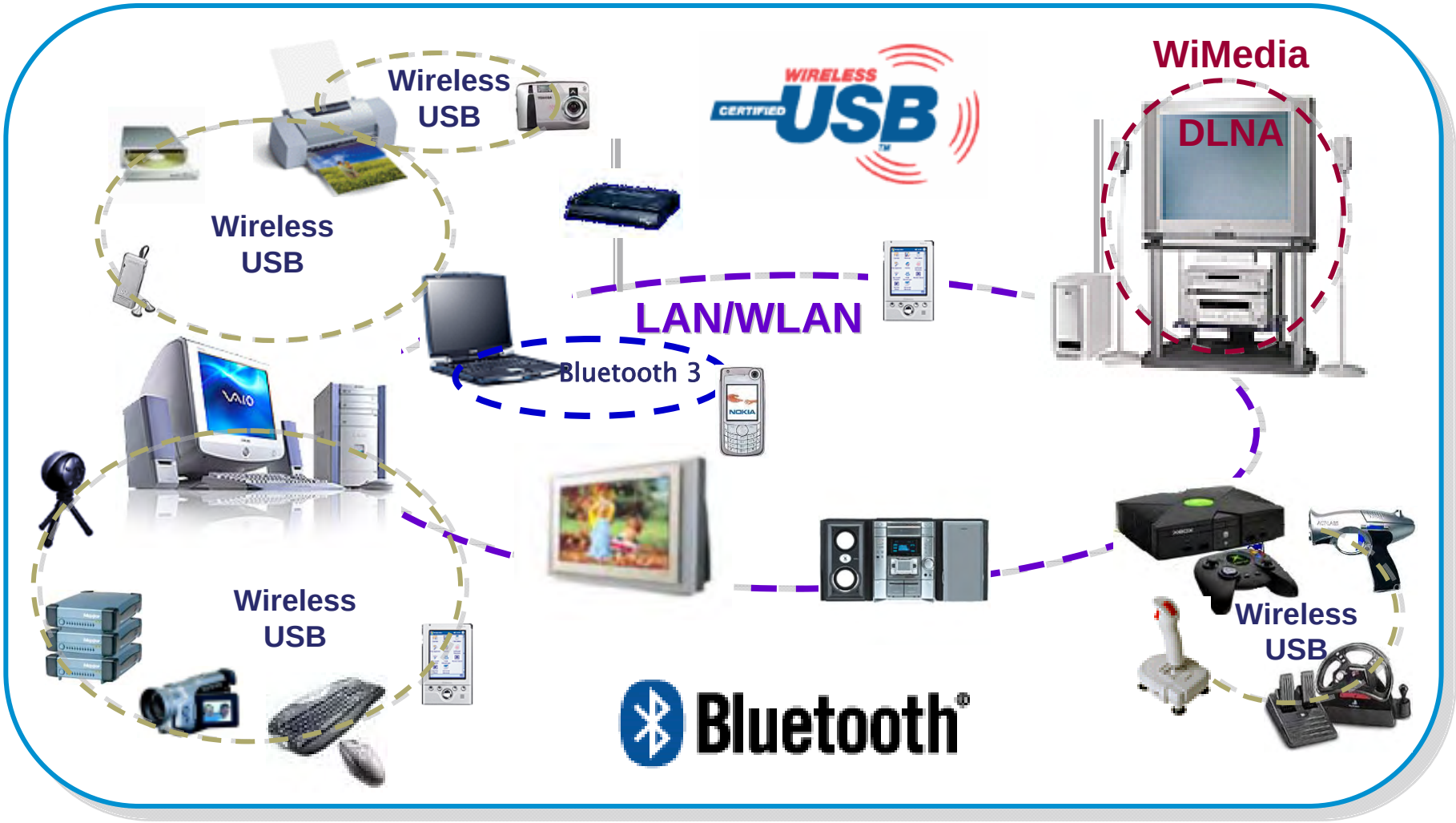
Ultrawideband: The "Ultra" White Space Technology

