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IEEE Oakland/East Bay Communications Society

Ultra-Wideband (UWB) Technology for Communication Applications

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What is UWB?

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- The most over-hyped wireless technology in the past few years!!!!

BUT…….

- 7,500MHz of available unlicensed spectrum
- Great opportunity for
  - low bit rate, low power networks (low duty cycle)
  - very high bit rate short range networks (large bandwidth)

Summary

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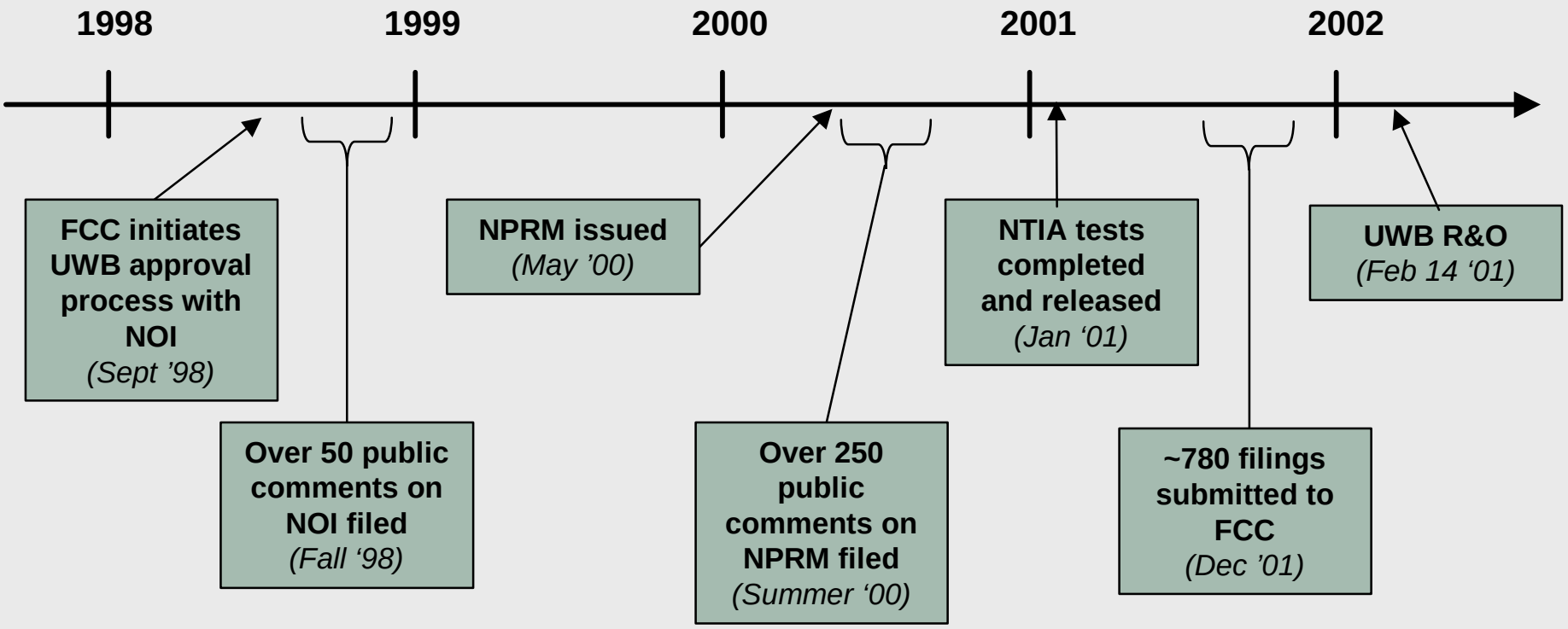
- Definition and characteristics
- Performance in the real world
- UWB receivers
- Potential advantages
- Commercial opportunities

FCC Regulatory Proceedings



Few Lessons Learned from Regulatory Process

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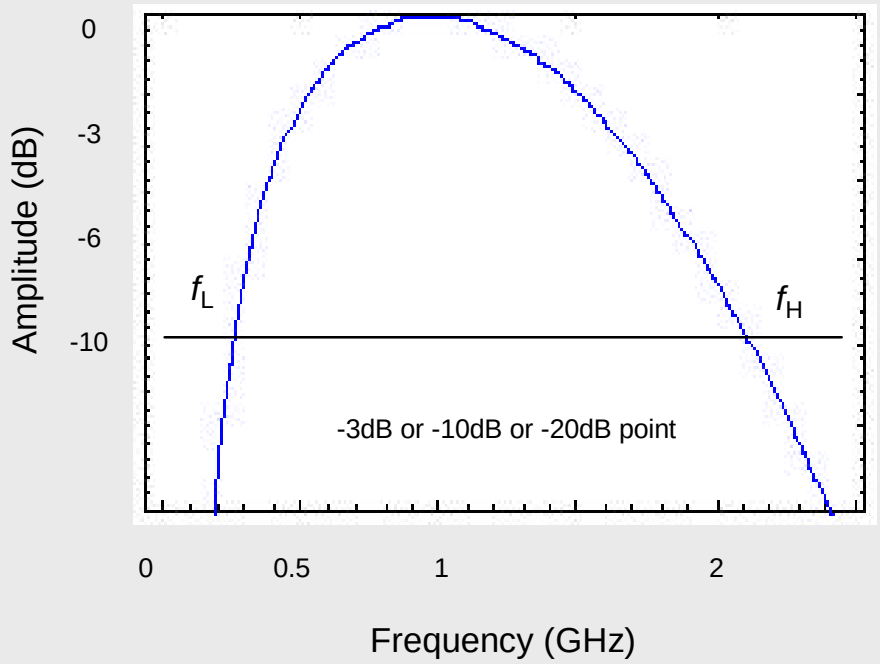
- FCC filings (docket# 98-153)
  - Lot of material submitted to the FCC
  - Technical and non-technical material mixed in the submissions
  - Extremely difficult to separate valid technical arguments from marketing claims (on both supporting and opposing sides)
  - Very few refereed and scientific papers presented
  - EVERY company will support ANY argument that will further their case
- Difficult to develop technologies with private equity funding without
  - regulatory approval
  - deterministic regulatory process
- Difficult for small companies with new technologies to break into the establishment

Definition of UWB

$$? \; ? \; 2\frac{f_H \; ? \; f_L}{f_H \; ? \; f_L} \; ? \; 20\%$$



A radio signal with fractional bandwidth (?) larger than 20%.

Examples:

(802.11a, Channel 36) -> 0.4%,

3-4 GHz -> 29%,

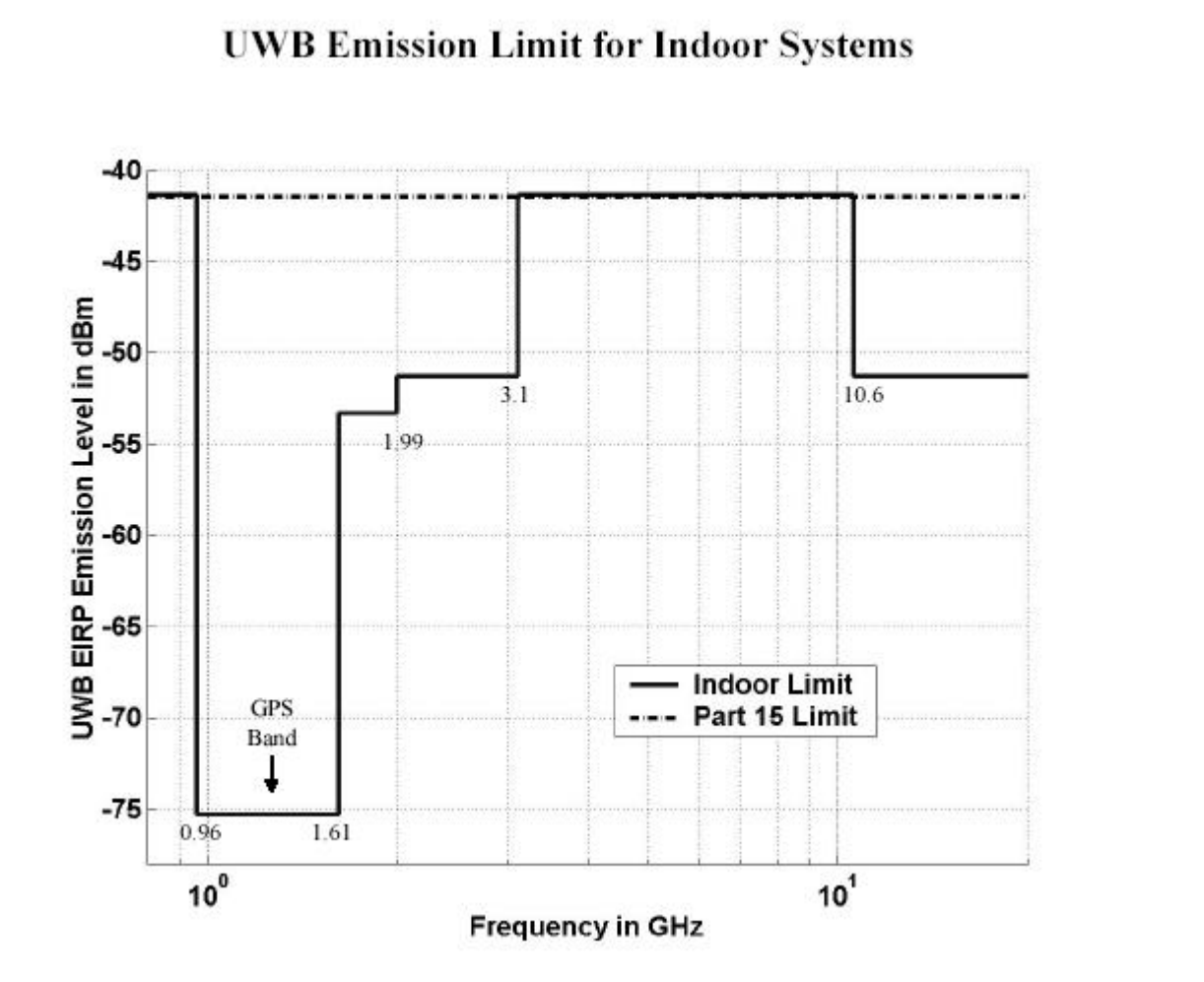
2-5 GHz -> 86%

UWB definitions*

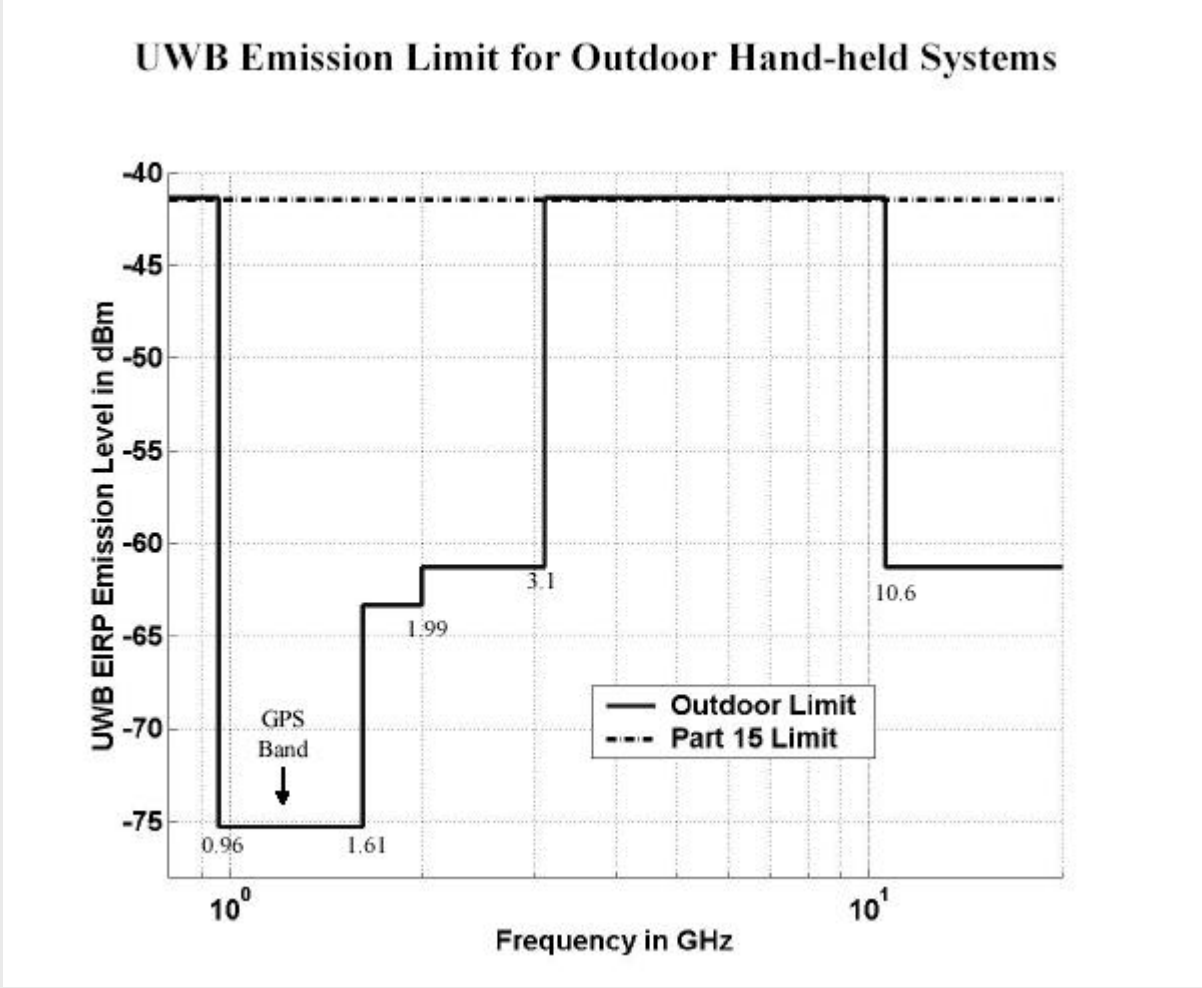
- 7,500MHz available spectrum for unlicensed use
  - US operating frequency: 3,100 – 10,600 MHz
  - Emission limit: -41.3dBm/MHz EIRP
  - Indoor and handheld systems
  - Other restrictions and measurement procedures in Report & Order
- UWB device defined as
  - Fractional bandwidth greater than 20%
  - Occupies more than 500 MHz
- UWB device NOT defined as
  - Modulation or pulsed modulation
  - Carrierless
  - Impulse radio

Source: FCC 02-48, UWB Report & Order, released 22 April 02

FCC spectral mask (indoor)

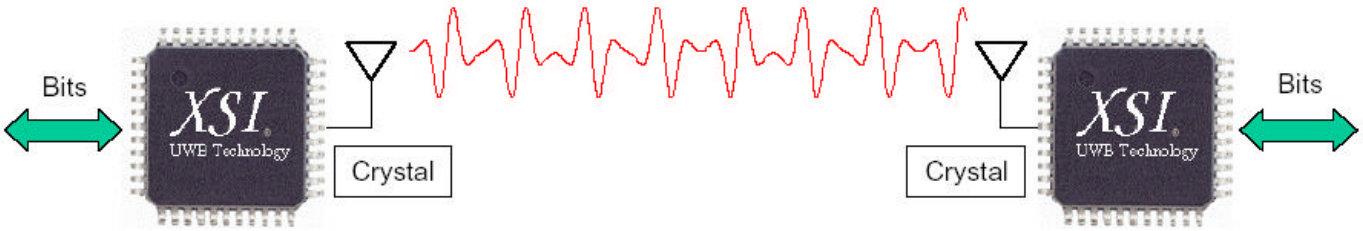


FCC spectral mask (outdoor)



XtremeSpectrum

Technology Description



- **Extreme spread spectrum radio**
- **Baseband direct sequence spread spectrum**
- **Coded biphase modulated wavelets**
- **Wavelets formed from the edges of gates**
  - Bandwidth comes from the rise time of the IC process
  - Moore's law radio—channel capacity grows linearly with IC process
  - Matches radio to processing, memory, storage & resolution roadmaps
- **Similar to unintentional emissions from digital devices**
- **High chip rate (GHz) easy to do in silicon & maps to interop w/ BT**
- **Low peak to average waveform easy to do in low-voltage silicon**
- **Provides ultrawideband-RF inbuilding propagation benefits**

PPM (source: Time Domain)

