



# Ultrawideband: The "Ultra" White Space Technology

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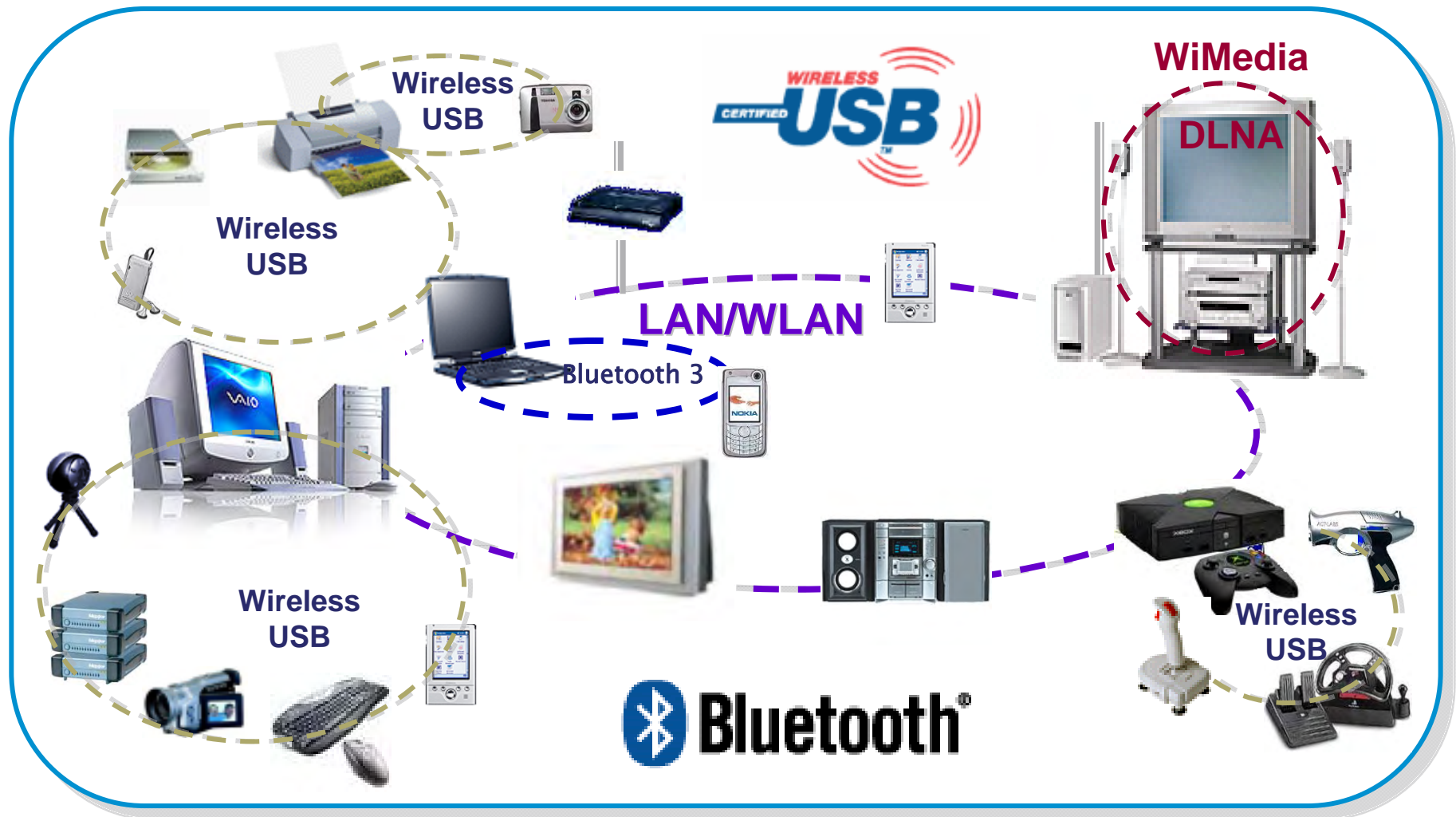


# Background

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- Why a WPAN?
- UWB Background
- WiMedia UWB
- Wireless USB background
- UWB and Spectrum Policy
- Cognitive radio
- Regulatory
- Use of Detect and Avoid (DAA) in UWB
- Performance limitations of radiometer processing
- Demo
- Q&A

# Why a WPAN? Wireless PAN Usage Models

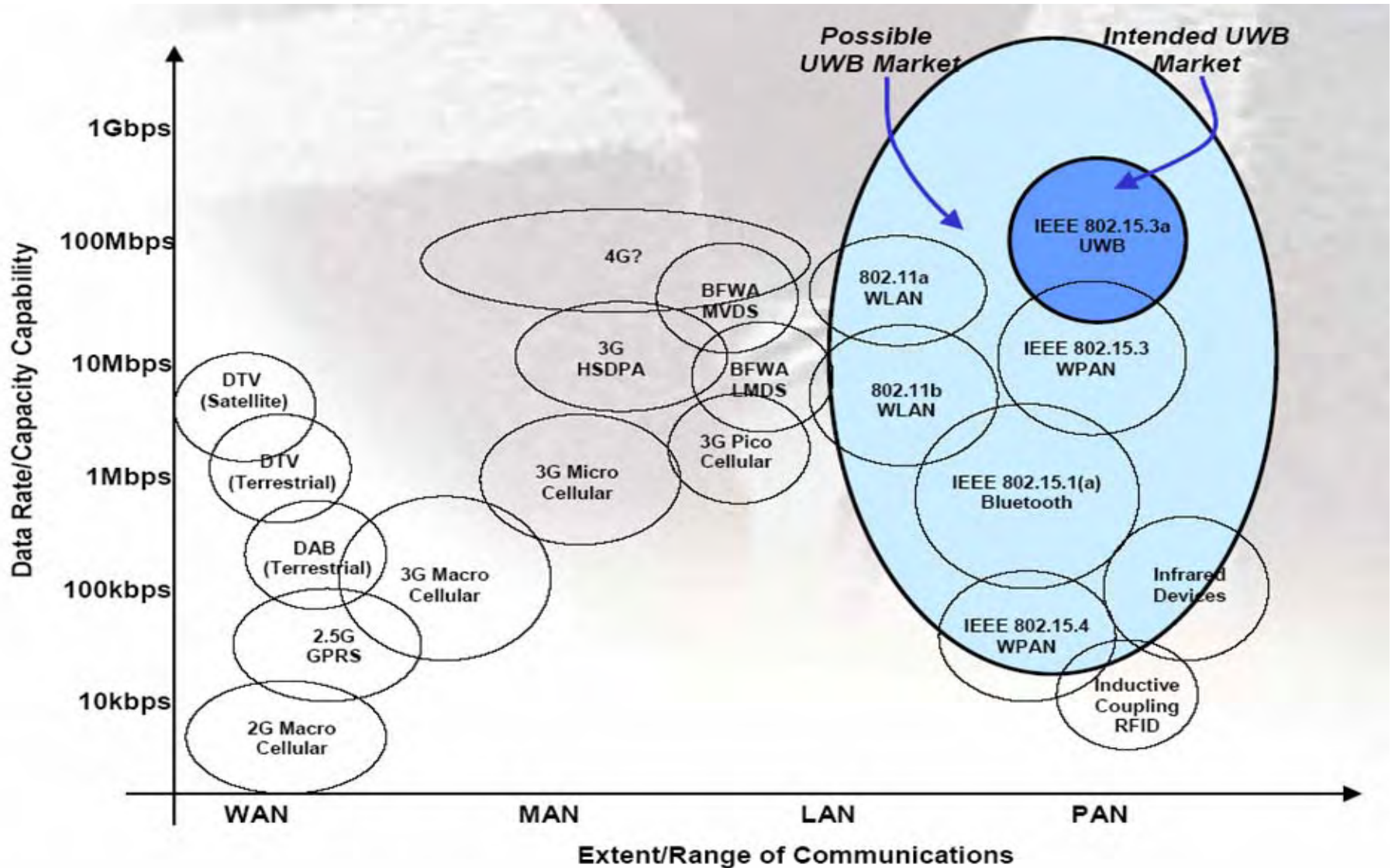


**A WPAN complements longer range access technologies**

# Why a WPAN?

Cable	Bandwidth/Use Issues	Wireless Alternative
<b>Serial &amp; USB 1</b> 	<ul style="list-style-type: none"> <li>Primarily for older PC peripherals</li> <li>230 Kbps</li> </ul>	<ul style="list-style-type: none"> <li>Bluetooth 1.1</li> <li>Bluetooth 3.0 will include UWB</li> </ul> 
<b>Ethernet Cable</b> 	<ul style="list-style-type: none"> <li>Primarily for older PC peripherals</li> <li>10 Mbps or 100Mbps</li> </ul>	<ul style="list-style-type: none"> <li>WiFi (802.11b/g)</li> <li>IEEE 802.11a</li> </ul> 
<b>USB 2.0</b> 	<ul style="list-style-type: none"> <li>USB 2.0 = 480 Mbps <i>(backwards compatible with USB 1.1= 12Mbps)</i></li> <li>Limited to 3-5 meters; depending on the speed of peripheral connection</li> </ul>	<ul style="list-style-type: none"> <li><b>No Current Wireless Solution Available</b></li> <li><b>There is a market need for a high speed, energy efficient cable replacement</b></li> </ul>
<b>FireWire/1394</b> 	<ul style="list-style-type: none"> <li>FireWire/ 1394 = 400Mbps</li> <li>Limited to 4.5 meters</li> </ul>	

# UWB WPAN fits a clear market need



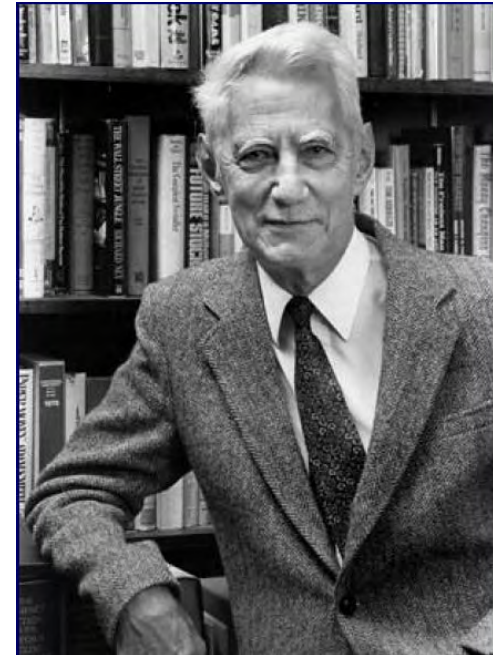


# What is UWB?

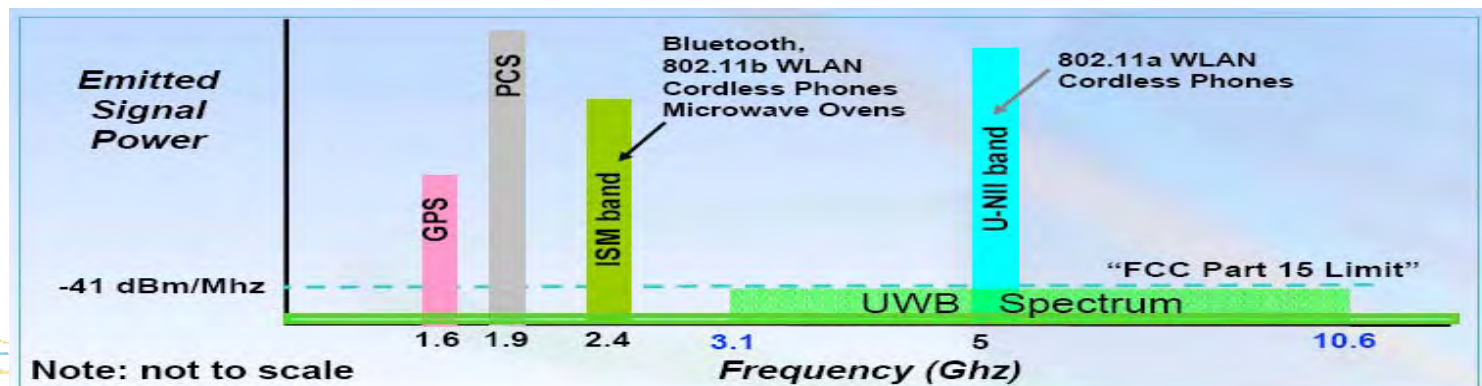
- FCC definition:
  - ▶  $B/F_c > 0.20$  or
  - ▶  $B > 500\text{MHz}$
- Why is this good?
  - ▶ Shannon...