Jim Lansford, Ph.D.
Chief Technology Officer
jim.lansford@alereon.com

Background

- 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

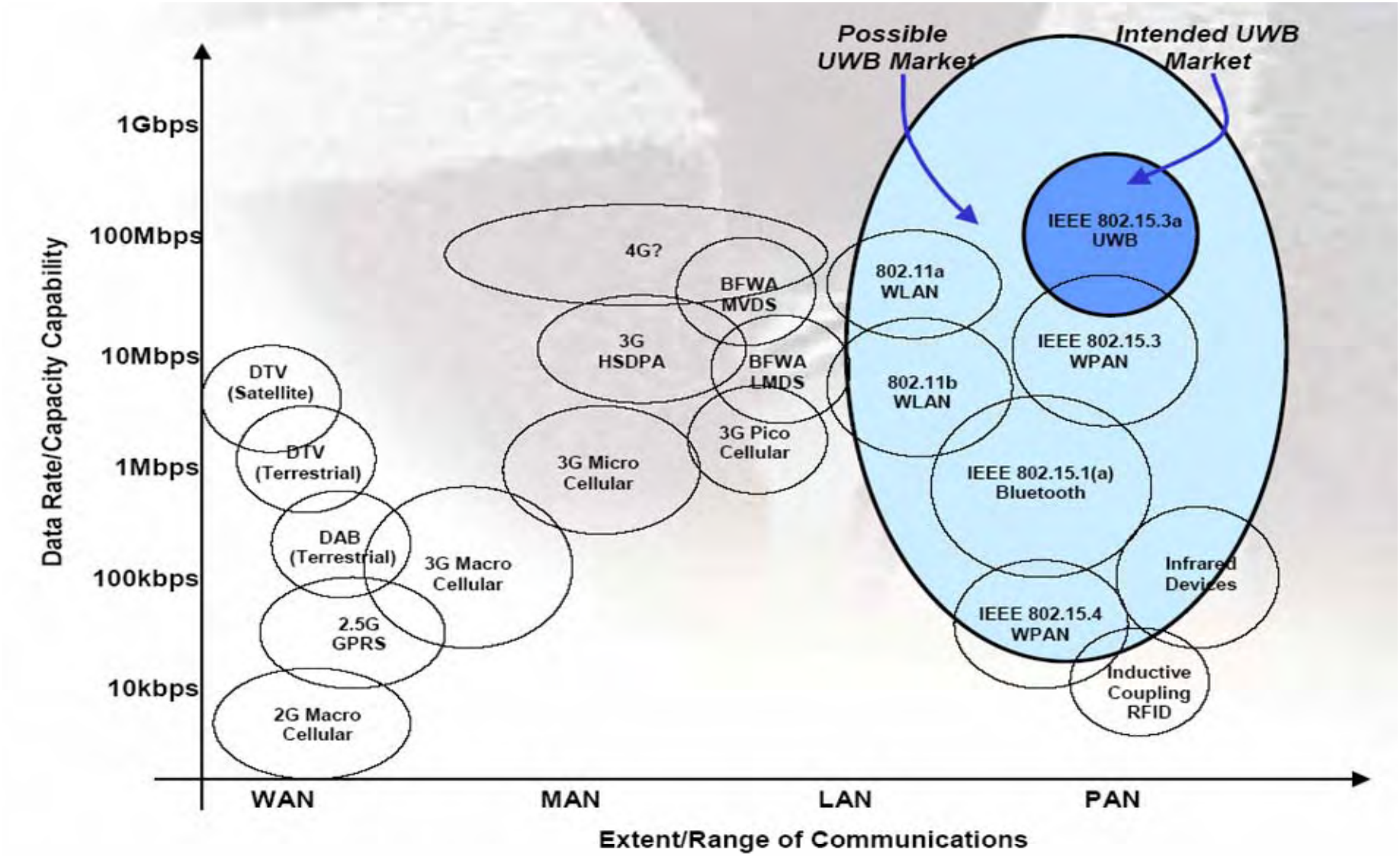


A WPAN complements longer range access technologies

Why a WPAN?

Cable	Bandwidth/Use Issues	Wireless Alternative
Serial & USB 1 	• Primarily for older PC peripherals • 230 Kbps	• Bluetooth 1.1 •Bluetooth 3.0 will include UWB 
Ethernet Cable 	• Primarily for older PC peripherals • 10 Mbps or 100Mbps	• WiFi (802.11b/g) • IEEE 802.11a 
USB 2.0 	• USB 2.0 = 480 Mbps *(backwards compatible with USB 1.1= 12Mbps)* • Limited to 3-5 meters; depending on the speed of peripheral connection	**• No Current Wireless Solution Available** **There is a market need for a high speed, energy efficient cable replacement**
FireWire/1394 	• FireWire/ 1394 = 400Mbps • Limited to 4.5 meters	**• No Current Wireless Solution Available**