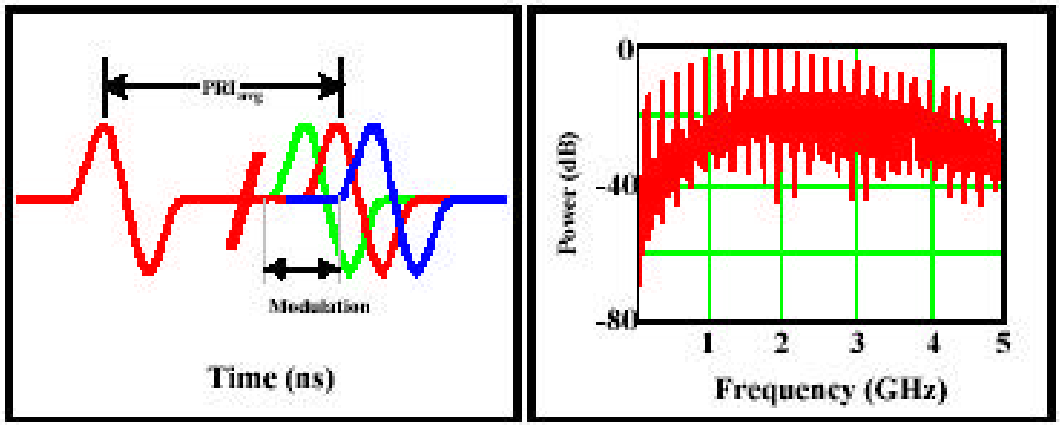
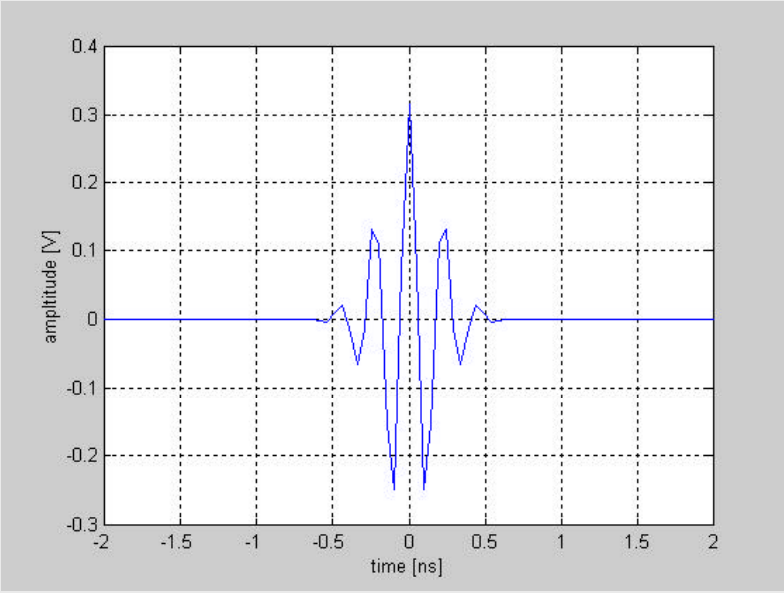
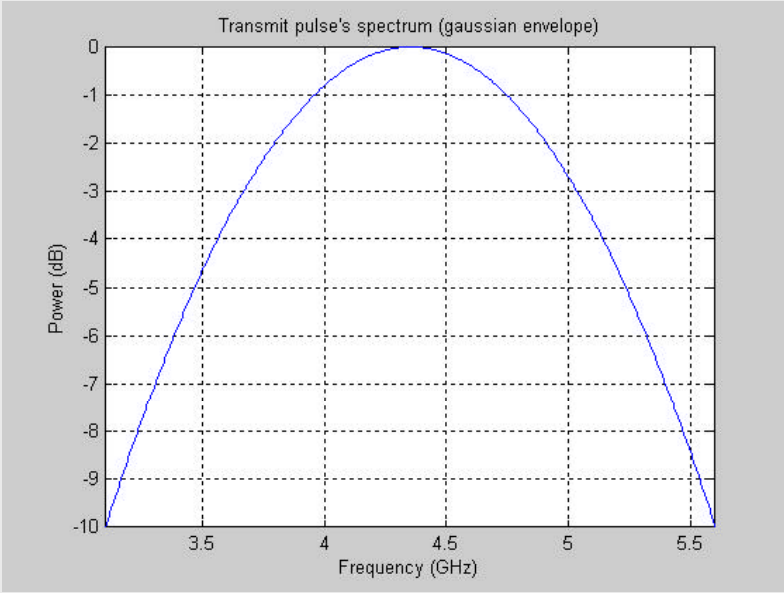


Figure 3. Pulse Position Modulation

Transmit signal





Think at a UWB signal as a very short RF burst (gaussian shaped in this case)

UWB Channel Characteristics

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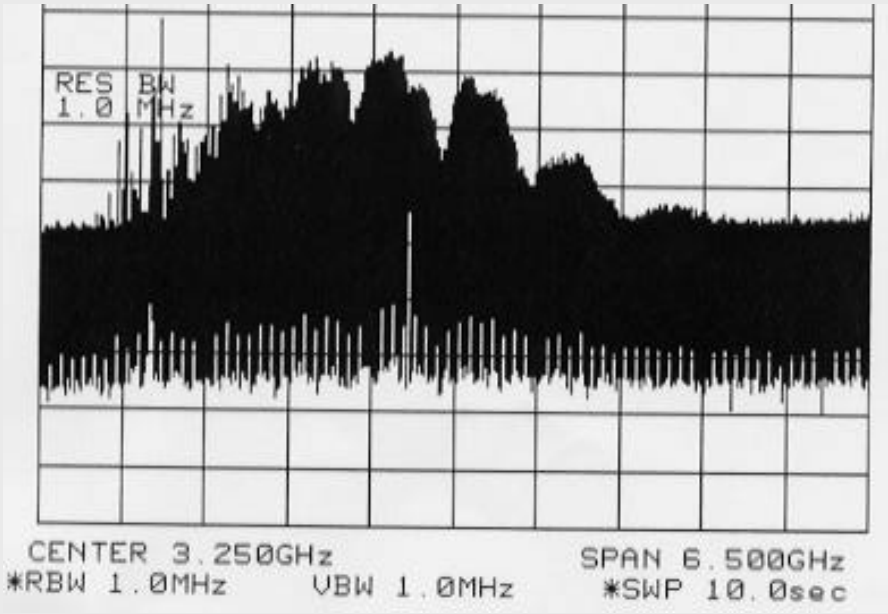
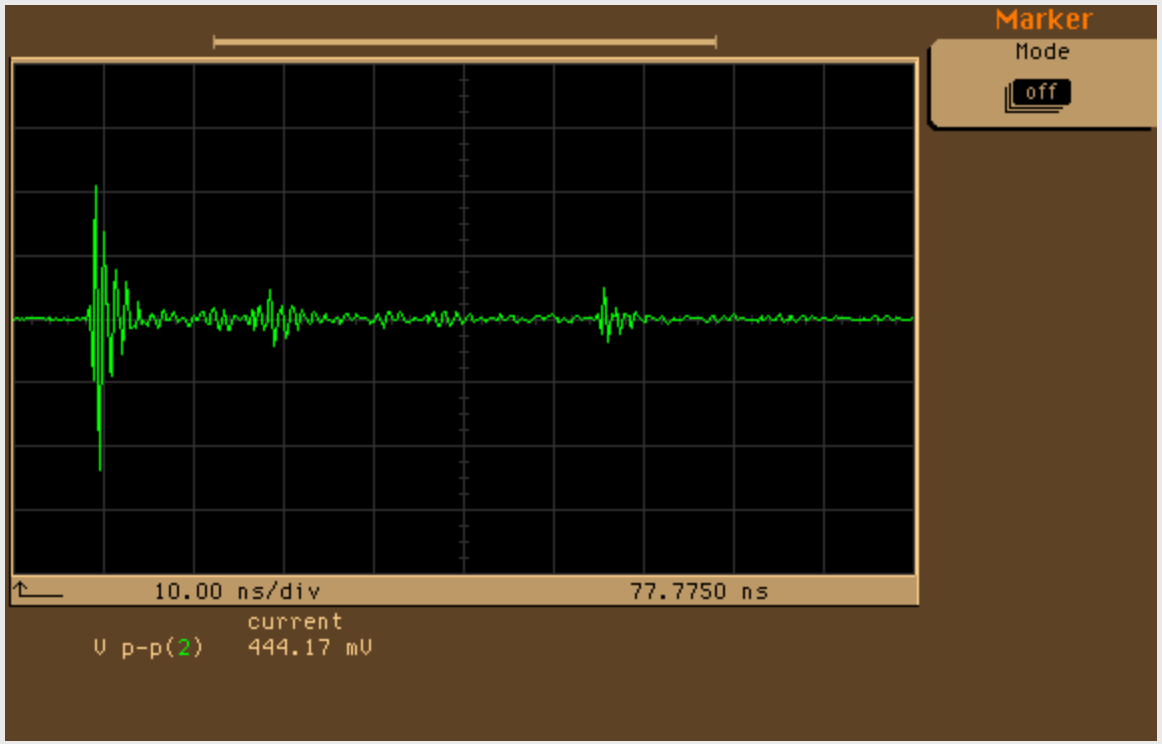
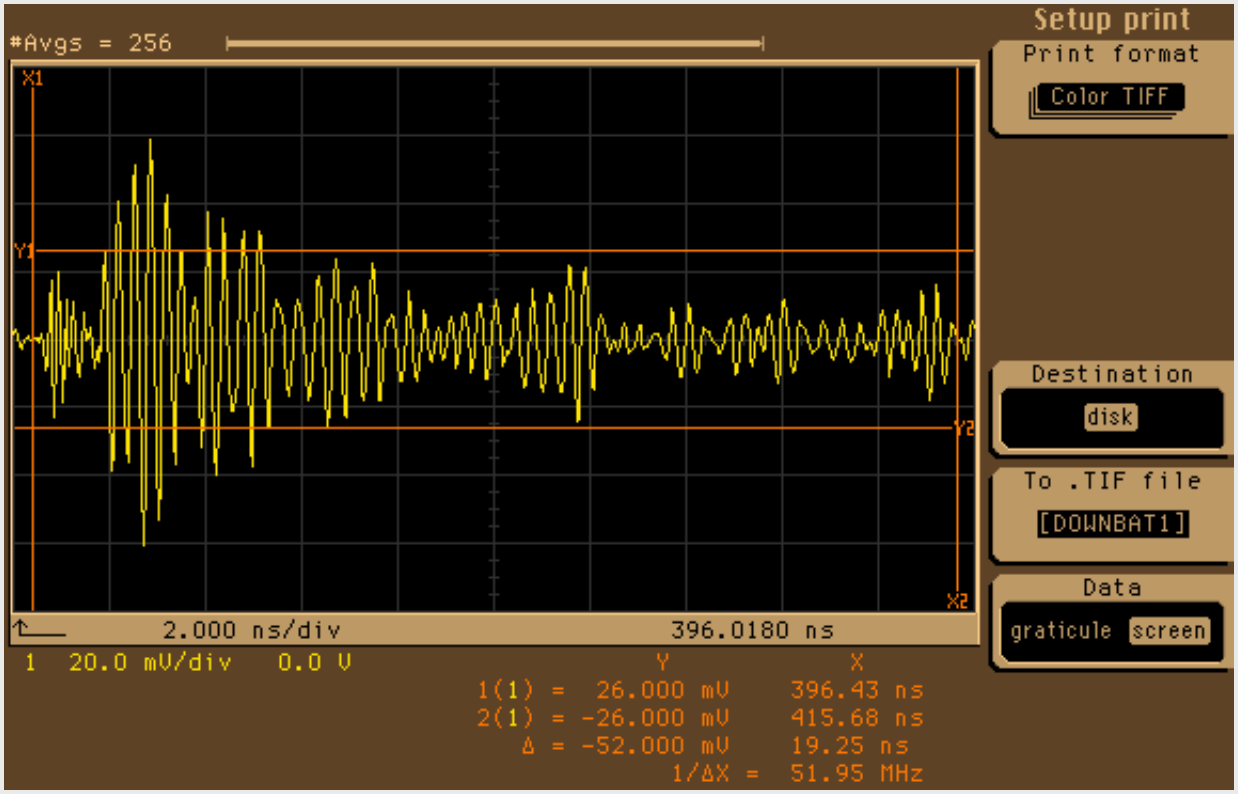