$$C = B \log_2(1 + \text{SNR}) \text{ bits/sec}$$

Capacity scales linearly with bandwidth, but logarithmically with power...HOWEVER recall SNR is a function of B

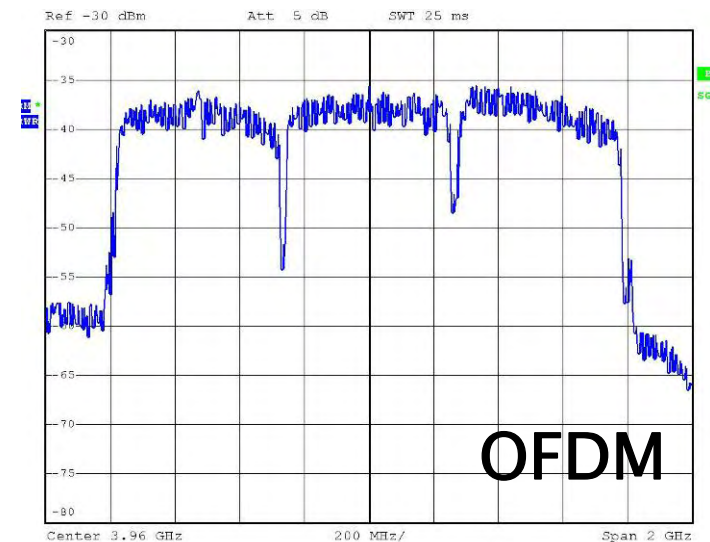
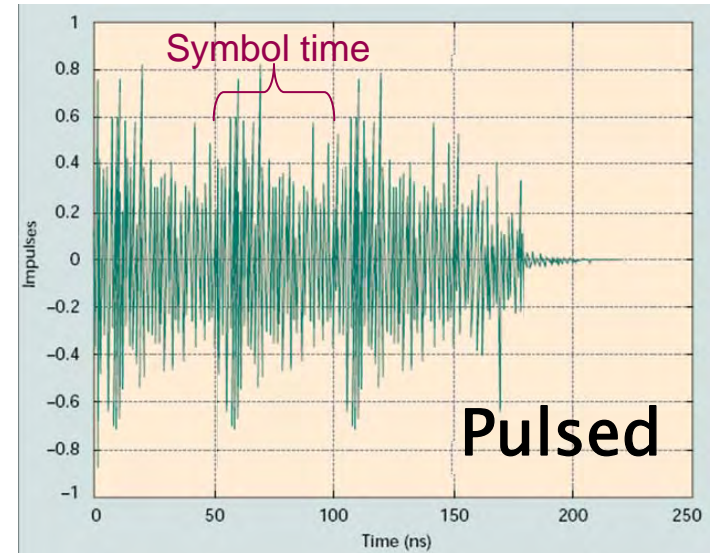


Claude Shannon



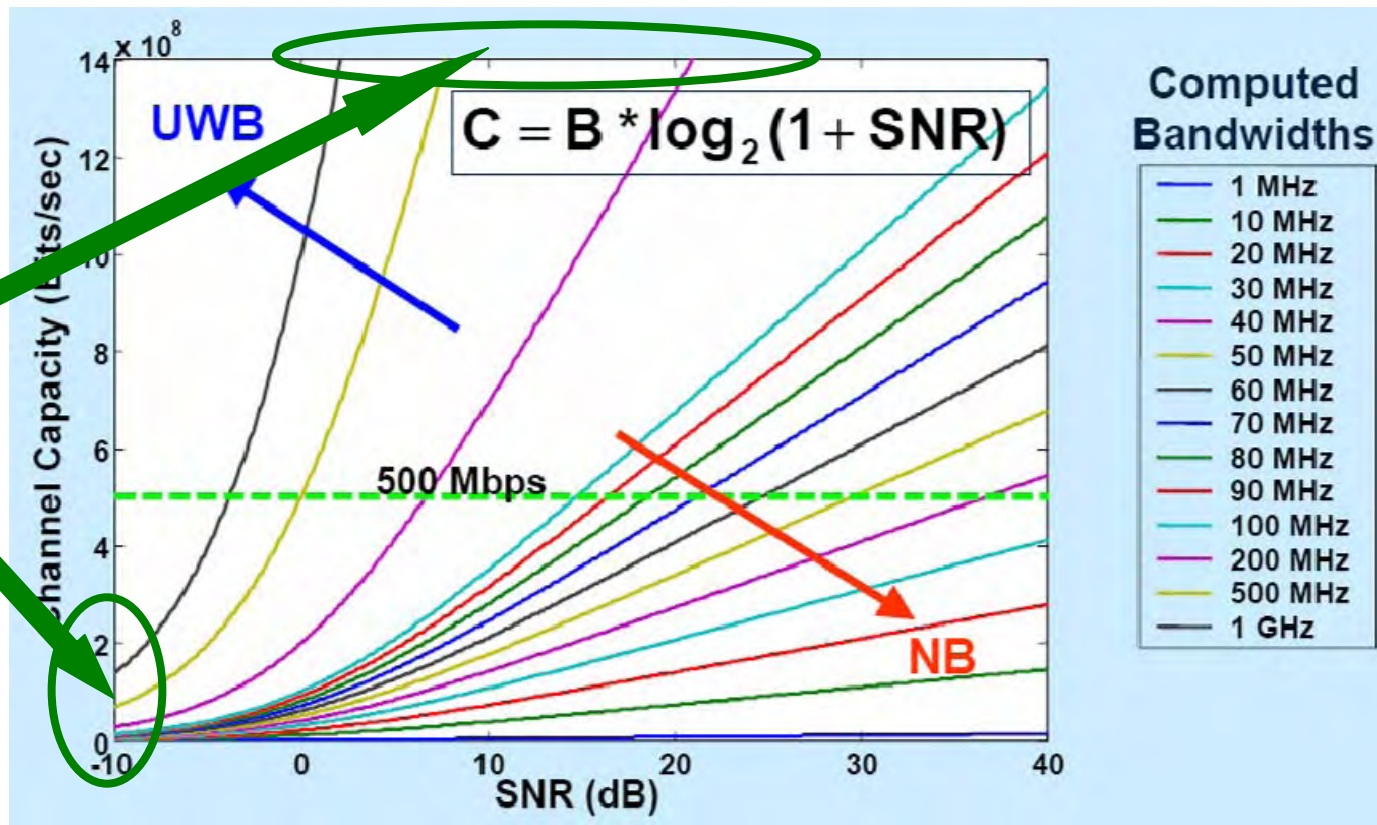
# UWB Background – Pulsed vs OFDM

- UWB was originally pulsed-based (Marconi's spark gap!)
  - ▶ Simple in concept, but...
  - ▶ Ideal for low data rate applications
  - ▶ Best when symbol time  $>$  delay spread of channel (low data rates)
  - ▶ Requires difficult rake receiver for most high speed applications
- High rate UWB will be OFDM
  - ▶ Similar to 802.11 a/g, cable modem, WiMax
  - ▶ Scales to high data rates
  - ▶ Simpler solution to multipath
  - ▶ Better spectral efficiency and lower OOB than pulsed



# Advantages of UWB

- UWB is ideal for high speeds
- UWB is ideal for low energy per bit

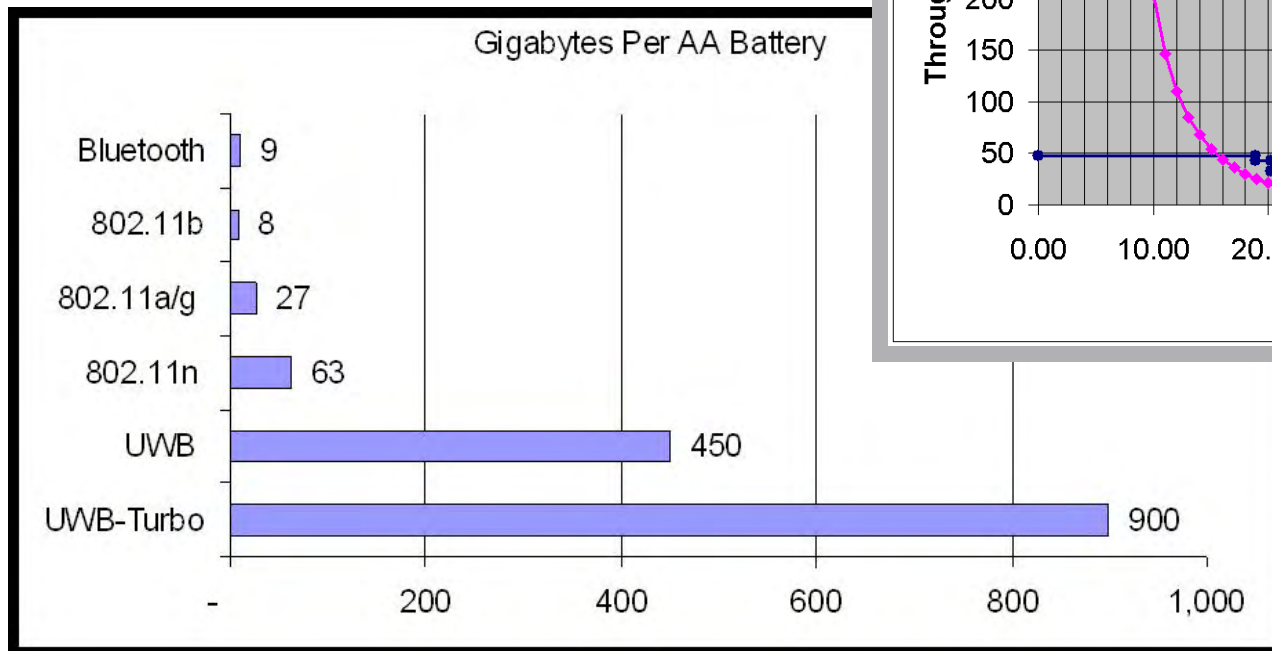
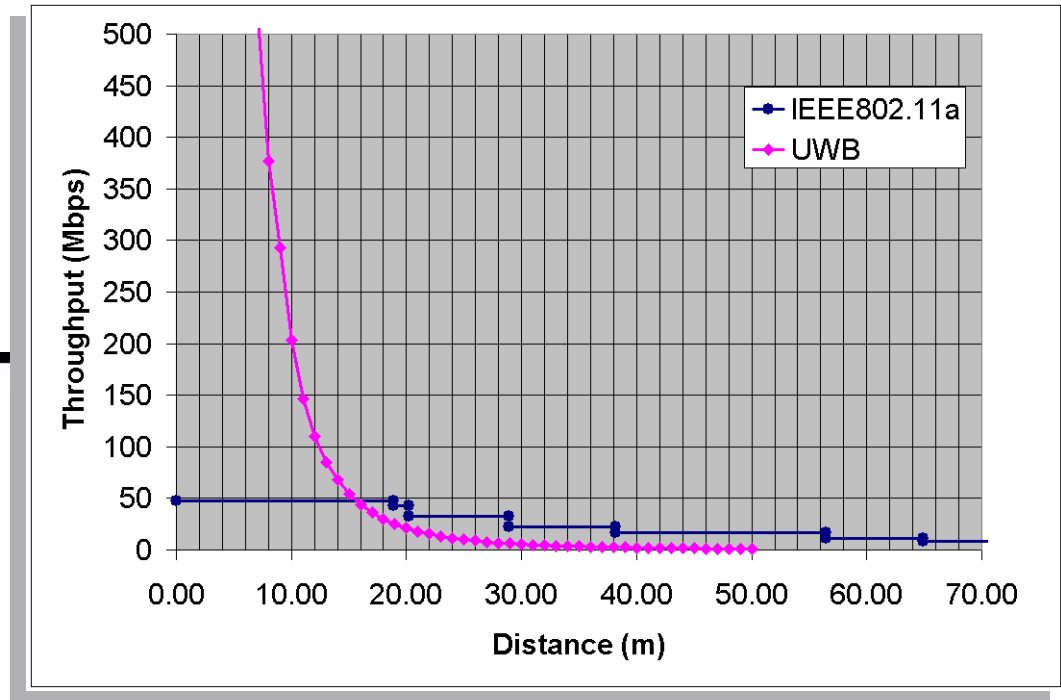