UWB WPAN fits a clear market need

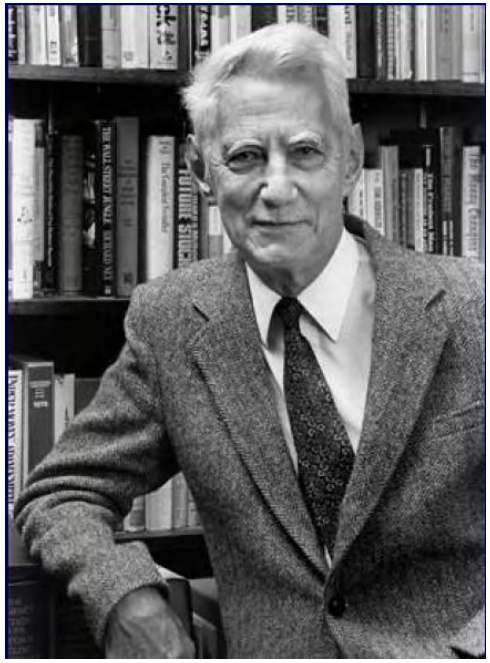


What is UWB?

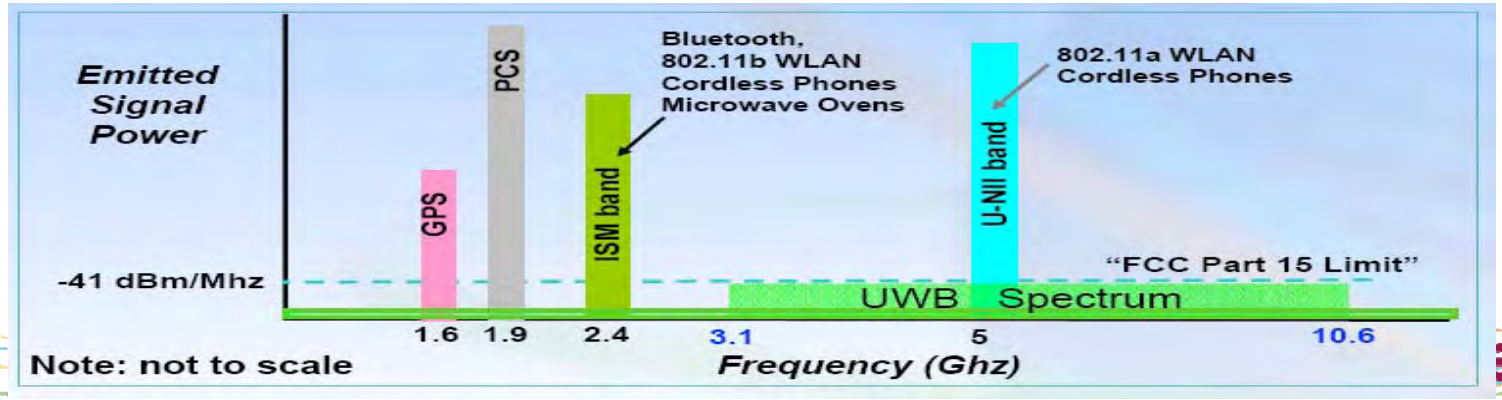
- FCC definition:
  - B/Fc > 0.20 or
  - B > 500MHz
- Why is this good?
  - Shannon…