- Signal bandwidth much greater than coherence bandwidth => Frequency-selective channel
- Symbol duration much smaller than coherence time (Doppler spread much smaller than signal bandwidth) => Slow-fading channel

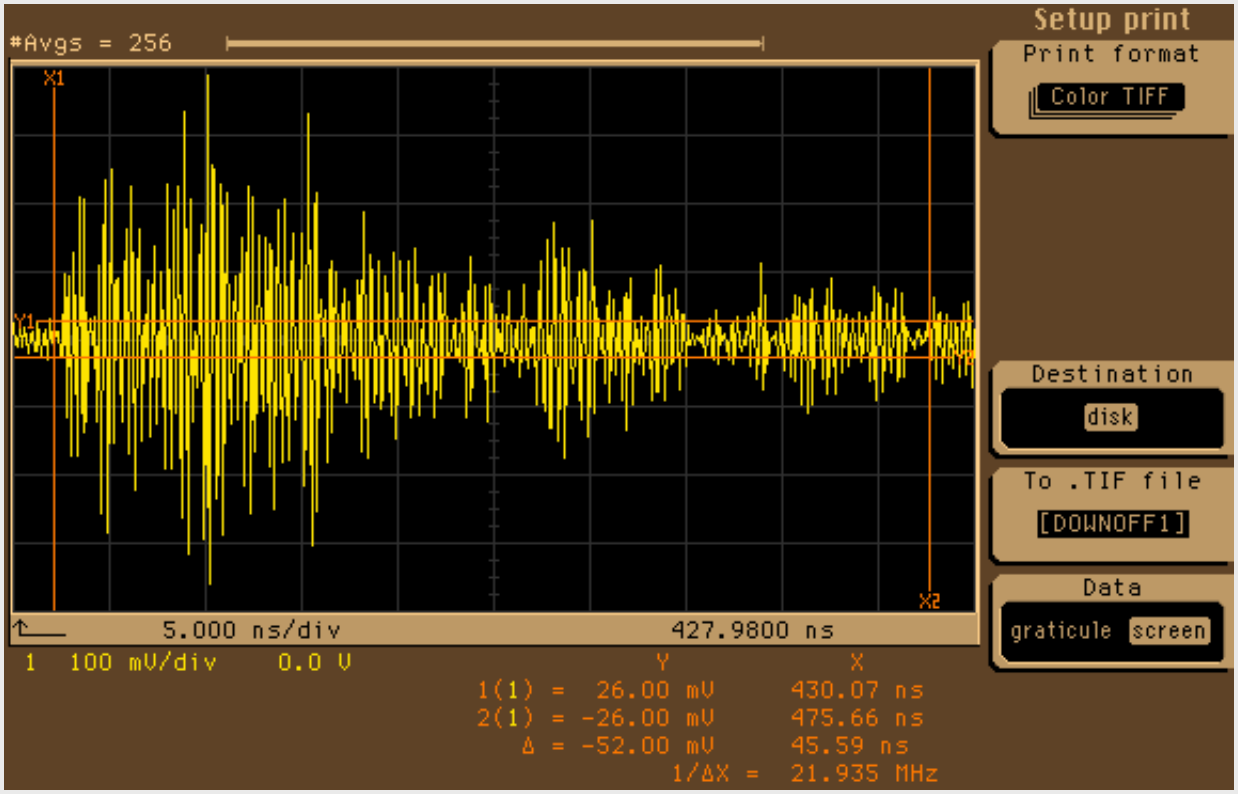
Multipath (1 of 4)