- UWB takes advantage of the “B” (bandwidth) term in Shannon’s capacity equation to achieve very high speeds at low power levels
- Opens new opportunities in wireless technology



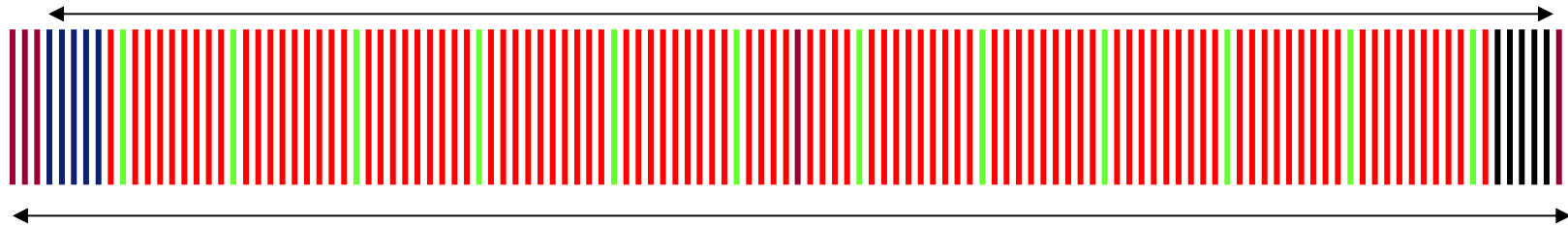
# Why will UWB become successful?

- Energy efficiency
  - ▶ >10x better than any other wireless technology
- Speed
  - ▶ Shannon says linear scaling in bandwidth beats log of  $1 + \text{SNR}$



# Multiband-OFDM UWB PHY Summary

507.35MHz



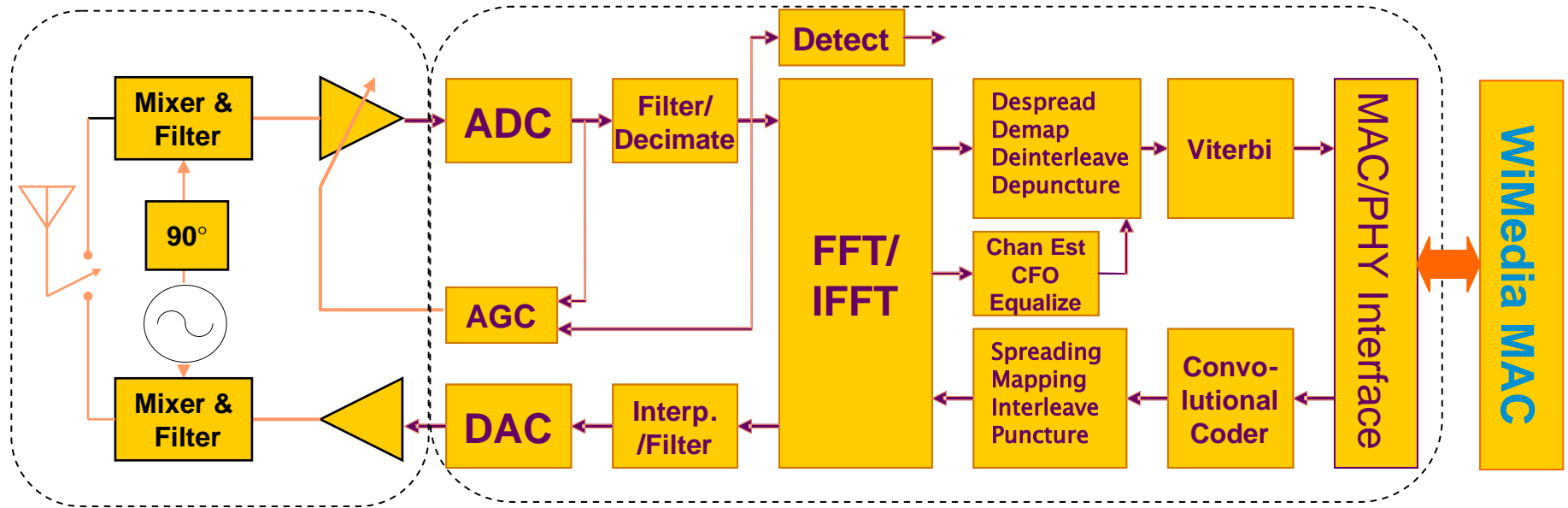
128 pt IFFT, 100 QPSK/DCM data tones, 12 pilots, 10 Guards, 6 nulls

Info Data Rate	Modulation	Coding Rate ( $R$ )	2X FDS	2X TDS	Coded Bits / 6 OFDM Symbol	Info Bits / 6 OFDM Symbol
53.3 Mbps	QPSK	1/3	YES	YES	300	100
80	QPSK	1/2	YES	YES	300	150
106.7	QPSK	1/3	NO	YES	600	200
110	QPSK	11/32	NO	YES	600	206.25
160	QPSK	1/2	NO	YES	600	300
200	QPSK	5/8	NO	YES	600	375
320	DCM	1/2	NO	NO	1200	600
400	DCM	5/8	NO	NO	1200	750
480	DCM	3/4	NO	NO	1200	900

## Symbol Statistics

- $T = 312.5 \text{ ns}, 60.5 \text{ ns ZP}$
- $N = 128 \text{ tones}$
- $\text{Tone spacing} = 4.125 \text{ MHz}$
- $\text{Total bandwidth} = 528 \text{ MHz}$