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

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

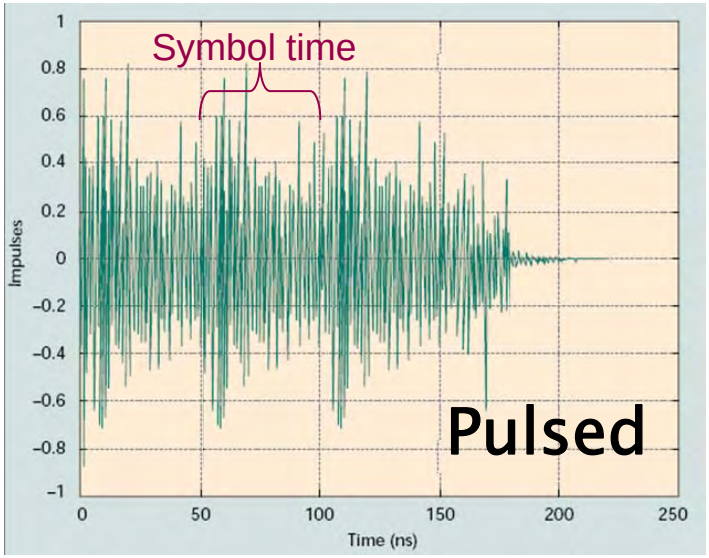


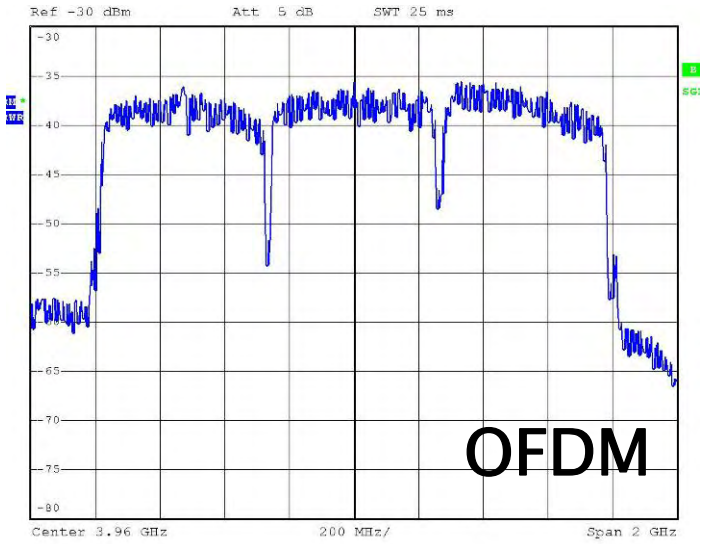
Claude Shannon



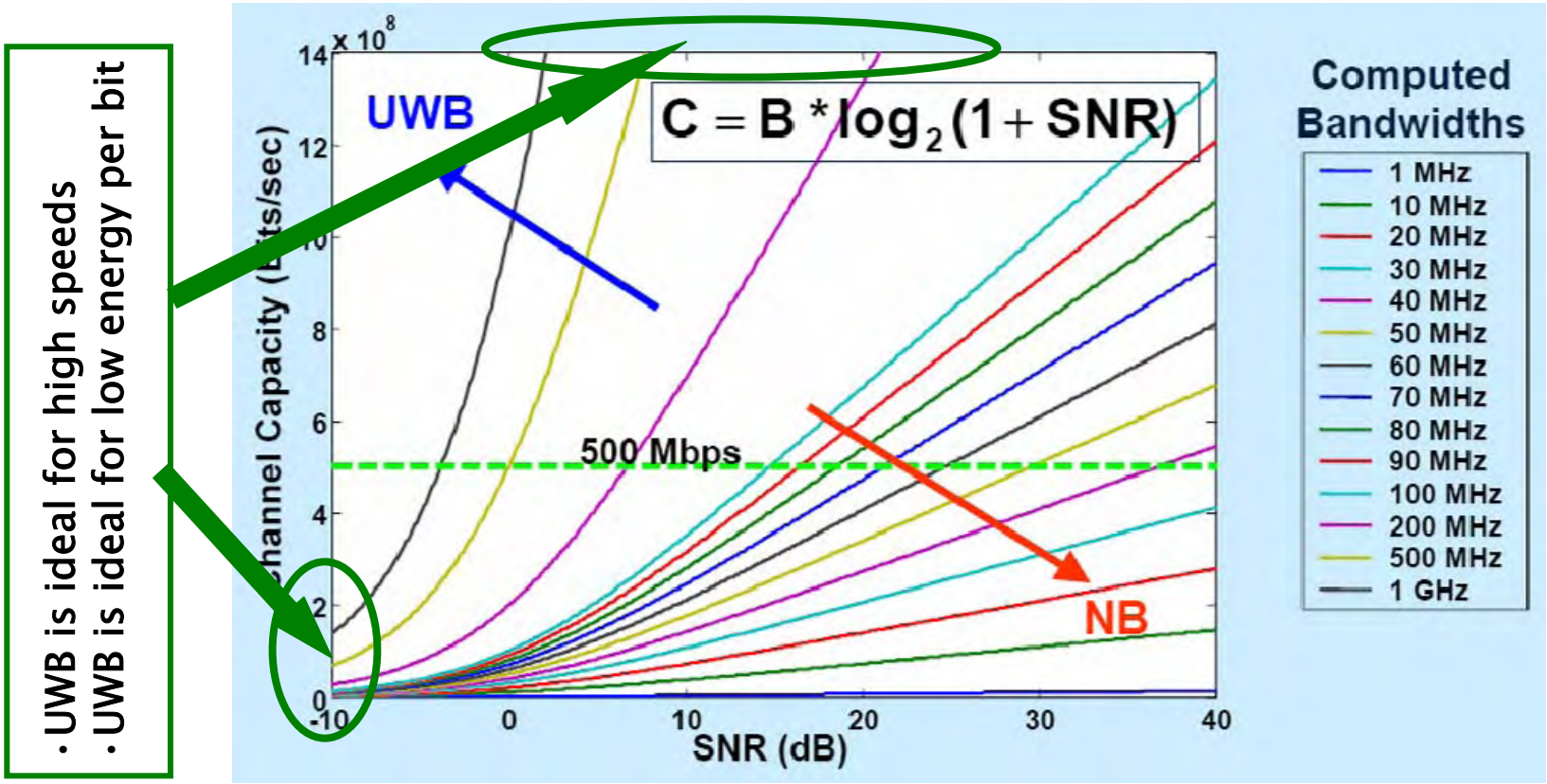
UWB Background – Pulsed vs OFDM

- 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 802.11a/g, cable modem, WiMax
  - Scales to high data rates
  - Simpler solution to multipath
  - Better spectral efficiency and lower OOB than pulsed