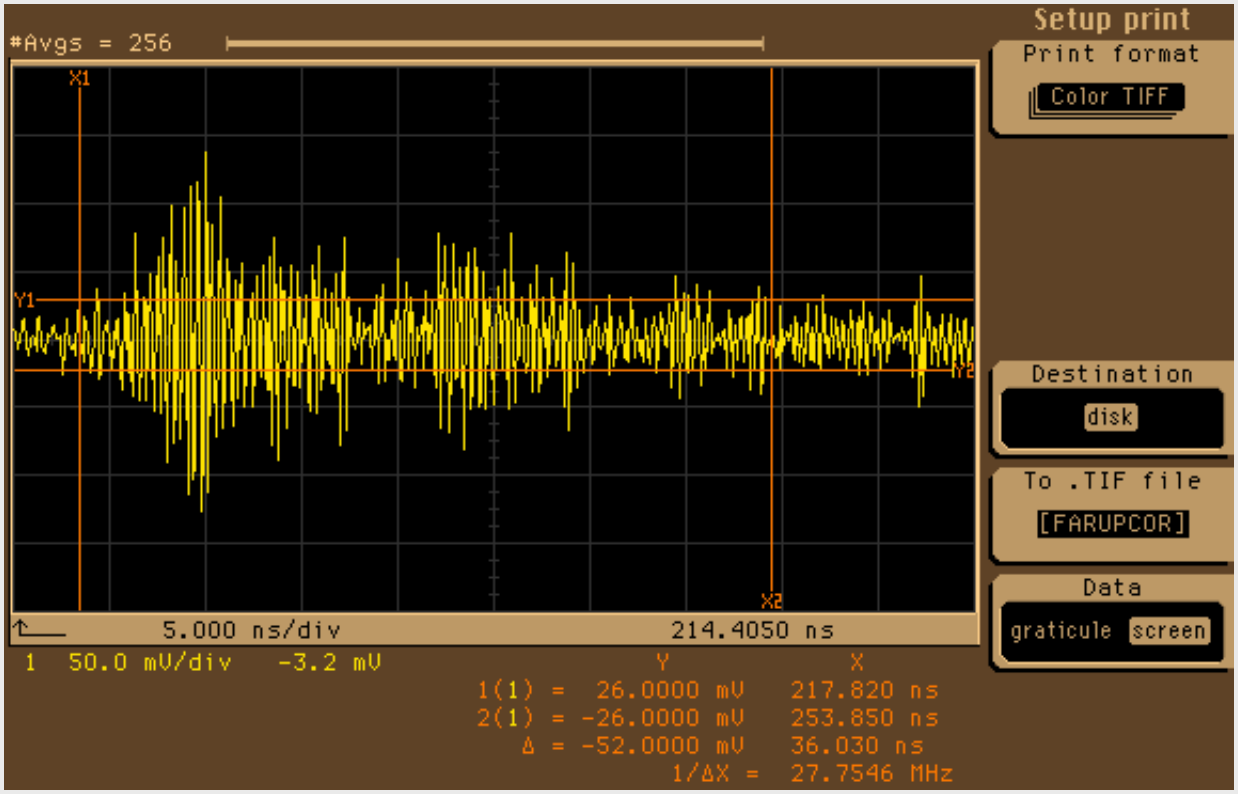
Multipath (2 of 4)



Multipath (3 of 4)



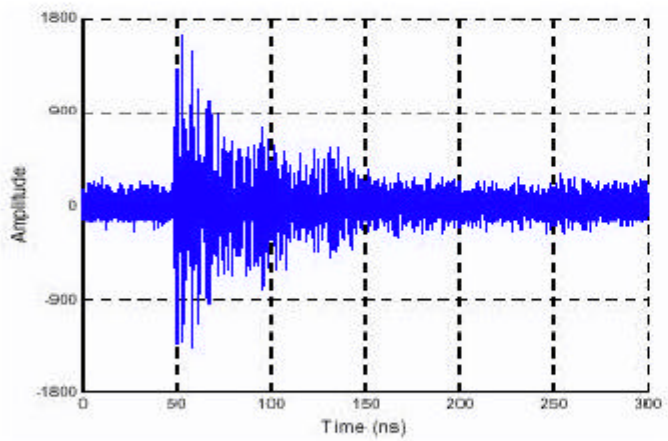
Multipath (4 of 4)

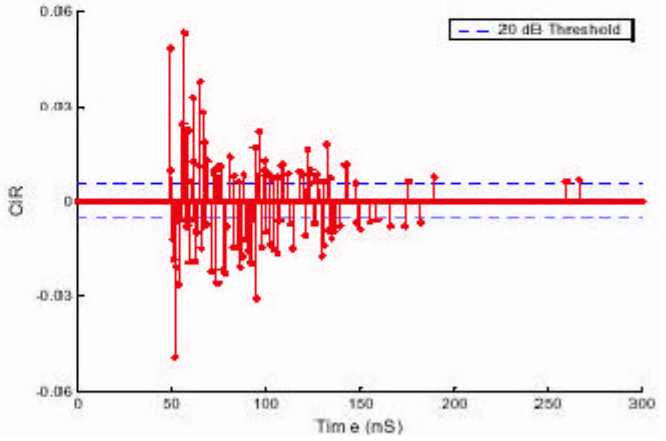


Source: Time Domain

Indoor Channel Impulse Response

Channel pulses (left) are processed with CLEAN algorithm to obtain CIRs (right). The "total power density" represented by the CIR can then be reported



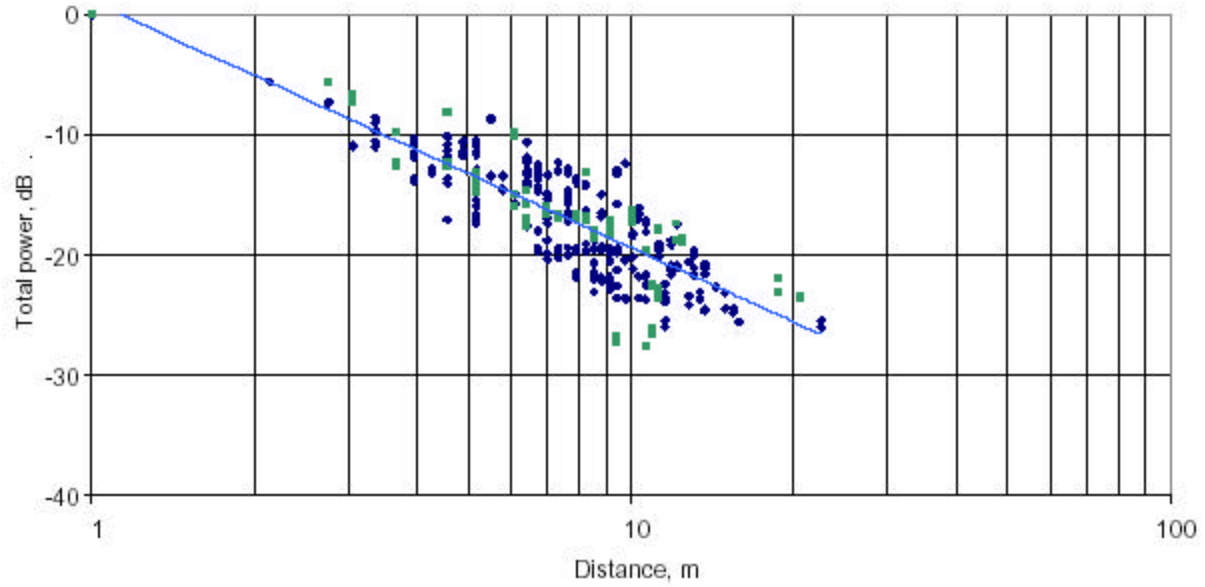


Source: Yano [1]

Source: Time Domain

Total Power Density vs. Distance

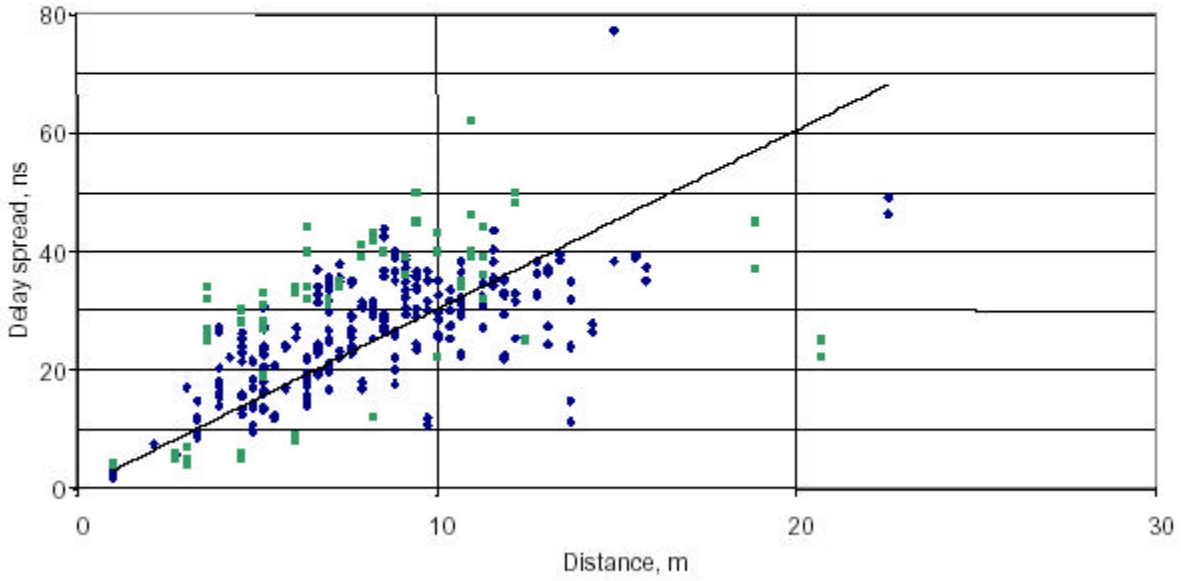
The same measurements [1] reveal that the "total power density" propagates approximately as 20 log(*d*), distance *d* is meters, and with smaller variance



