameter	**Value**
Data Rates(PHY – SAP)	110 Mbps, 200 Mbps and 480 Mbps(optional)
Range	10m, 4m and below
Power Consumption	100mW and 250mW
Power management modes	Capabilities such as power save, wake up etc
Co-located piconets	4
Interference susceptibility	Robust to IEEE systems, PER < 8% for a 1024 byte packet length

IEEE 802.15.3a Technical Requirements and Selection Criteria (2)

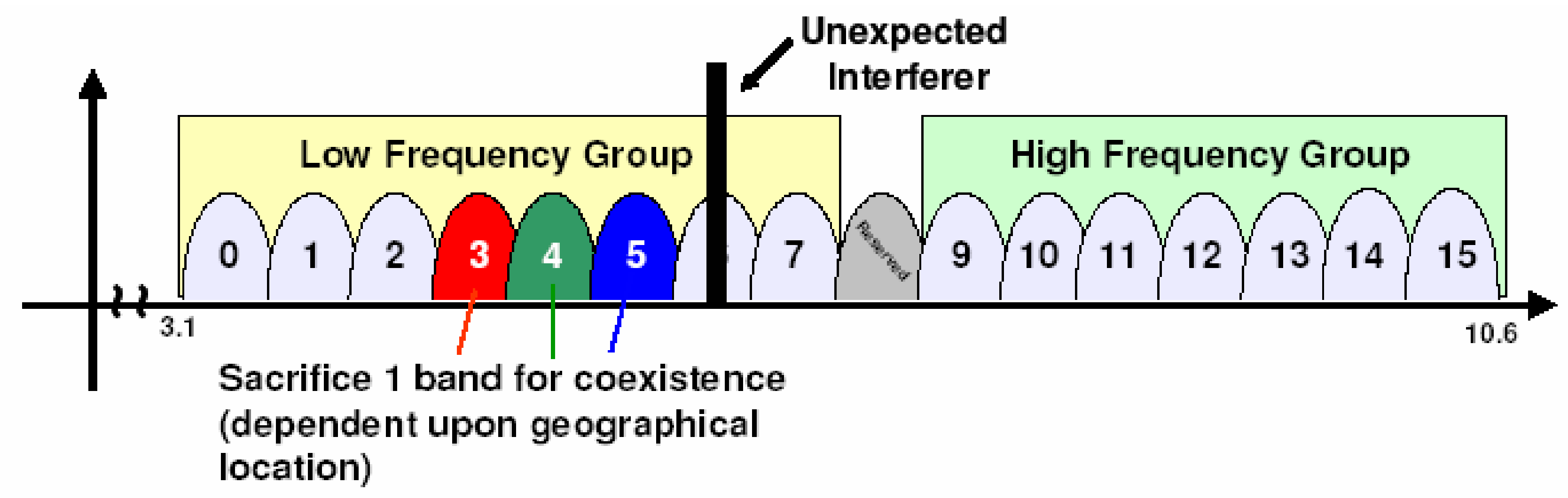
Parameter	**Value**
Co-existence capability	Reduced interference to IEEE systems, interfering average power at least 6dB below the minimum sensitivity level of non-802.15.3a device
Cost	Similar to Bluetooth
Location awareness	Location information to be propagated to a suitable management entity
Scalability	Backwards compatibility with 802.15, adaptable to various regulatory regions (such as the US, European countries, or Japan).
Signal Acquisition	<20µs for acquisition from the beginning of the preamble to the beginning of the Header
Antenna practicality	Size and from factor consistent with original device

Multi-band UWB

- The short duration of the pulses of impulse radio presents several technical challenges :
  — The short duration makes them more susceptible to timing jitter.
  — Increasing the pulse repetition frequency (PRF) would make the system more vulnerable to ISI.
- A more recent approach to UWB is a multi-band system where the UWB frequency band from 3.1 – 10.6 GHz is divided into several smaller bands. Each of these bands has a bandwidth greater than 500MHz, to comply with the FCC definition of UWB. Several companies like *Femto Devices*, *Focus Enhancements*, *General Atomics*, *Intel*, *Staccato Communications*, *Texas Instruments*, *Time Domain*, *Mitsubishi*, *Matsushita*, *Philips*, *Samsung and Wisair* support this approach.