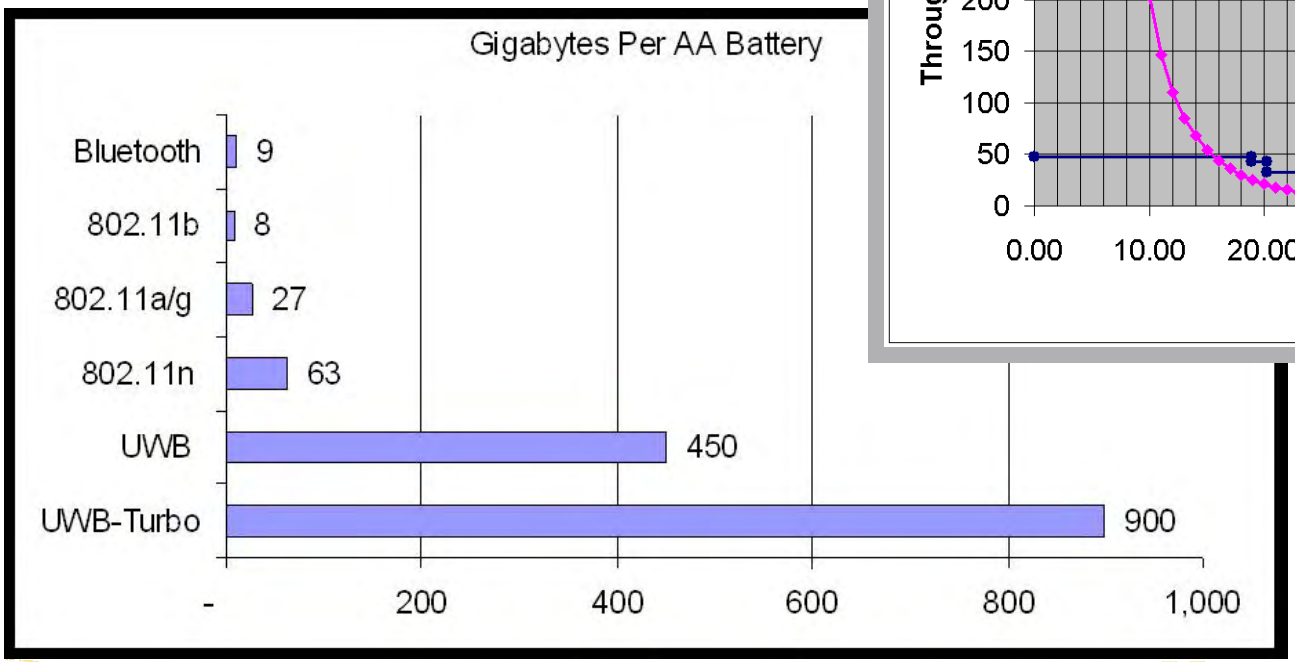
Advantages of UWB

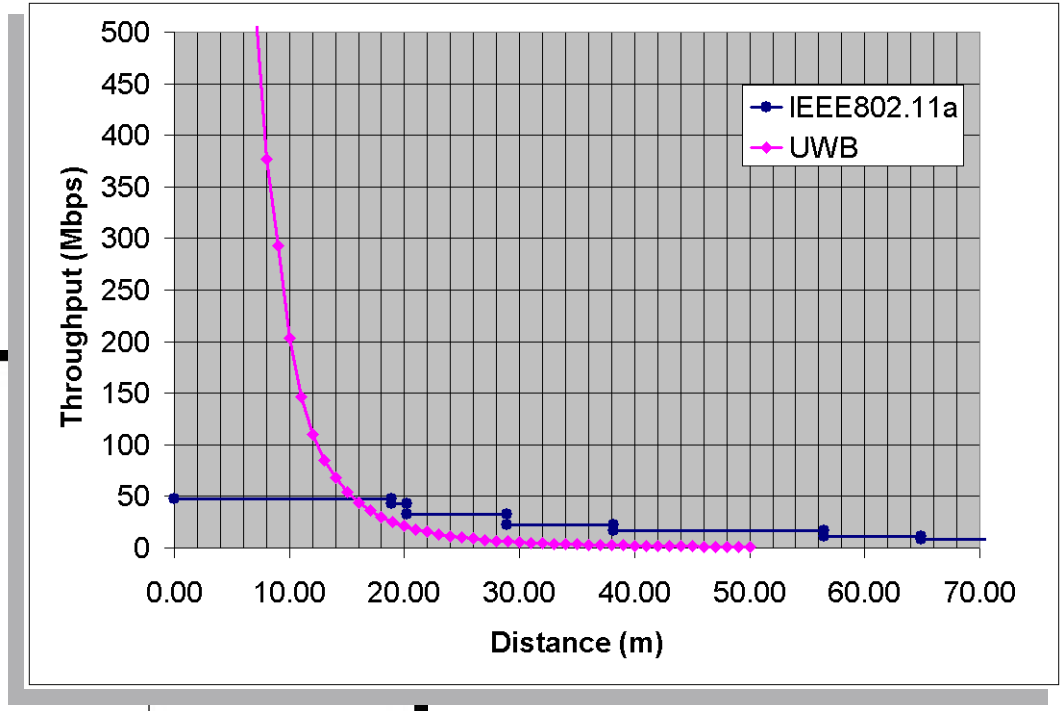


- UWB takes advantage of the "B" (bandwidth) term in Shannon's capacity equation to achieve very high speeds at low power levels