Source: Time Domain

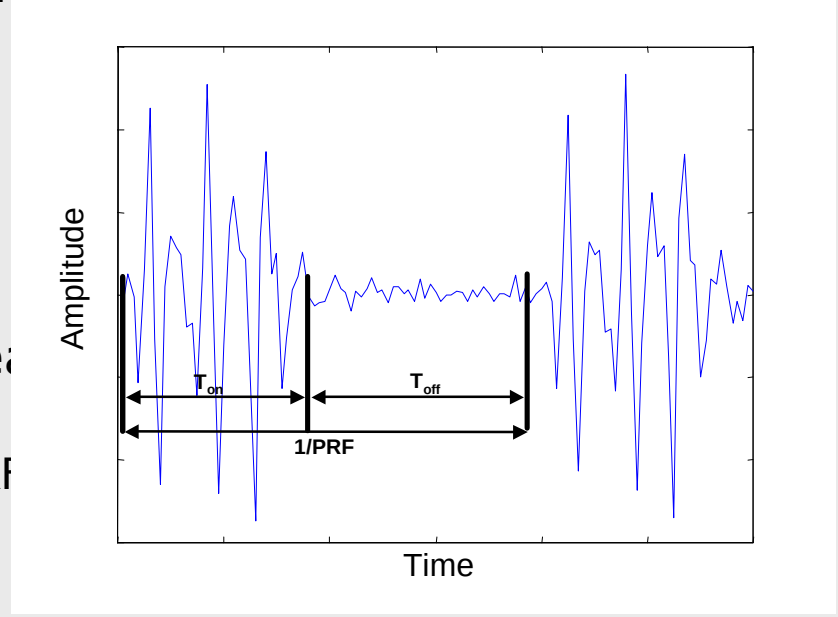
RMS Delay Spread vs. Distance

The same measurements [1] further reveal that the rms delay spread varies approximately as $?_0 d$, distance d is in meters, and here $?_0$=3 nano seconds



UWB Classification (source: GA)

- PRF
  - The rate at which pulses are transmitted, i.e. # pulses/second
  - PRF represents the average rate if pulses are transmitted aperiodically
  - Implies a specific Power/Pulse
    - FCC limits impose power/pulse as a function of PRF
    - Drops 3dB with each doubling of PRF
- Duty Cycle $\frac{T_{on}}{(T_{on} + T_{off})}$
- Ton is dominated by Delay Sprea
  - Ton + Toff = 1/PRF
  - Duty Cycle ? Delay Spread * PRF



Mutual Interference of UWB Systems (source: GA)

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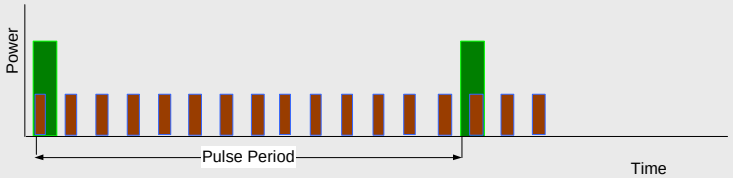
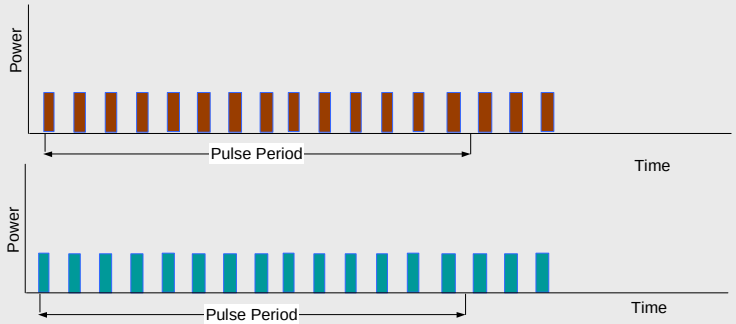
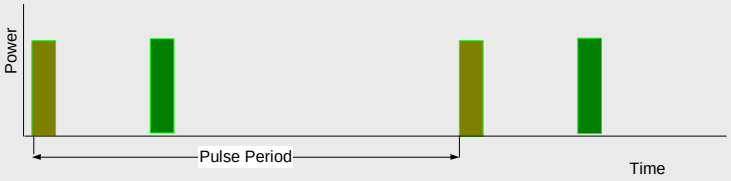
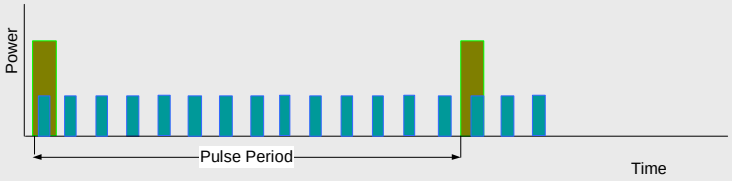
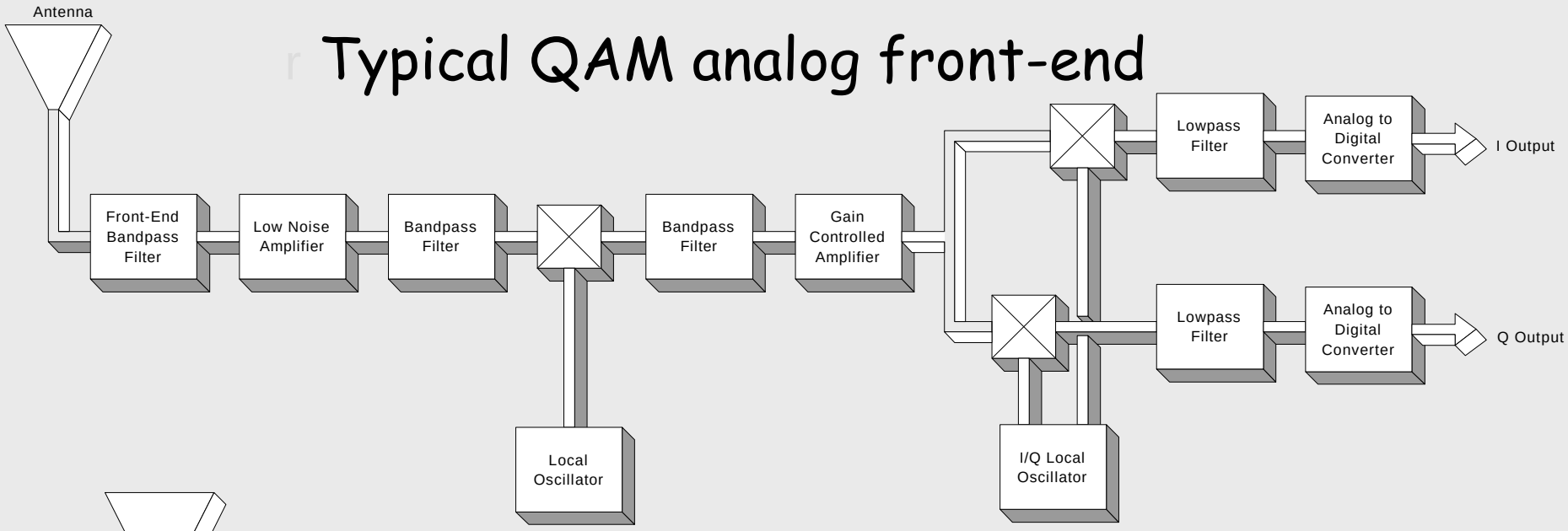
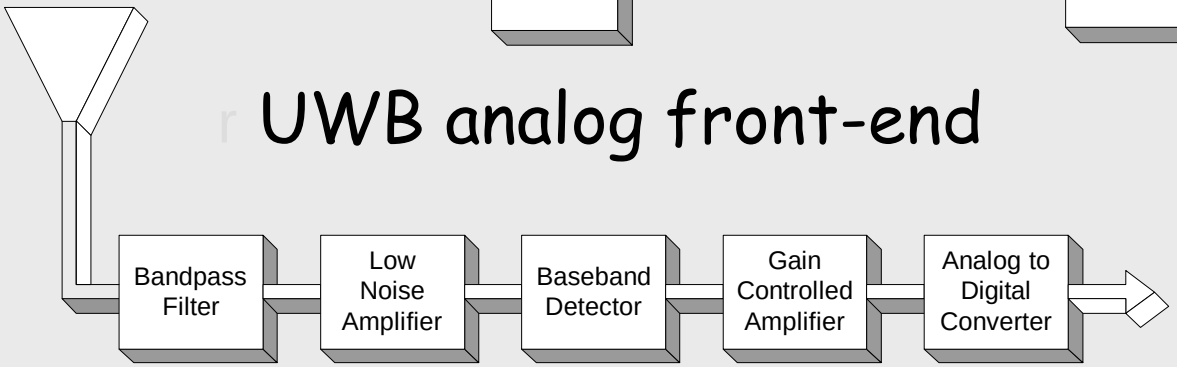
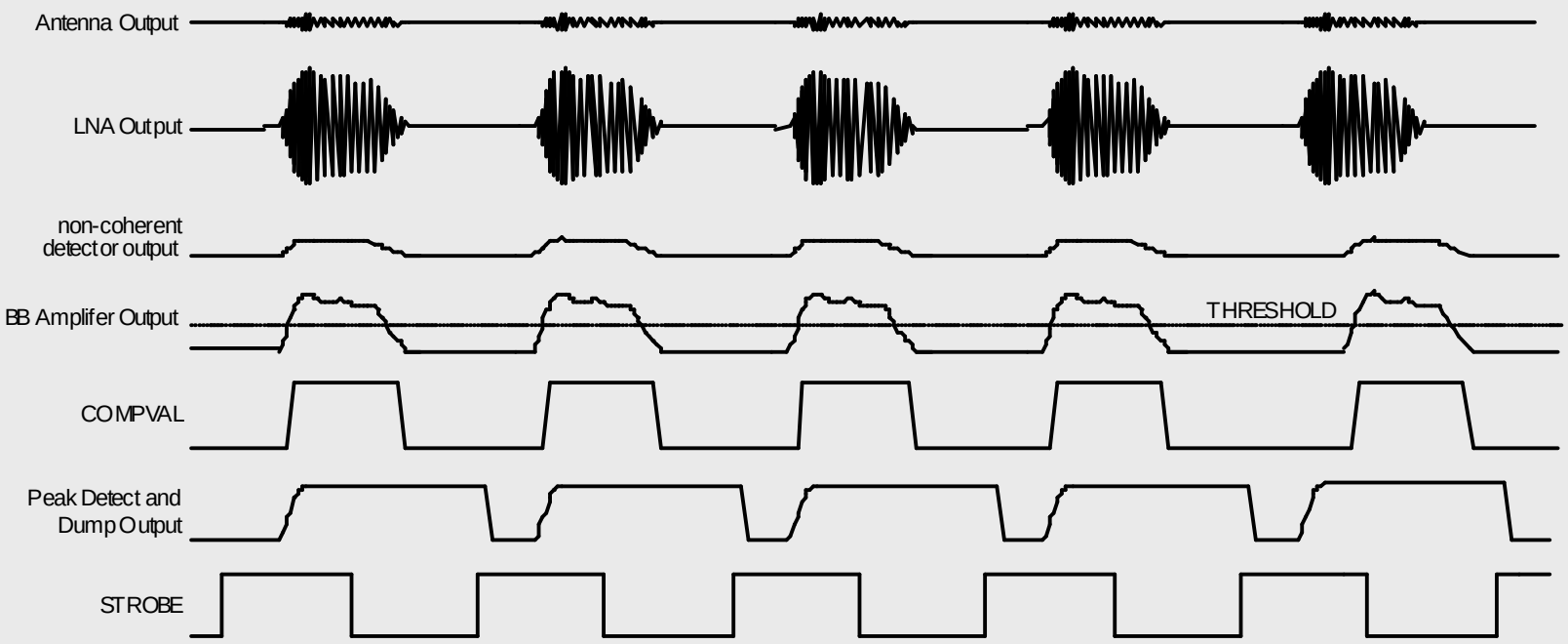
	Impact of Low PRF on:	Impact of High PRF on:
High PRF	 **Tricky!**	 **Variable Impact (function of coding)**
Low PRF	 **Low Impact (function of duty cycle)**	 **Low Impact (noise like)**