Multi-band Spectrum Allocation

- At the recent March 2003 meeting of the IEEE 802.15.3a group, the majority of the proposals presented involved a multi-band UWB system.

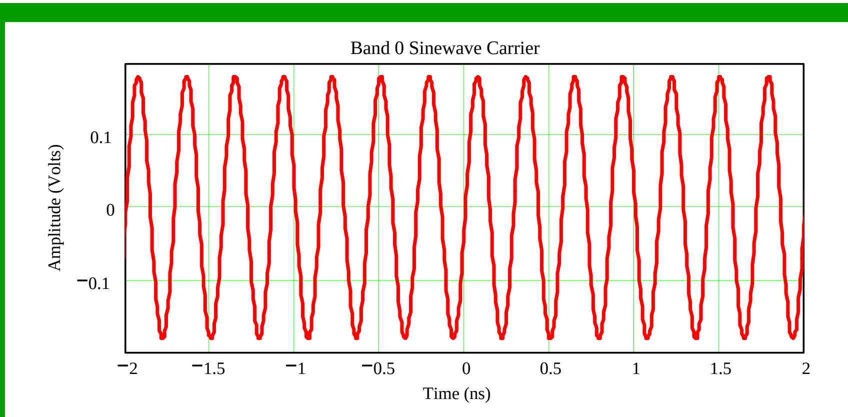


Time Domain's Multiband Spectrum Allocation

Signal Design