- Opens new opportunities in wireless technology

Why will UWB become successful?

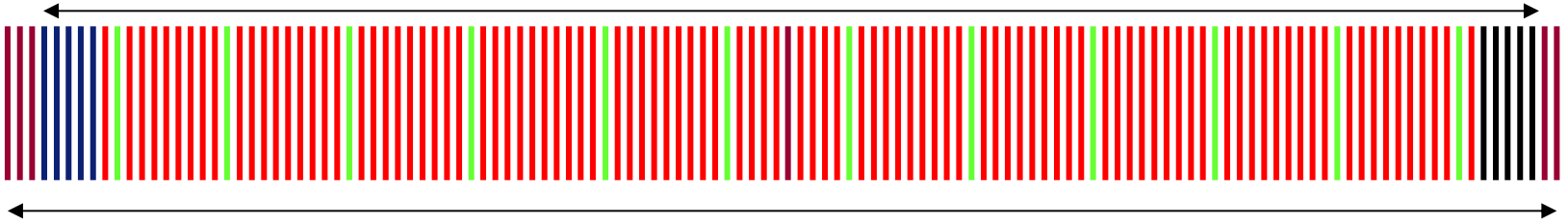
- Energy efficiency
  - >10x better than any other wireless technology
- Speed
  - Shannon says linear scaling in bandwidth beats log of 1+SNR