Analog front-end comparison





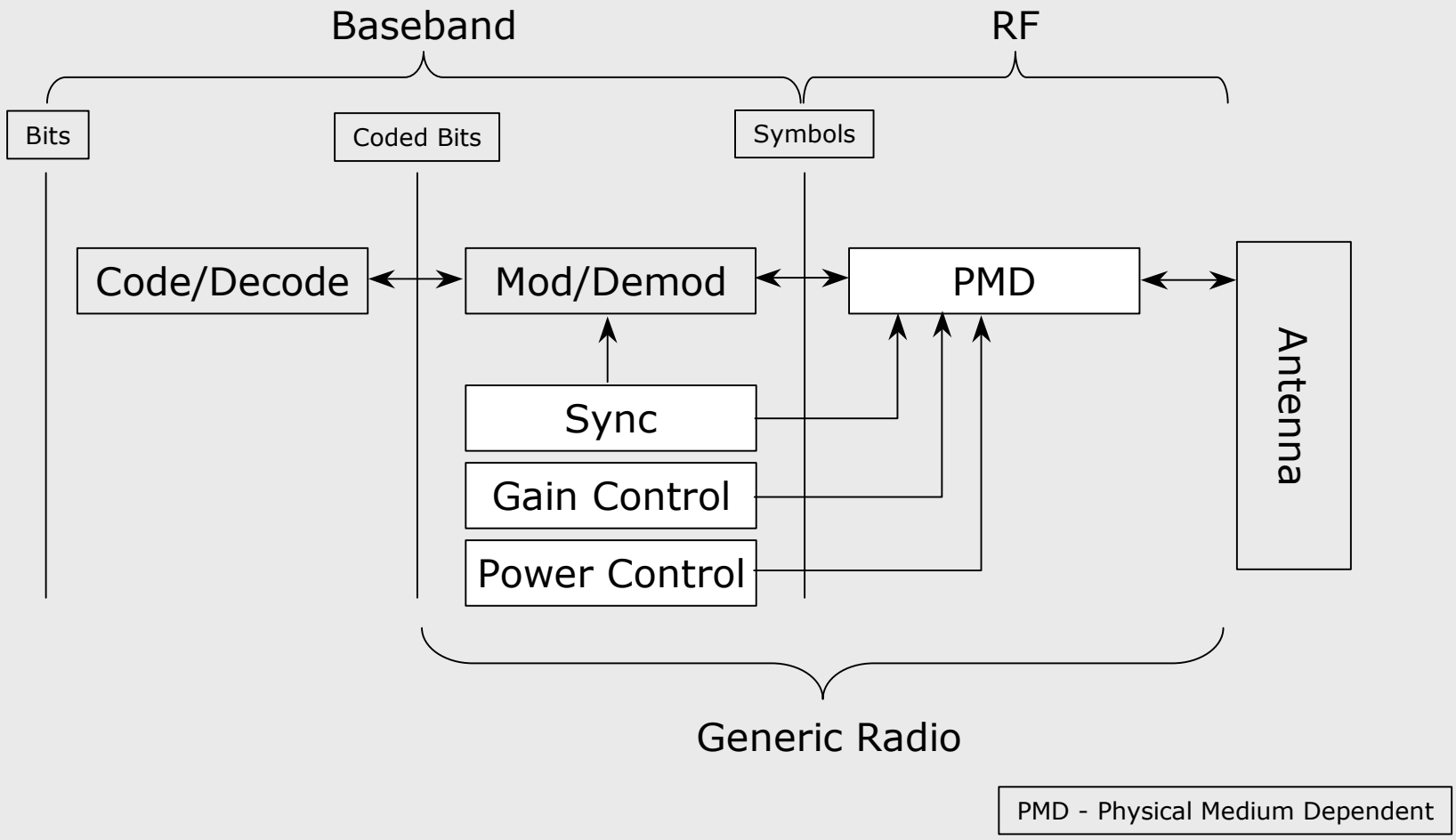
Simple receiver



Patent: US 6,275,544

More information in: "A UWB Architecture for Wireless Video Networking", G.R.Aiello, L. Taylor, M. Ho (ICCE 2001)

PHY Partitioning



Potential advantages

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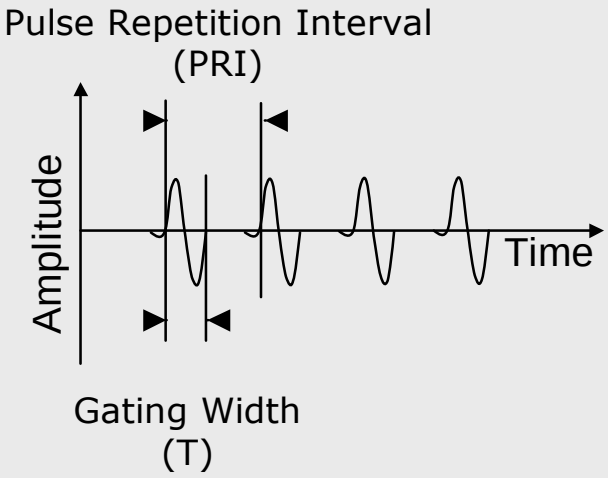
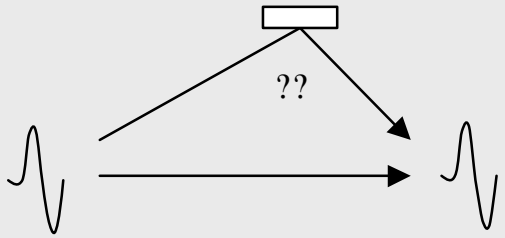
What	Why
Low cost	Baseband radio architecture
Low power	Low transmit duty cycle
Co-existence	Low power spectral density
Interference robust	Large bandwidth (processing gain)
High capacity	Large bandwidth
Multipath robust	Large bandwidth (frequency diversity)
Communication/location	Large bandwidth (fast rise time)

NOT ALL AT THE SAME TIME!!!