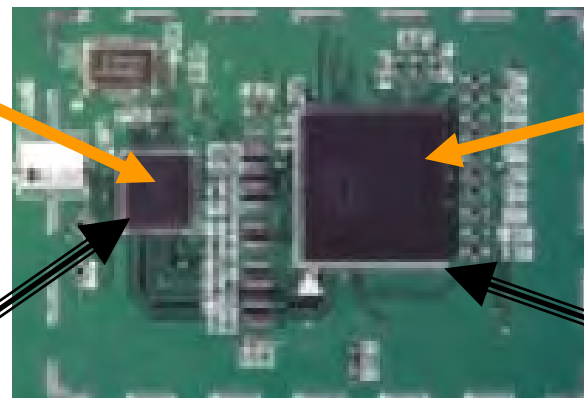
# The WiMedia Radio



RF

Baseband/MAC

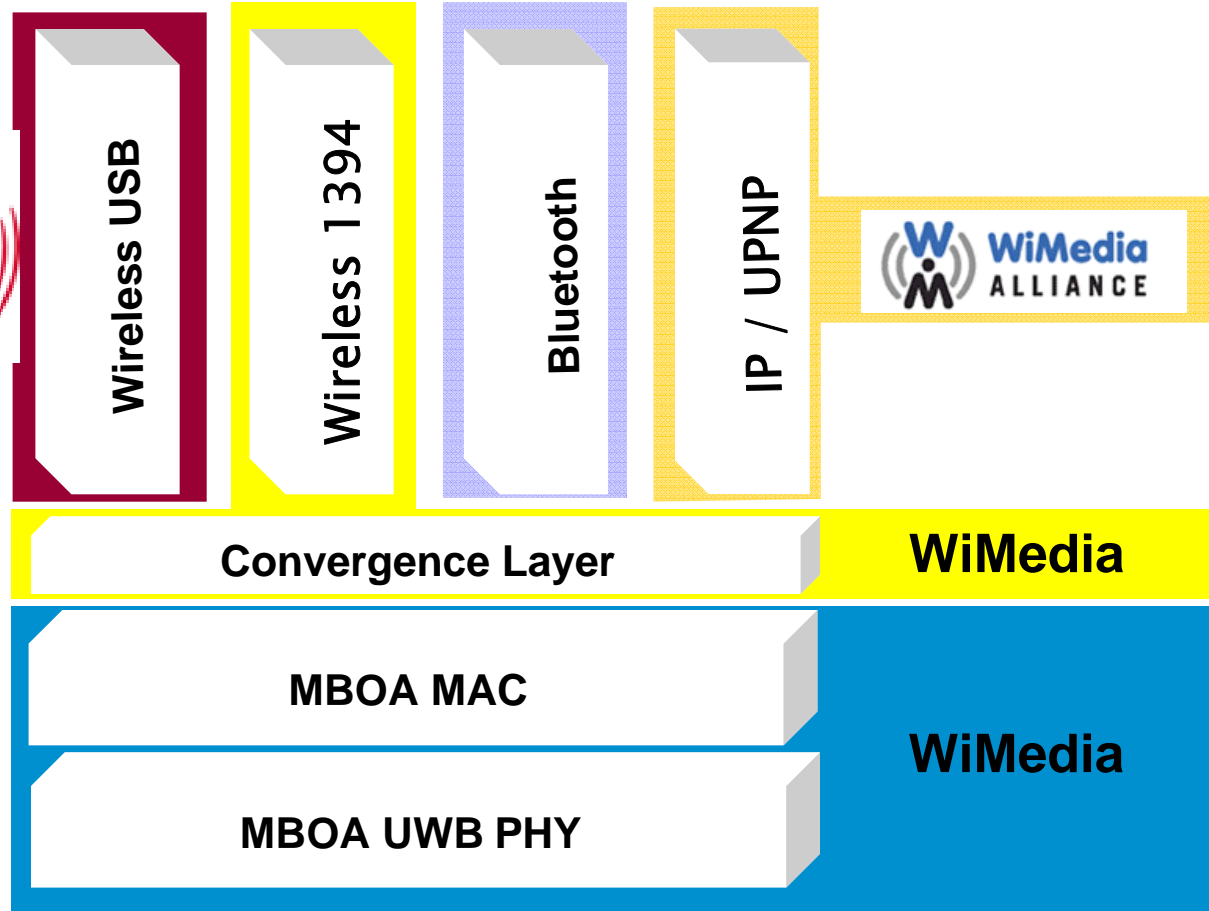
5mm x 5mm



10mm x 10mm

# Where WiMedia fits in the stack....

Potential Applications Using UWB



WiMedia is working with the SW industry to enable UWB deployment



# TDMA MAC - interleaved protocols

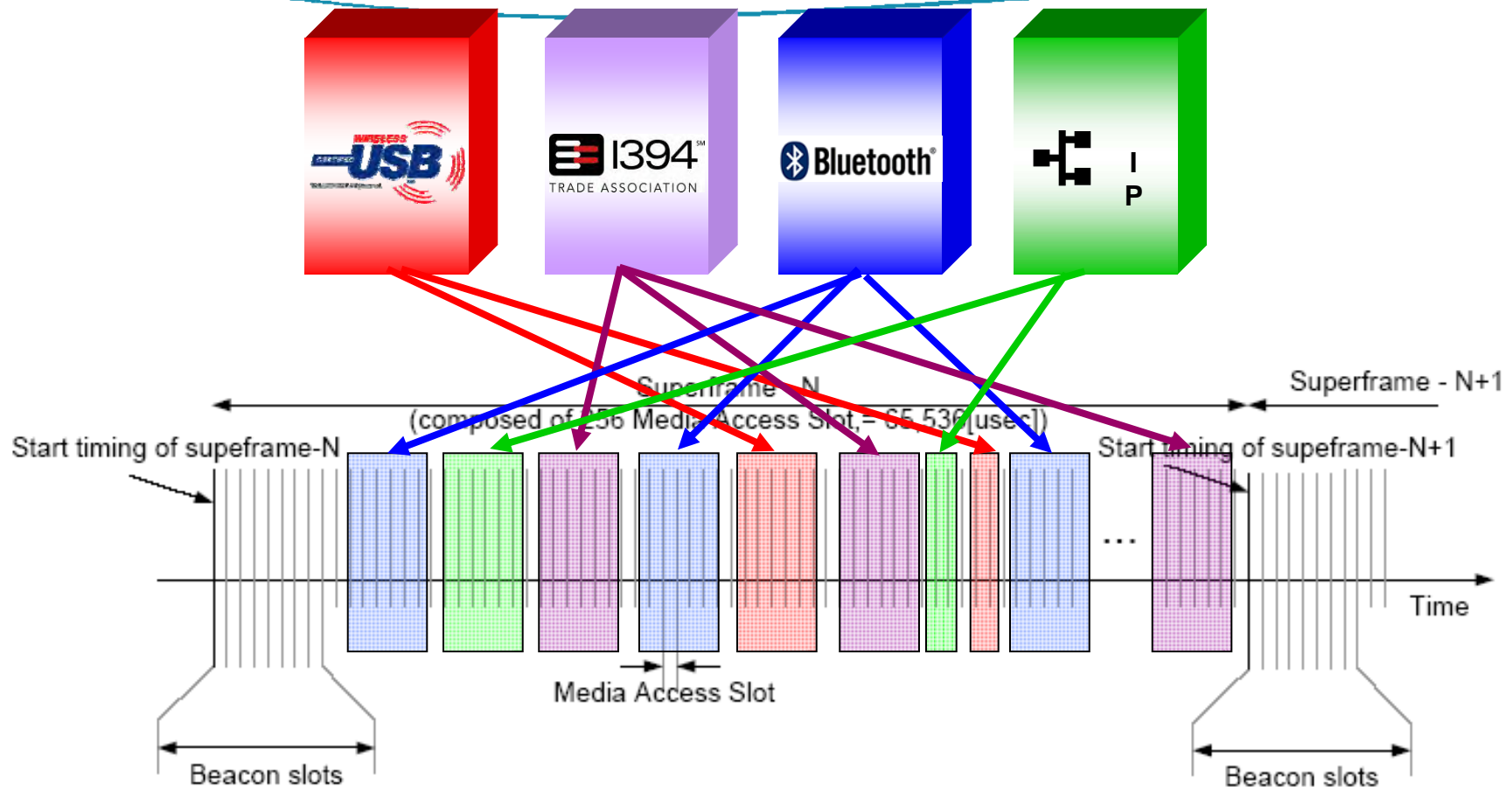


Figure 2 — MBOA MAC superframe structure

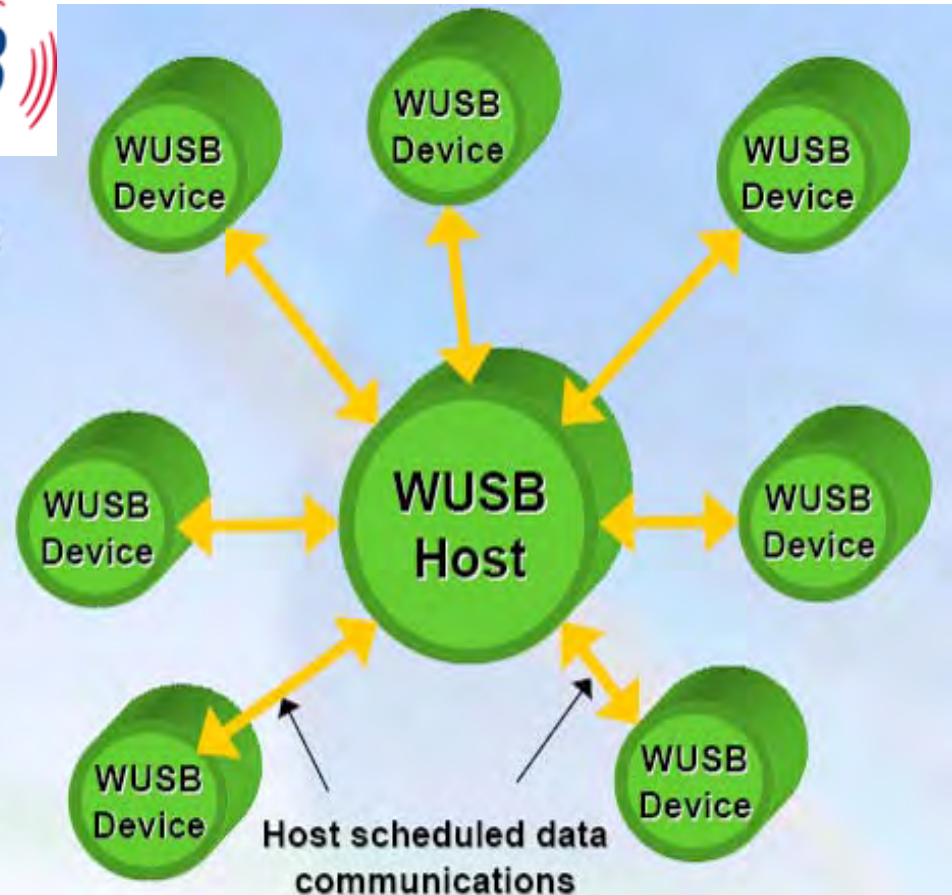
Any combination of protocols can be spread across a superframe

# Wireless USB – first wave of products!

## Topology



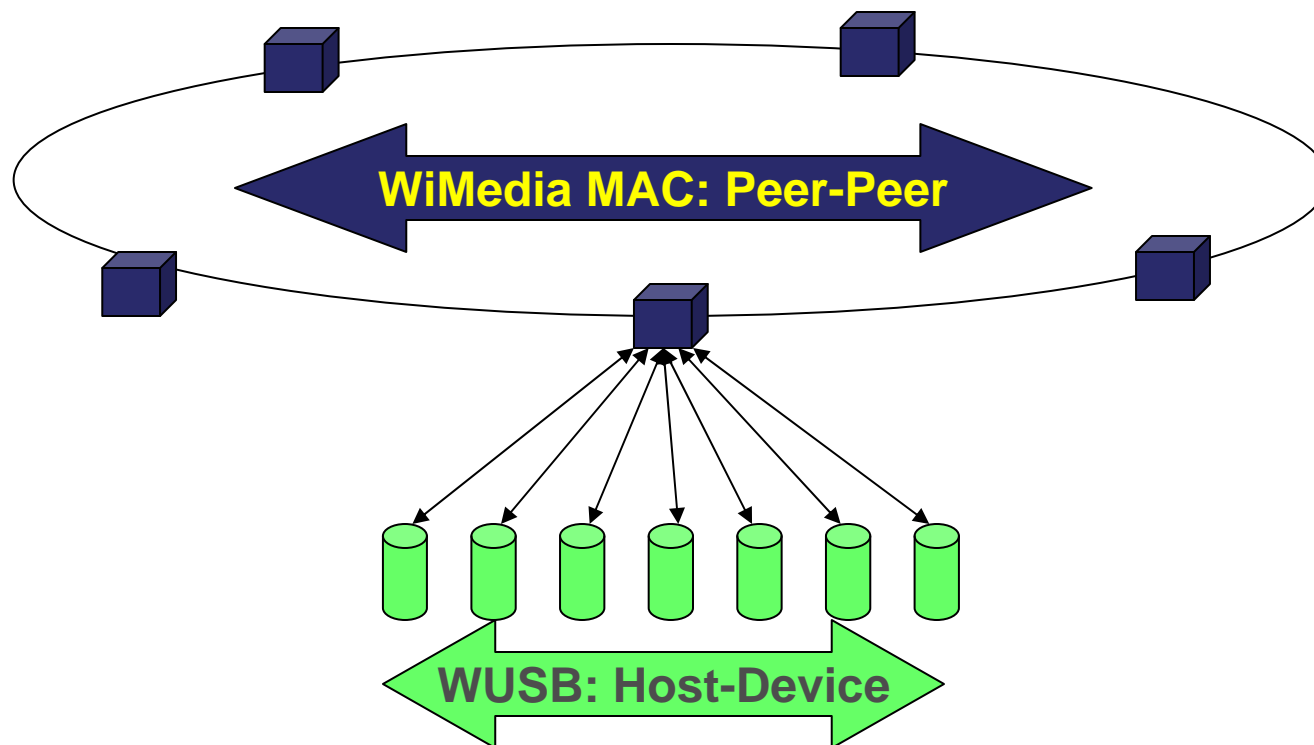
- Fundamental connection relationship is hub-and-spoke
- Connection model is a wire replacement
  - Connections are point to point between a WUSB host and a WUSB peripheral
- WUSB Cluster is a WUSB Host with one or more peripherals (up to 127)
- WUSB Clusters may co-exist within an overlapping spatial environment with minimum interference (4 - 10 clusters)