Multiband-OFDM UWB PHY Summary

507.35MHz



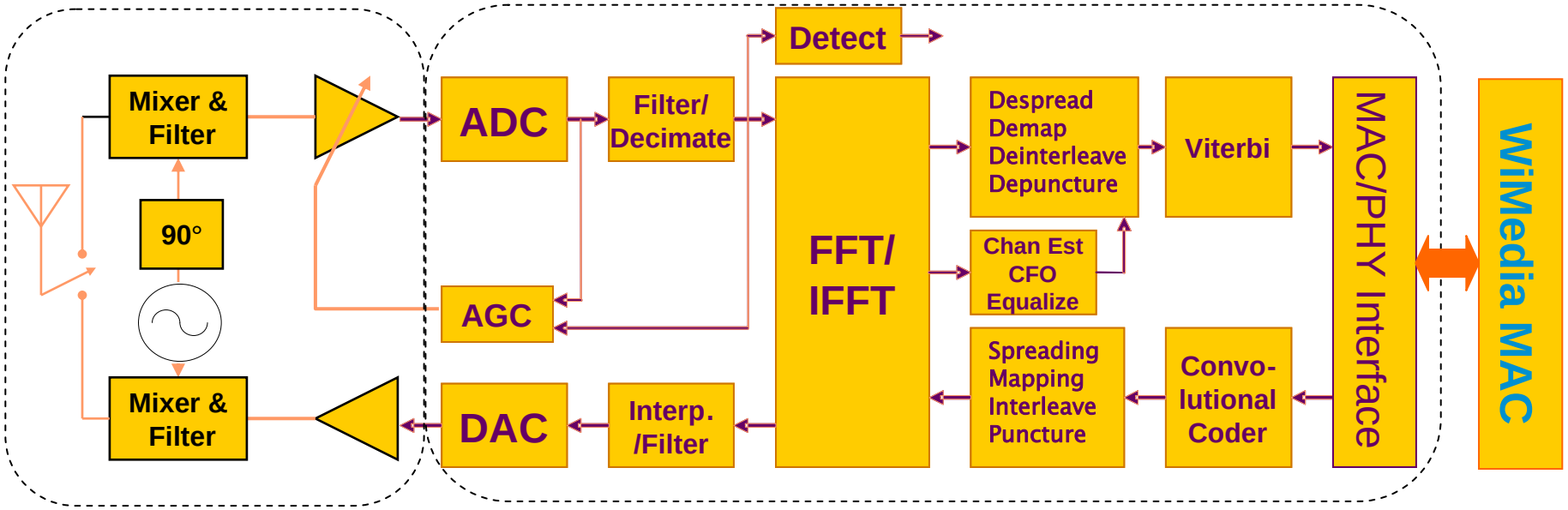
128 pt IFFT, 100 QPSK/DCM data tones, 12 pilots, 10 Guards, 6 nulls

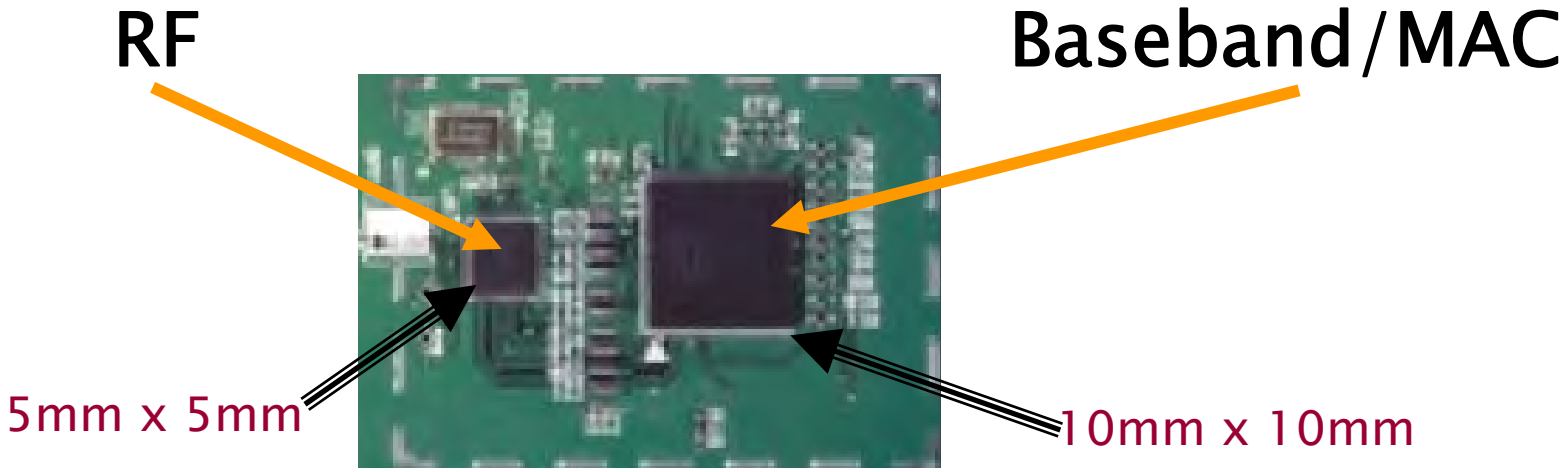
Info Data Rate	Modu-lation	Coding Rate (*R*)	2X FDS	2X TDS	Coded Bits / 6 OFDM Symbol	Info Bits / 6 OFDM Symbol
53.3 Mbps	QPSK	1/3	YES	YES	300	100
80	QPSK	1/2	YES	YES	300	150
106.7	QPSK	1/3	NO	YES	600	200
110	QPSK	11/32	NO	YES	600	206.25
160	QPSK	1/2	NO	YES	600	300
200	QPSK	5/8	NO	YES	600	375
320	DCM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