3.79 ns chip time

Rectified cosine envelope



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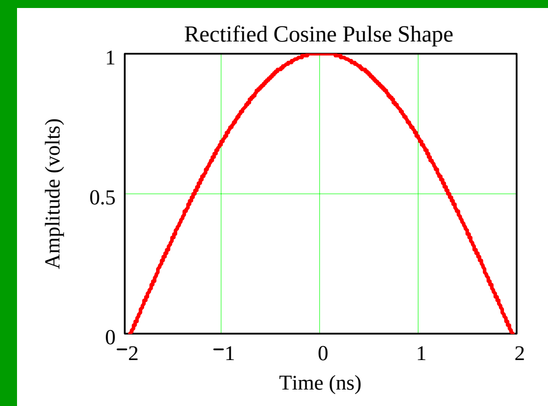
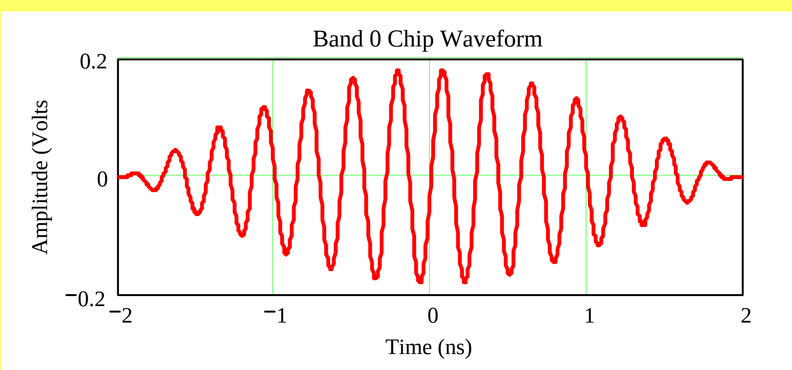
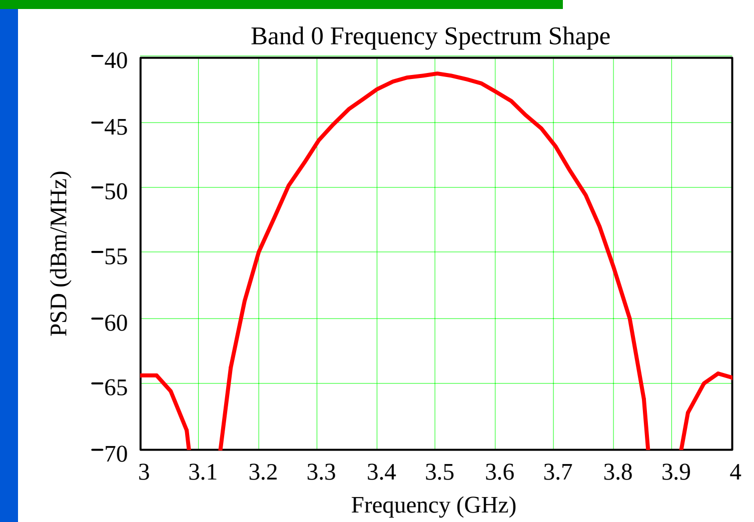
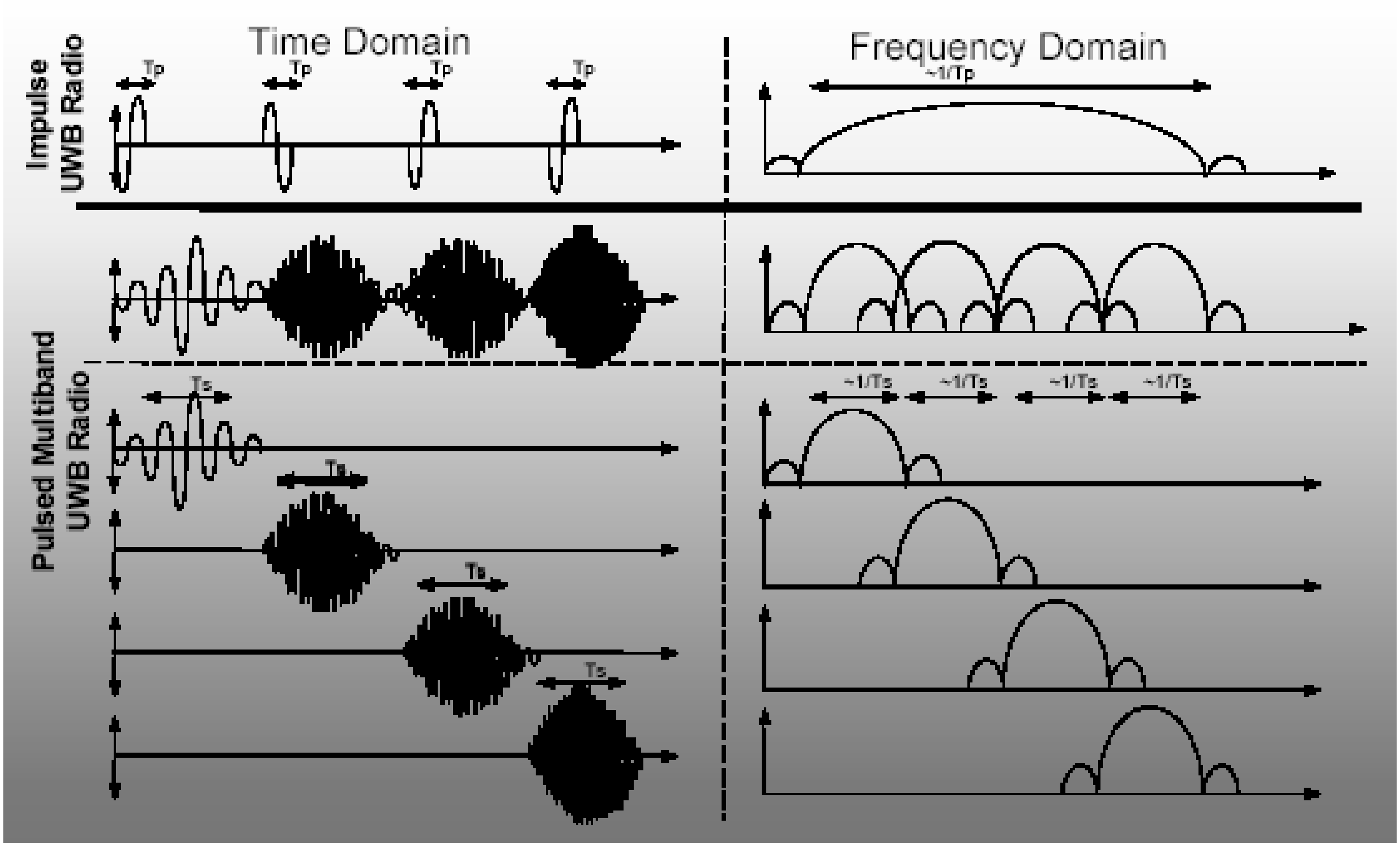