Multipath fading





?T ~ T or PRI for multipath interference

- Narrow pulse widths
  - Less likelihood of constructive/destructive summation
  - Less margin required for multipath fading

Capacity

$$C ? W \log_2(1 ? SNR)$$

- Capacity basically
  - Proportional to bandwidth W
  - LOG proportional to SNR
- Alternative channel model
  - Multipath fading
  - Perfect channel information
  - Few dominant paths
- Capacity approaches AWGN capacity as bandwidth increases

Example link budget

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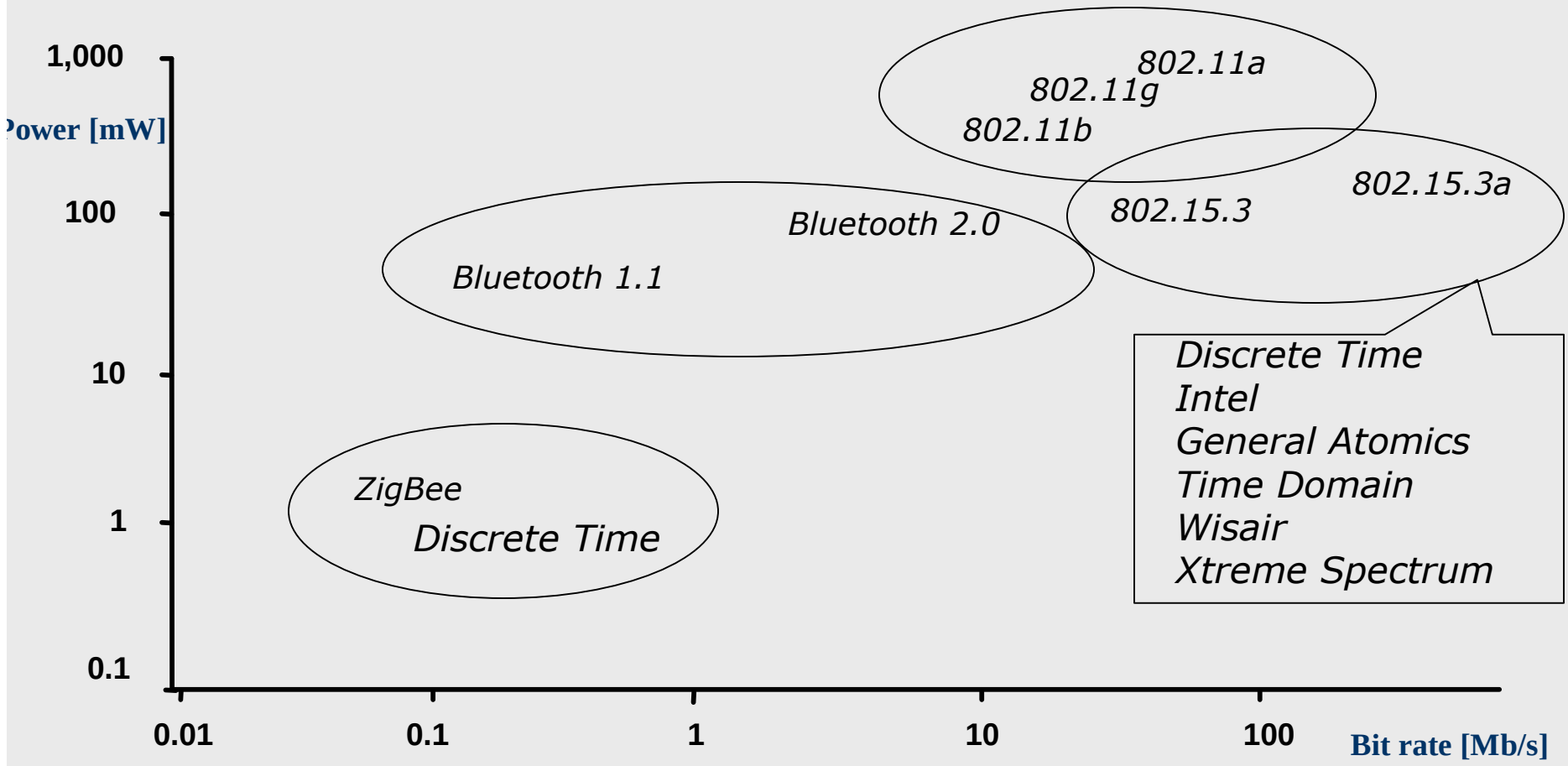
Transmitter parameters			
Bandwidth	**0.5**	**2.5**	**GHz**
Number of frequency channels	**15**	**3**	
Center frequency	3.5	3.5	**GHz**
Pulse repetition frequency	20	20	MHz
Total bit rate	**300**	**60**	**Mbps**
Transmitter			
FCC limit	-41.25	-41.25	dBm/MHz
Tx voltage/pulse (pk-pk) into 50Ohm	**0.61**	**3.06**	**V**
Receiver parameters			
Rx antenna gain	4	4	dBi
Noise figure	7	7	dB
Ep/No	8	8	dB
Receiver parameters			
Available SNR (signal pk/noise rms)	35.41	42.40	dB
Range (d = 2)	**177**	**395**	**ft**

Market comparison



IEEE 802.15.3a Summary Requirements

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- Bit rate: 110-200Mbps, option to 480Mbps
- Range: 30ft
- Power consumption: 100mW
- BER (top of the PHY): 10e-5
- Co-located piconets: 4
- Cost: similar to Bluetooth
- Co-existent with 802.11a

IEEE 802.15.3a Original Schedule

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Today →

November (2001)	Approve 15.3a Study Group
December	Issue Call For Applications
January (2002)	Application Presentations
March	Application Presentations
July	Channel Model Presentations
October	Issue Call For Proposals
November	Approval of PAR by ExCom Approval of PAR and 5 Criteria by WG
January (2003)	Proposal Presentations
March (2003)	Proposal Presentations
May (2003)	Proposal Presentations Proposal Selection Voting
July (2003)	Generation and acceptance of baseline draft text
September (2003)	Presentation and approval of Alt PHY draft text Approval to conduct a letter ballot

UWB Companies*

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Company	Location	VC Capital raised	Initial market	Time to market
Aetherwire	Bay Area	N/A	Localizers	?
LLNL	Bay Area	N/A	Radar	Now
Multispectral	DC	N/A	Military	Now
Time Domain	Alabama	~$50M	WLAN	2002
Xtreme Spectrum	DC	~$27M	WPAN	2002
General Atomics	San Diego	N/A	WPAN	2003
Intel	Bay Area	N/A	WPAN	N/A
Pulselink	San Diego	Two rounds	Wireless Nwks	2003
Pulsicom	Israel	Seed	Location	?
Cellonics	Singapore	?	IP licensing (?)	Now
Discrete Time Comm.	Bay Area	Seed	Low power, WPAN	2003
I-tech	Slovenia	?	Discrete TX/RX	Now
Wisair	Israel	$4.2M	WPAN/WLAN	?

**information derived from companies' public announcements and websites*

Conclusions

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- UWB is 7,500MHz of available unlicensed spectrum
- Exciting opportunity for new technologies
- Performance in real world is tricky
- Coordination of UWB vendors useful to increase interoperability and co-existence
- UWB industry focused on high bit rate WPANs (IEEE 802.15.3a)
- Market opportunity for
  - low bit rate, low power networks (low duty cycle)
  - very high bit rate short range networks (large bandwidth)