- Supports bridge to USB (wired) devices
- Dual Role Device

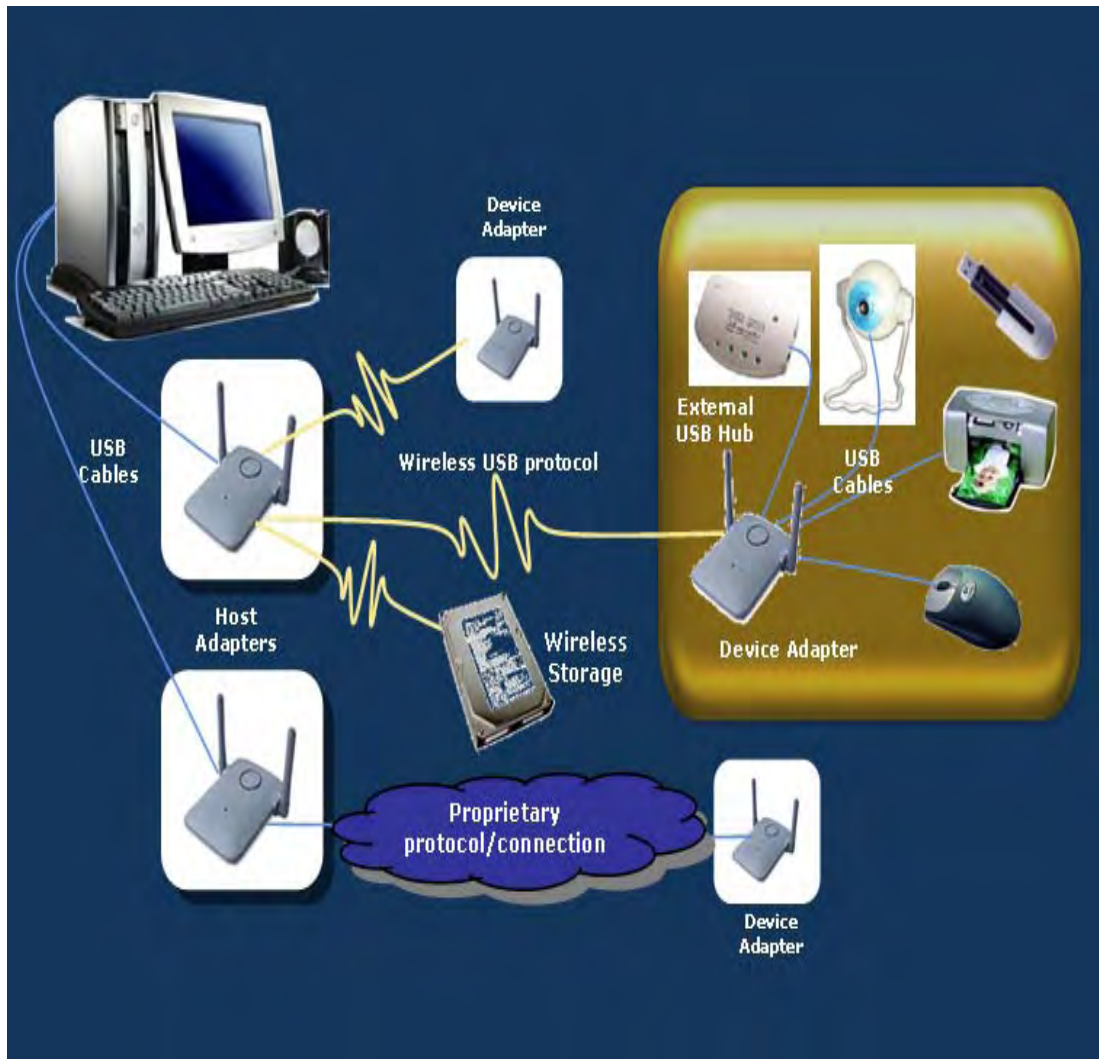
# WUSB and the WiMedia MAC

WUSB is a hierarchical (host-dev) subnet within a peer-peer network





# Wireless USB Products



- **Host Wire Adapters**
  - Dongles the plug into existing PCs
  - WUSB will be built into PC hosts over time
- **Device Wire Adapters**
  - Bridge from existing wired USB devices to host via wireless hub
- **Embedded**
  - As WUSB proliferates, it will become embedded and communicate with hosts directly



# Examples of initial products

- Products are in production

- ▶ FCC certification
- ▶ WiMedia Certification
- ▶ WUSB certification

- HWA/DWA products launched first
- Embedded products will be in the market later this year
- Eliminates the USB cable!



ExpressCard/34

Mini PCI



Cardbus



Wireless USB Dongle



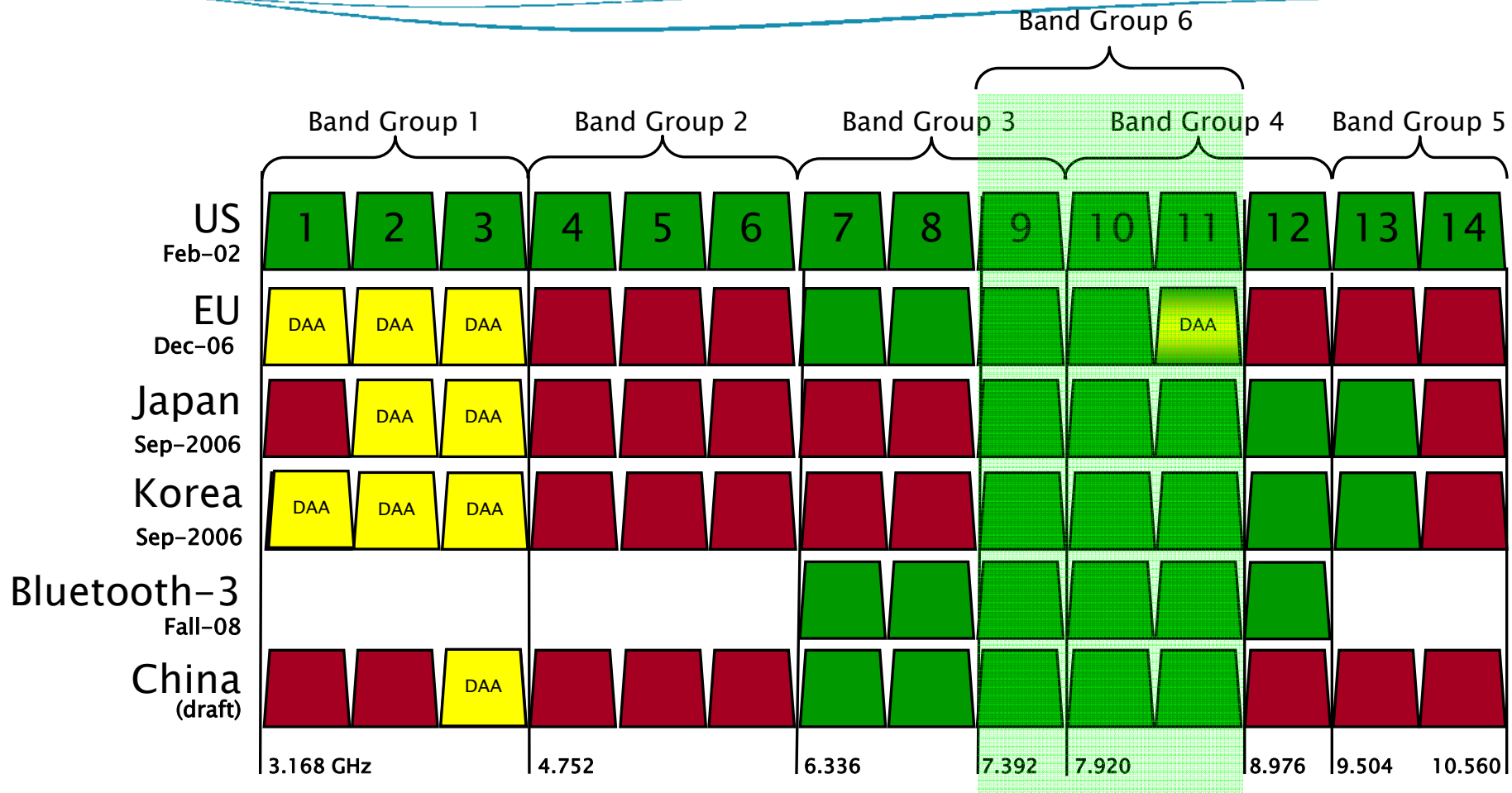
MiniCard



# UWB and Spectrum Policy

- **UWB was developed as an “underlay”**
  - ▶ FCC bought into the concept
  - ▶ Most of the rest of the world has been skeptical
  - ▶ It’s a coexistence problem
  - ▶ Mostly a concern in C-Band (3-5GHz) because of incumbents
  - ▶ Much less concern in X-Band (6-10GHz)...can operate as a “pure” underlay except in 8.5-9GHz
- **What are the issues?**
  - ▶ Detecting the presence of an “incumbent” signal (WiMax, typically – can also be radar)
  - ▶ Dropping emissions in the shared band so that interference on the “incumbent” is minimized
  - ▶ Together, these are called “Detect and Avoid” (DAA)
- **This is a form of cognitive radio**
  - ▶ Similar to “waterfilling”
- **TBD: Detection level/confidence and suppression level**

# WW Regulatory Spectrum

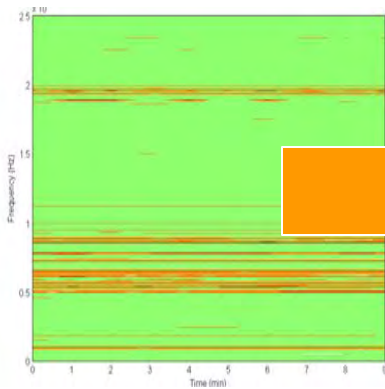


## Notes

- EU – Band 1/2 are not usable today; Band 3 is usable today. By 2010 B1/2/3 will all require DAA that may not be implementable. By 2010 B1 will all require DAA that is implementable
- Japan – Band 3 is legal today; Band 2/3 will require DAA end 2008
- Korea – Band 3 is legal today; Band 1/2/3 will require DAA mid-2010. Prelim DAA rules in place
- China – Band 3 DAA will be required after 2010
- Canada – Still no rules as of 7/2008. Hope to ship by end 2008

# Why a "Cognitive" Radio?

- FCC Chairman Powell: "Recent advances in smart radio technologies have the potential to provide more innovative, flexible, and comprehensive use of spectrum while at the same time minimizing the risk of harmful interference. On a real-time basis, smart radios determine their location or environment, have the flexibility to select the best frequencies to use, know how to avoid interference with existing users, and can use vacant spectrum channels."