Multi-band UWB Concept



Multi-band Characteristics

- Flexibility
  - — Multiple bands of information may be managed
  - — Multi-band allows efficient filling of available spectrum
- Scalable performance
  - — Multi-band can efficiently support high and low data.
  - — Can scale with backward compatibility with new spectrum availability
  - — E.g., with 16 bands:

    BPSK: 1bit/band/33.33ns (30MHz) frame = 480 Mbps

    QPSK: 2bits/band/33.33ns (30MHz) frame = 960 Mbps
- Peaceful co-existence
  - — dynamically manage bands to avoid interference
  - — Accelerate worldwide regulatory acceptance with flexible spectral use

TI Physical Layer Proposal for IEEE 802.15.3a (March 2003)

Company	**Texas Instruments**
Spectrum Allocation: # of bands	3 (additional bands can be added in the future)
Bandwidths	503.25 MHz
Frequency ranges	3.168 GHz – 4.752 GHz
Modulation Scheme	TFI-OFDM, QPSK
Coexistence method	null band for WLAN (~5 GHz)
Multiple access method	not available

TI Physical Layer Proposal for IEEE 802.15.3a (March 2003)

Company	**Texas Instruments**
# of simultaneous piconets	not available
Error correction codes	Convolutional code
Code rates	11/32 @ 110 Mbps, 5/8 @ 200 Mbps, 3/4 @ 480 Mbps
Link margin	5.5 dB @ 10 m @ 110 Mbps, 10.2 dB @ 4 m @ 200 Mbps, 12.2 dB @ 2 m @ 480 Mbps
Symbol period	312.5 ns OFDM symbol
Multipath mitigation method	1-tap (robust to 60.6 ns delay spread)

Intel Physical Layer Proposal for IEEE 802.15.3a (March 2003)

Company	**Intel**
Spectrum Allocation: # of bands	7 (+ optional 6 bands for future use)
Bandwidths	550 MHz
Frequency ranges	3.6 GHz – 6.9 GHz, (7.45 GHz – 10.2 GHz optional)
Modulation Scheme	M-ary Bi-orthogonal Keying, QPSK
Coexistence method	null band for WLAN (~5 GHz)
Multiple access method	DS/FH CDMA, optional FDMA

Intel Physical Layer Proposal for IEEE 802.15.3a (March 2003)

Company	**Intel**
# of simultaneous piconets	not available
Error correction codes	Convolutional code, Reed-Soloman code
Code rates	6/32 @ 110 Mbps, 5/16 @ 200 Mbps, 3/4 @ 480 Mbps
Link margin	6.3 dB @ 10 m @ 108 Mbps, 8.0 dB @ 4 m @ 288 Mbps, 4.0 dB @ 4 m @ 577 Mbps
Symbol period	3 ns
Multipath mitigation method	frequency interleaving of MBOK chips; time frequency codes; feed forward filter

XtremeSpectrum Physical Layer Proposal for IEEE 802.15.3a (March 2003)

Company	**XtremeSpectrum**
Spectrum Allocation: # of bands	2
Bandwidths	1.368 GHz, 2.736 GHz
Frequency ranges	3.1 GHz – 5.15 GHz, 5.825 GHz – 10.6 GHz
Modulation Scheme	BPSK, QPSK
Coexistence method	null band for WLAN (~5 GHz)
Multiple access method	Avoidance

XtremeSpectrum Physical Layer Proposal for IEEE 802.15.3a (March 2003)

Company	**XtremeSpectrum**
# of simultaneous piconets	Ternary CDMA
Error correction codes	Convolutional code, Reed-Soloman code
Code rates	1/2 @ 110 Mbps, RS(255,223) @ 200 Mbps, RS(255,223) @ 480 Mbps
Link margin	9.9 dB @ 10 m @ 110 Mbps, 13.2 dB @ 4 m @ 200 Mbps, 3.4 dB @ 2 m @ 600 Mbps
Symbol period	731 ps (Low band), 365.5 ps (High band)
Multipath mitigation method	Decision feedback equalizer