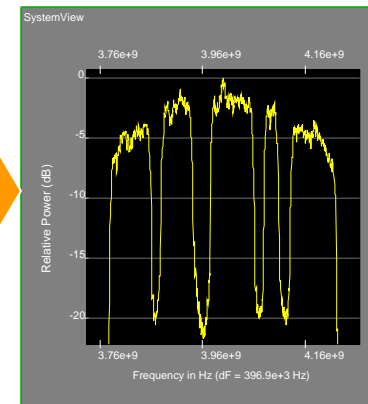
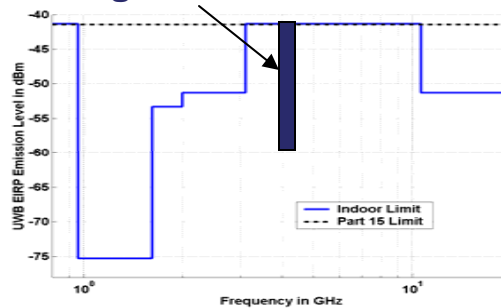


>99% of spectrum between 2.5 and 5GHz unused at any instant

## Policy Based Cognitive Radio

- Measures local interference
- Observes local propagation
- Knows application requirements
- Knows local regulatory policy
- >> Can Adjust Power, Spectrum, BW, and Throughput

"Notch" dictated by local regulations



"Sculpted" spectrum

DAA is a form of Cognitive Radio

IEEE ComSoc/SP Meeting

July 17, 2008

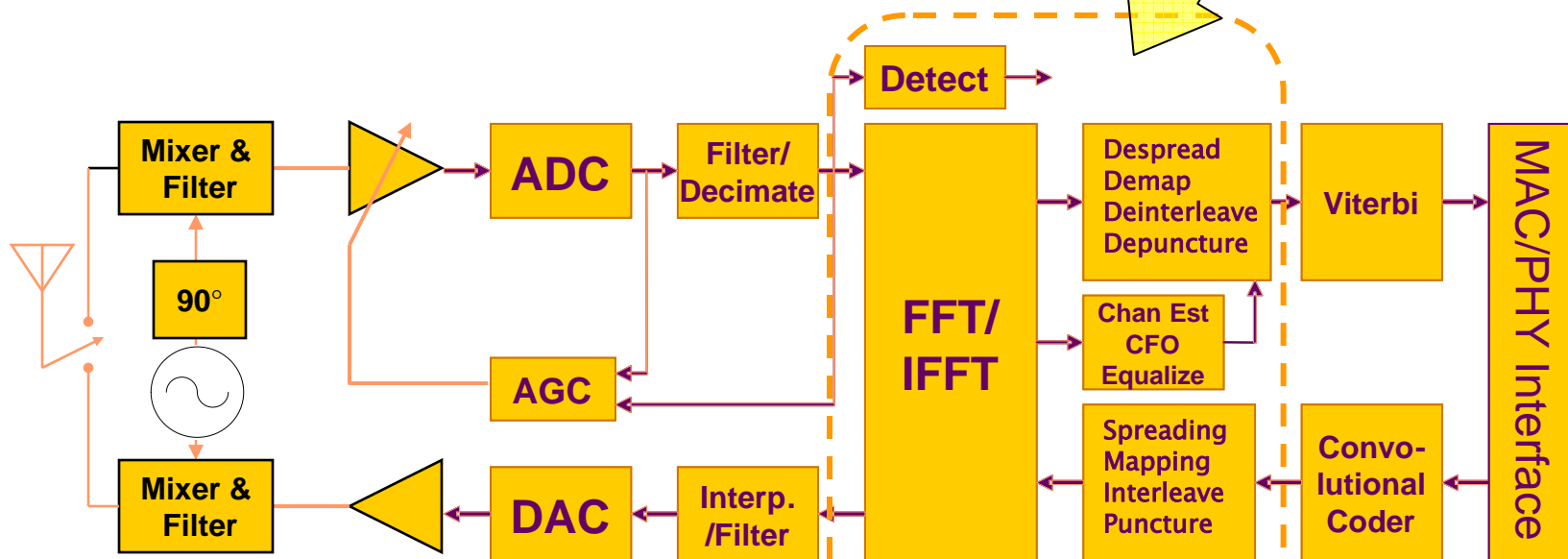
alereon



# How does MB-OFDM implement DAA?

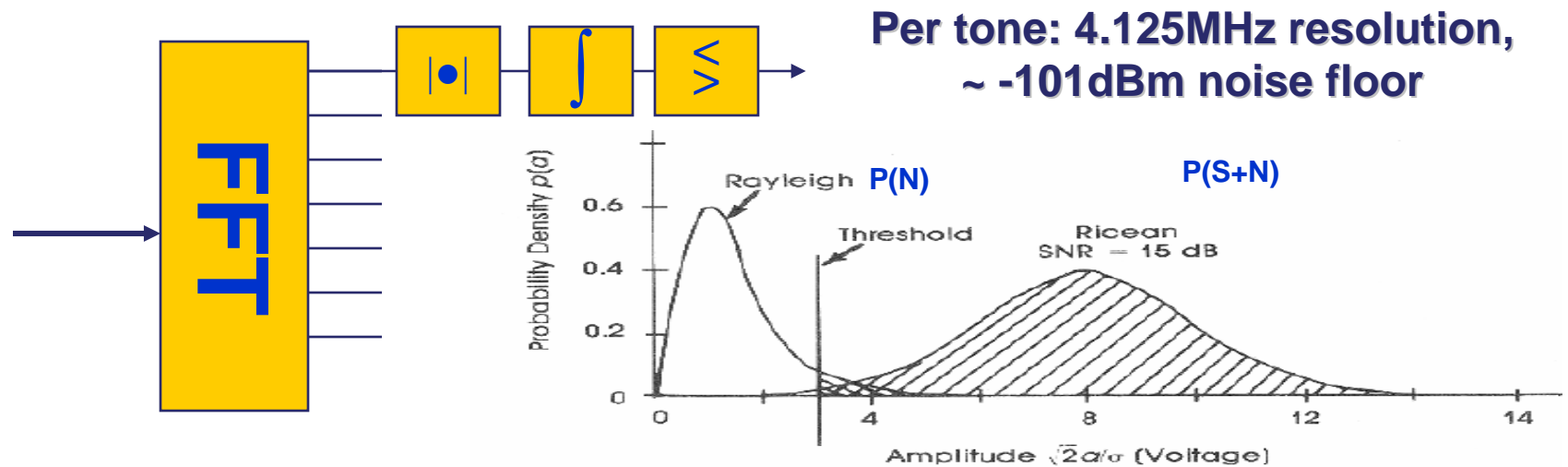
- Detect: Channelized radiometer
  - ▶ 128 channel FFT inherent in the design
  - ▶ Integrate spectra to achieve desired  $P_D$
- Avoid: Bandstop filter (frequency domain)
  - ▶ 128 point IFFT
  - ▶ Additional signal processing techniques can increase notch depth, subject to RF linearity

**Alereon's  
CogniPHY™  
Technology**



# Detection

- Channelized radiometers have been used for decades
  - ▶ Narrowband detection in a wideband channel
  - ▶ Used in Radar and communication intercept receivers
  - ▶ Theory well developed
- If FFT bins (magnitude) contain noise alone, distribution is Rayleigh
- If narrowband signal + noise, distribution is Rician
- Must detect time varying signals to avoid false detect on spurs



# DAA in a WiMedia TDMA MAC

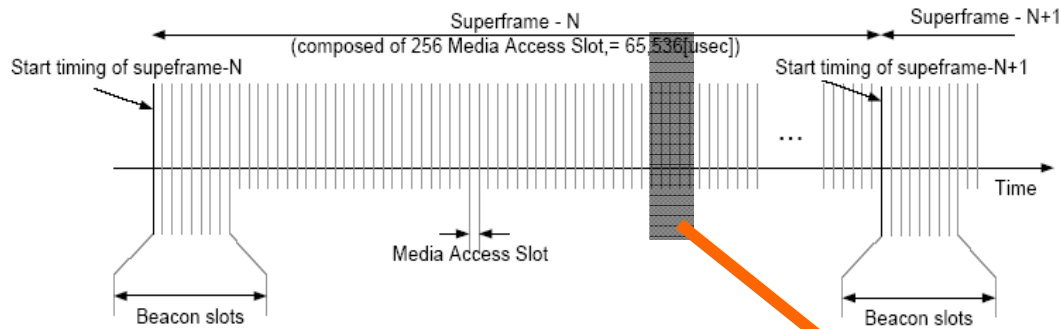
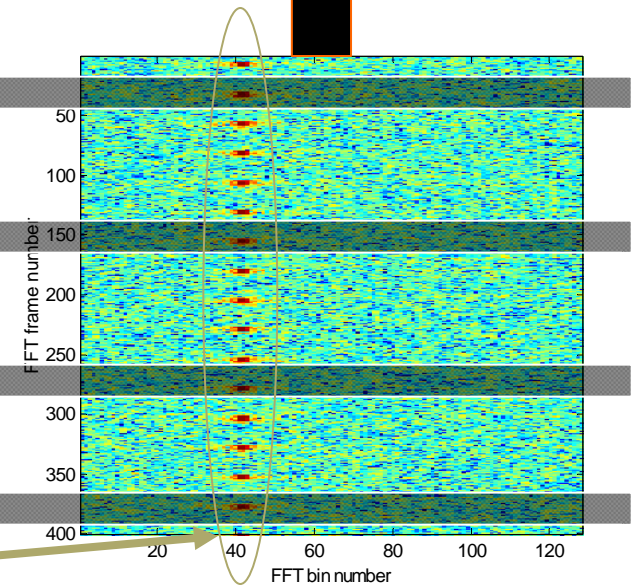
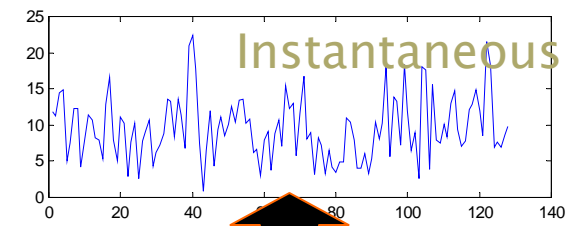
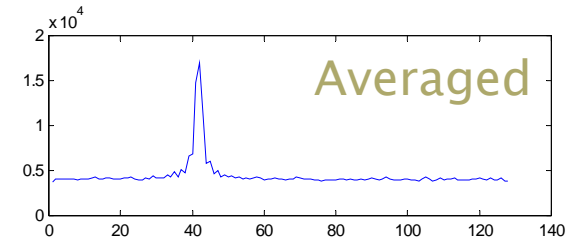


Figure 2 — MBOA MAC superframe structure



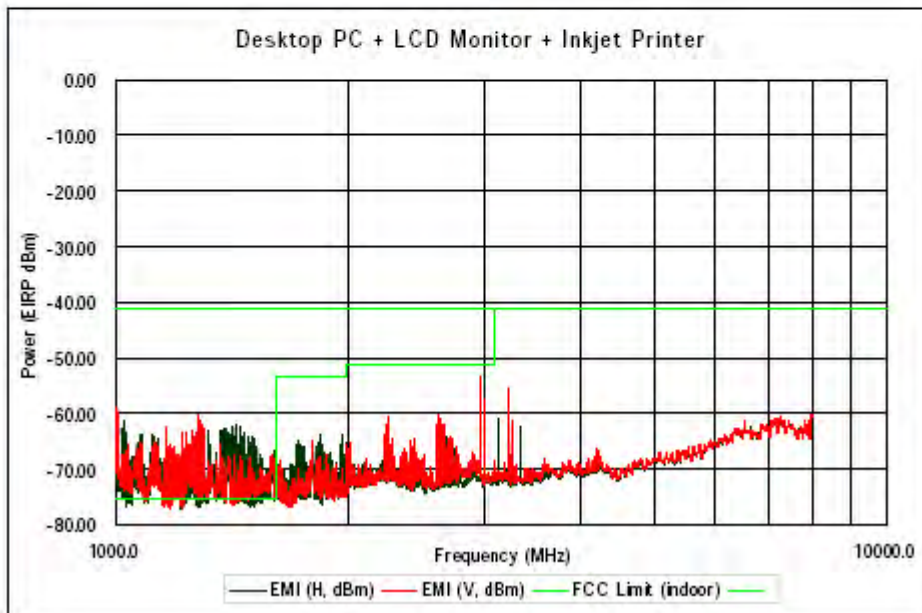
WiMax beacons

- WiMedia MAC is TDMA
- Slots can be reserved for spectrum sampling (“silent periods”)
  - All network Tx shut off
- Larger number of slots increases probability of detecting beacon
  - But reduces UWB data throughput
- Work continues to explore cyclostationary signals

# DAA's Problem: Acceptable $P_{FA}$



Desktop PC with flat panel display and inkjet printer attached.

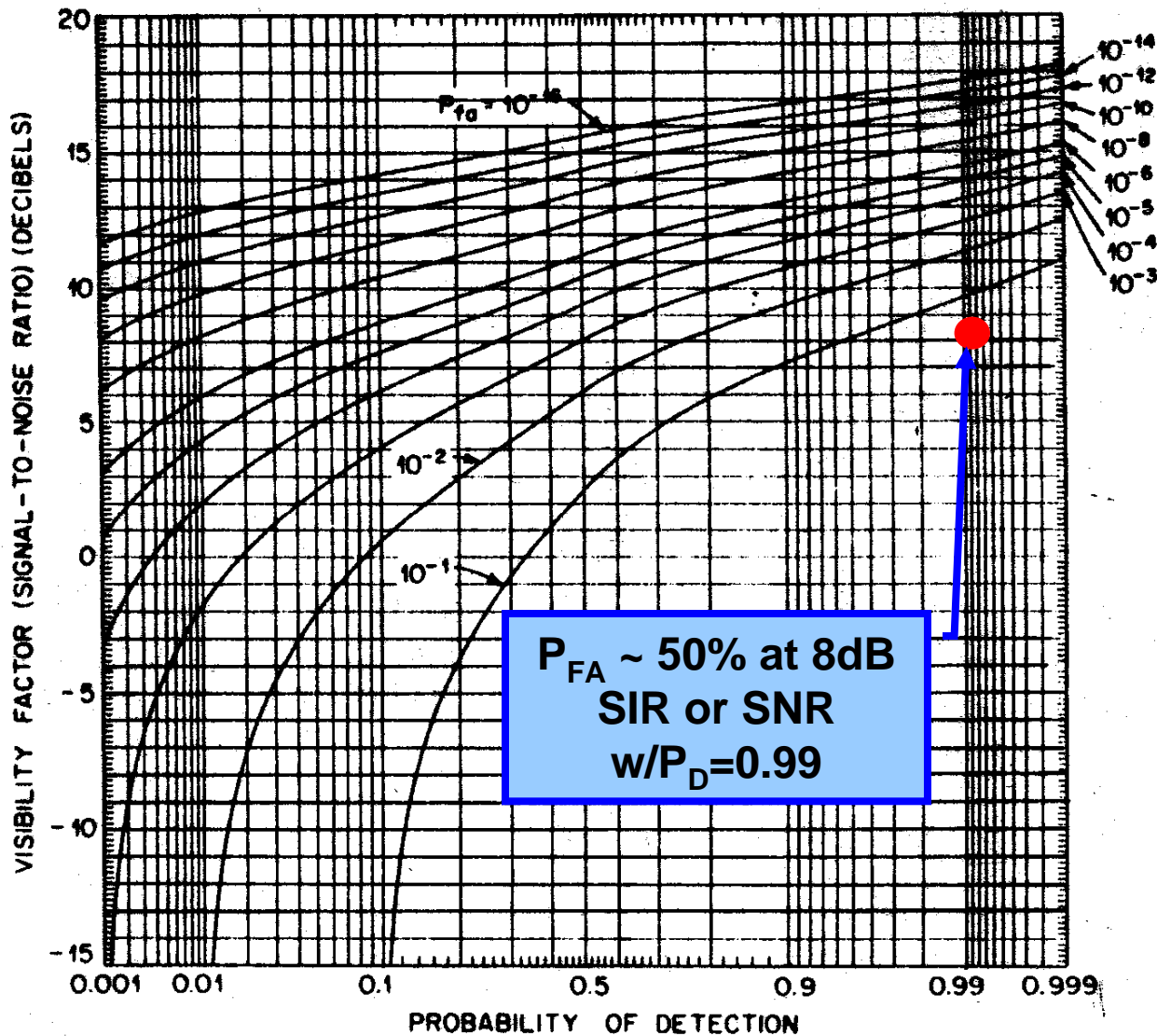


Source: TDK RF Systems

- Ambient noise levels around typical PC are high
- Radiometer detection may not be able to successfully yield acceptable  $P_D$  without unacceptable  $P_{FA}$ 
  - ▶ Radiometer is not “smart” enough to discriminate WiMax from spurs/noise
- More exotic signal processing will be required
- Use of upper bands may be a better solution

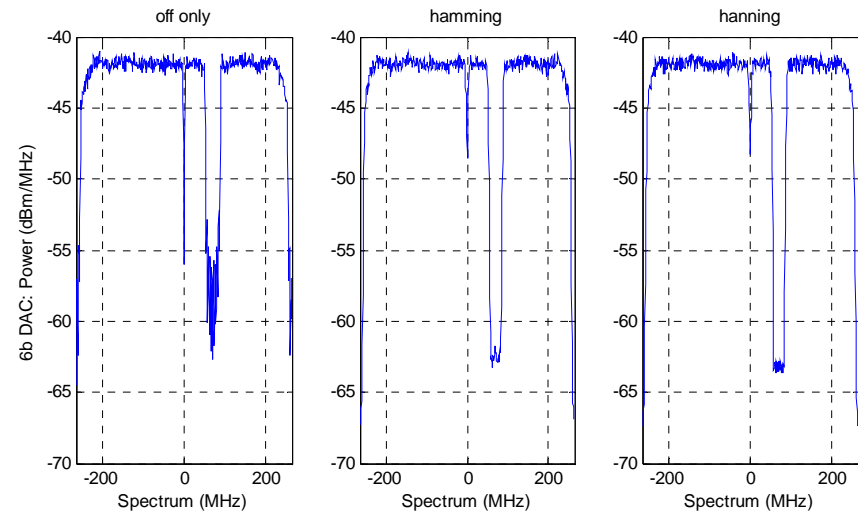
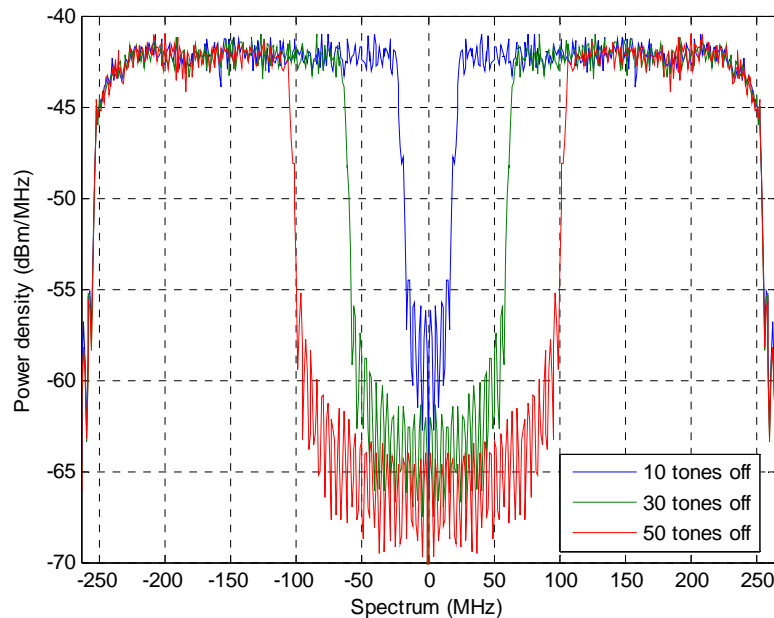


# Radiometer detection – $P_D$ vs $P_{FA}$



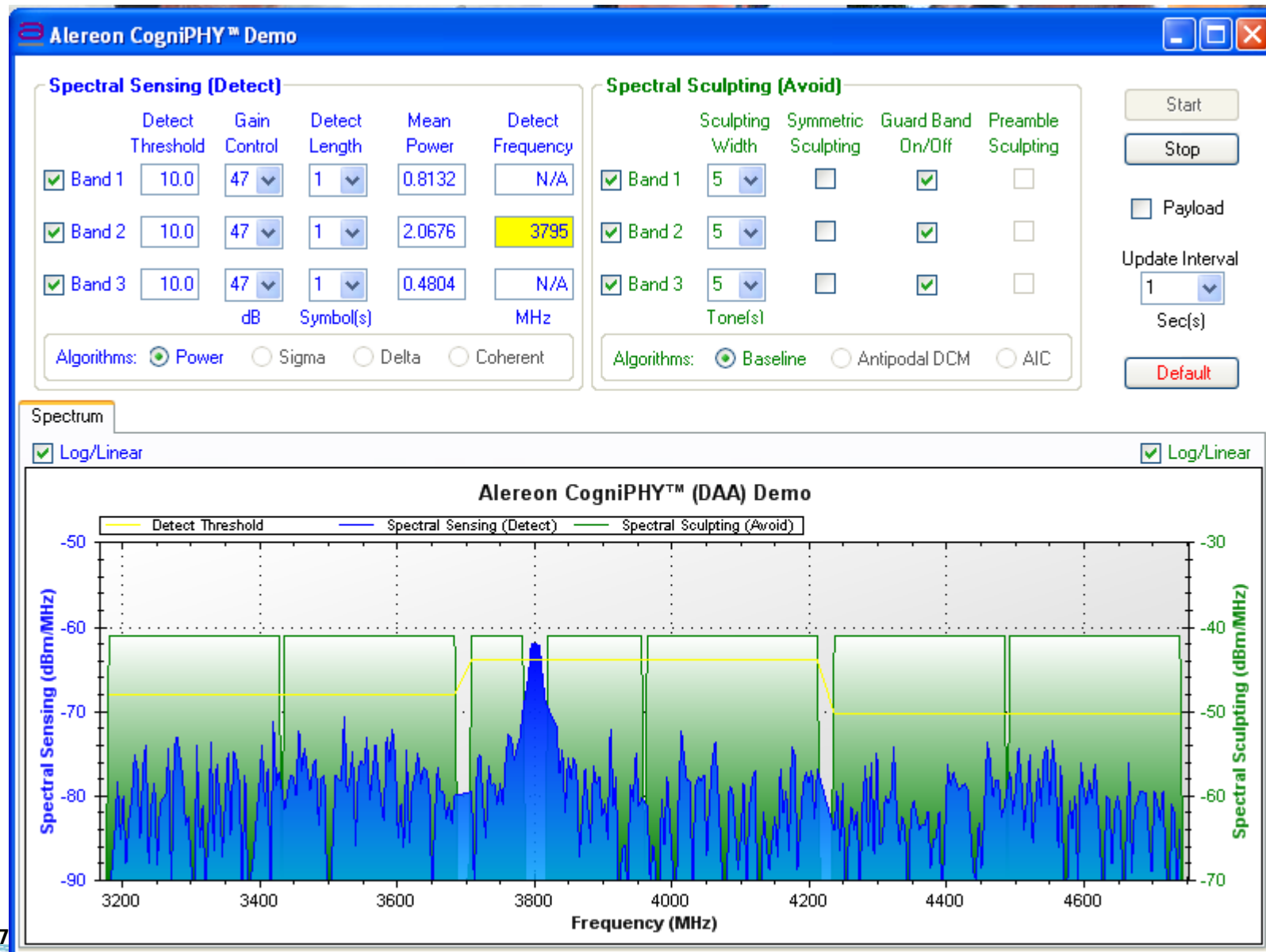
- Detection probability is fixed by regulations
- False alarm probability is thus dictated by SNR
  - ▶ KTB is best case
  - ▶ Interference typically dominates background noise

# Spectral Sculpting Techniques

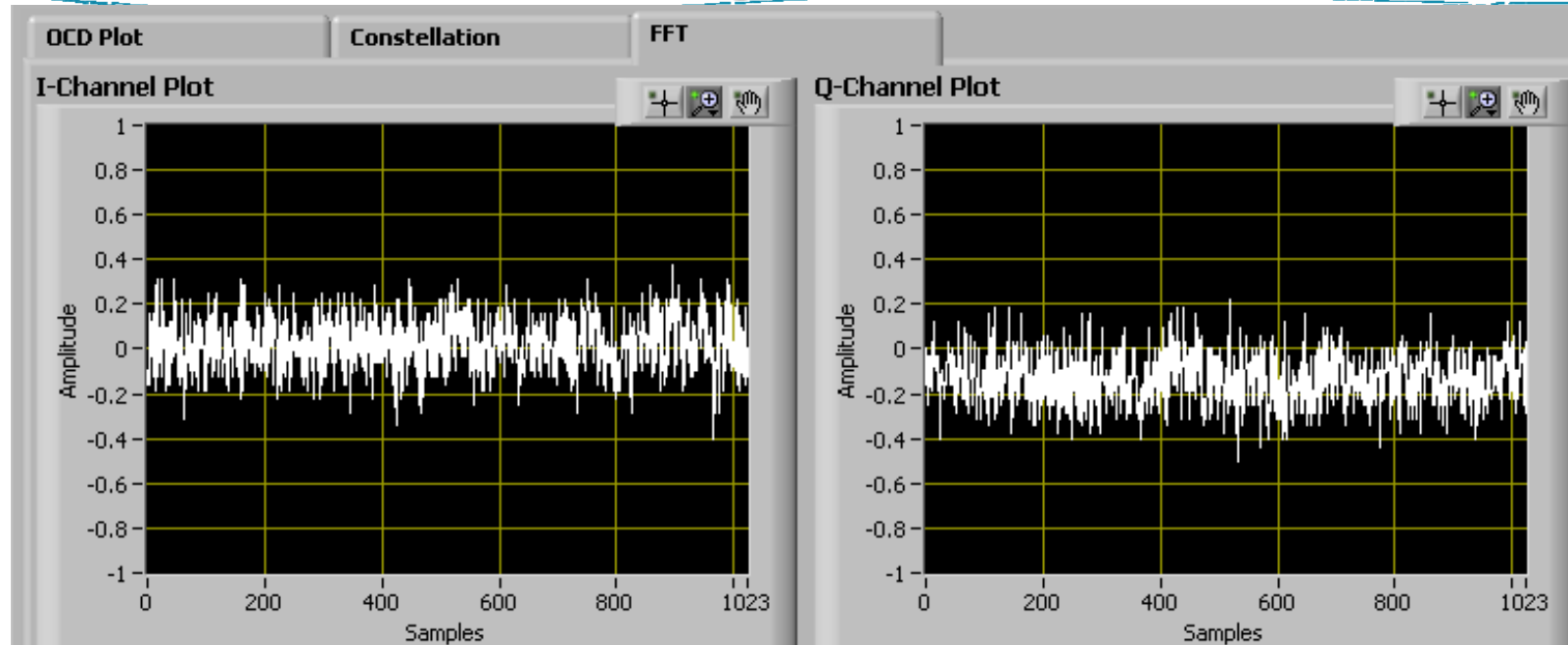


- Notches created by applying weight vectors to IFFT
- Depth a function of:
  - ▶ DAC bit resolution
  - ▶ RF EVM
  - ▶  $\text{Sin}(x)/x$  limits (with weighting)

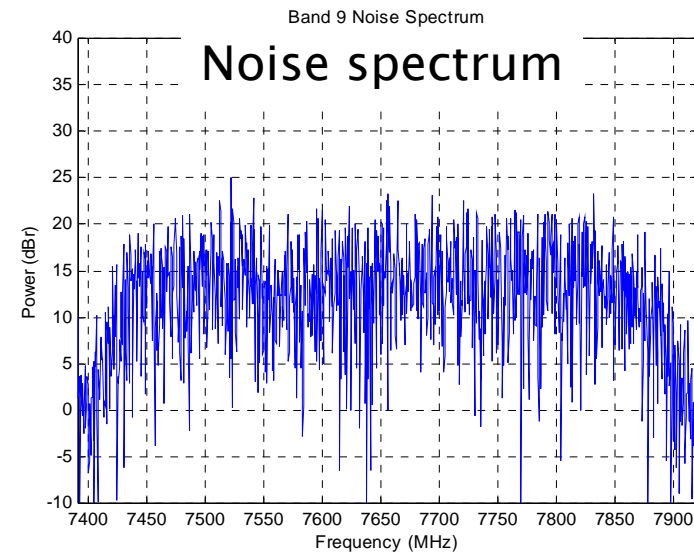
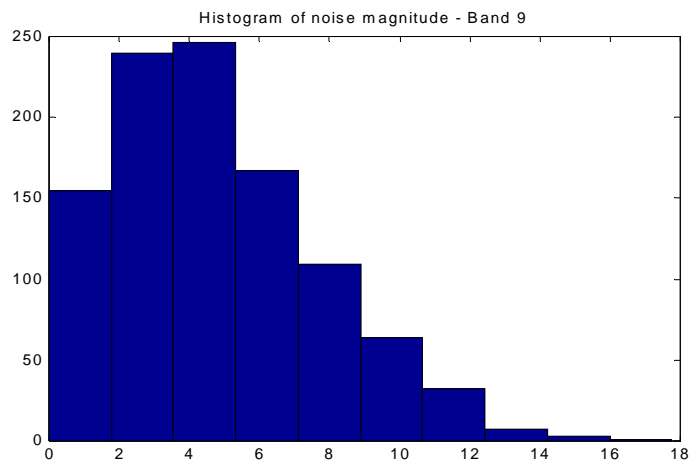
# Alereon's CogniPHY™ Technology (Band Grp 1)



# More data from CogniPHY™ (Band 9)



Histogram of FFT magnitude



# Going forward: C-Band+DAA vs X-Band

## ▪ LOW BAND

### ▪ System

- ▶ Reasonable path losses
- ▶ FR4 is well characterized

### ▪ RFIC difficulties

- ▶ Fair performance in CMOS
- ▶ Very good performance in SiGe

### ▪ Baseband

- ▶ Comparable to 802.11g complexity
- ▶ Much faster, but much smaller data path

### ▪ MAC

- ▶ Must implement complex signal processing algorithms
- ▶ Notching due to false alarms
- ▶ Silent periods interrupt QoS
- ▶ Channel could be useless

## ▪ HIGH BAND

### ▪ System

- ▶ Higher path losses
- ▶ Challenging board layouts (use modules!)

### ▪ RFIC difficulties

- ▶ Phase noise
- ▶ I/Q imbalance (mag/phase error)
- ▶ Overall EVM (incl IP3, P1 dB)
- ▶ CMOS very difficult

### ▪ Baseband

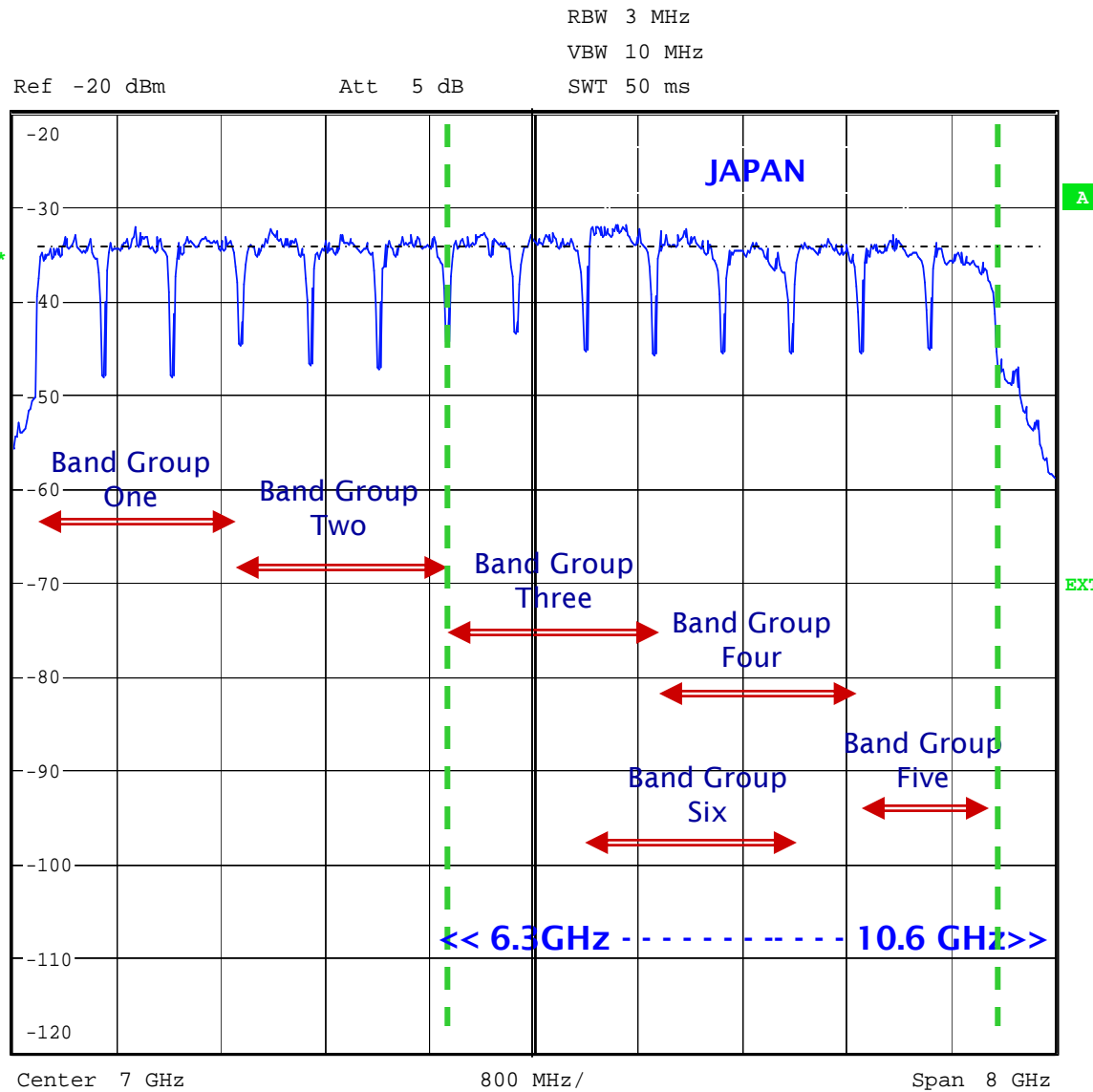
- ▶ Similar complexity
- ▶  $\pm 20$ ppm tracking is more difficult

### ▪ MAC

- ▶ No silent periods or notching
- ▶ QoS will work



# Here is the future...



Alereon's AL5000 Worldwide UWB PHY

# Conclusion

- DAA is a form of cognitive radio for “white space processing”
  - ▶ Uses spectral sampling and sculpting
  - ▶ Avoids narrowband interference
  - ▶ Requires large dynamic range and linearity
  - ▶ DAA performance is questionable... $P_{FA}$  may be unacceptable
- Regulations are essentially done worldwide
- Upper bands pose RFIC design challenges, but don't require DAA
  - ▶ Dual band radios will be the norm
- UWB represents a great opportunity in consumer electronics
  - ▶ Enables compelling usage models that cannot be served as efficiently using other wireless technologies
  - ▶ Ideal for exchanging large volumes of information to/from mobile devices
  - ▶ Wireless USB and High Speed Bluetooth will be widespread by 2010