Symbol Statistics

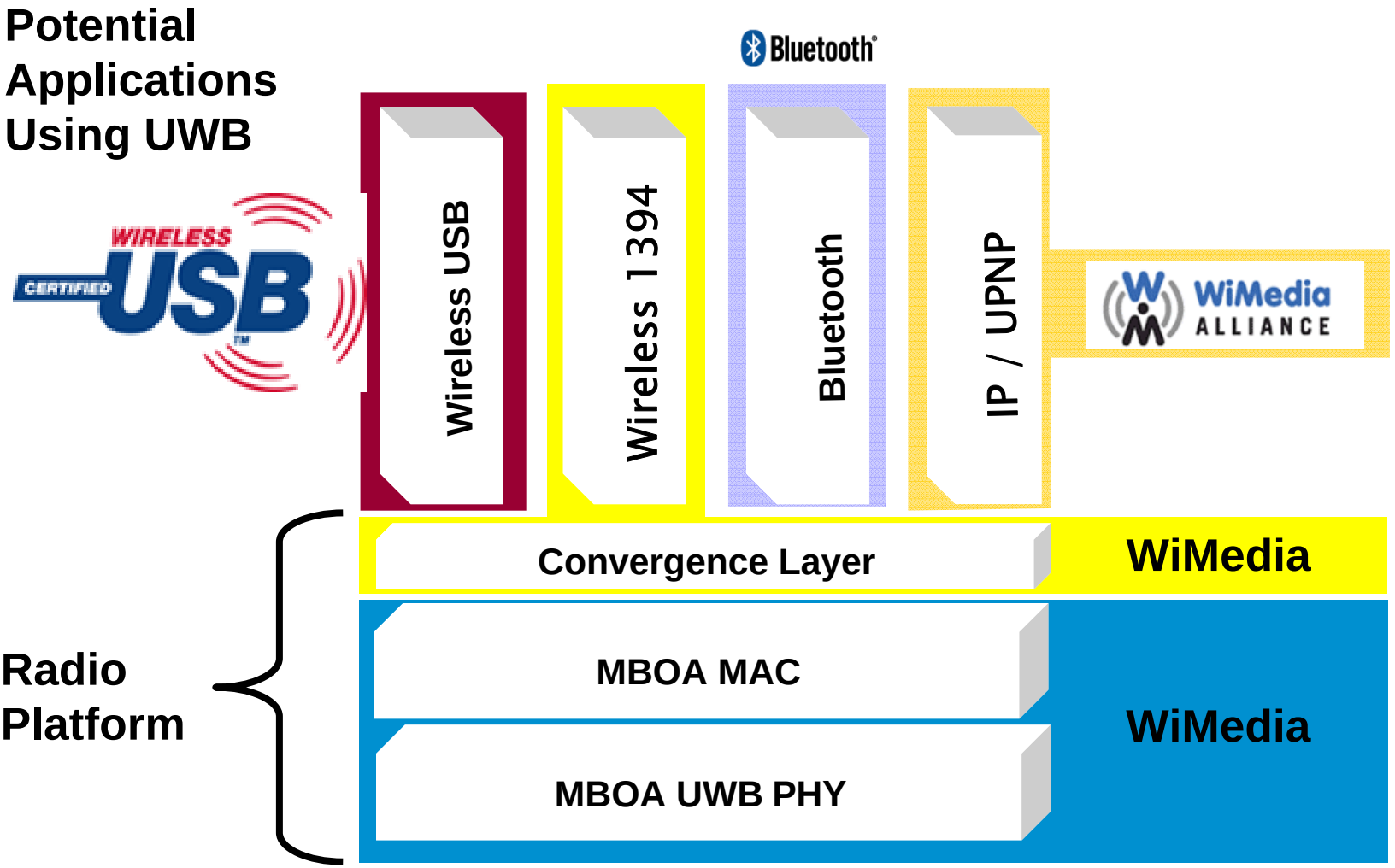
- ***T = 312.5 ns, 60.5ns ZP***
- ***N = 128 tones***
- ***Tone spacing = 4.125 MHz***
- ***Total bandwidth = 528 MHz***

The WiMedia Radio





Where WiMedia fits in the stack….



WiMedia is working with the SW industry to enable UWB deployment

TDMA MAC - interleaved protocols

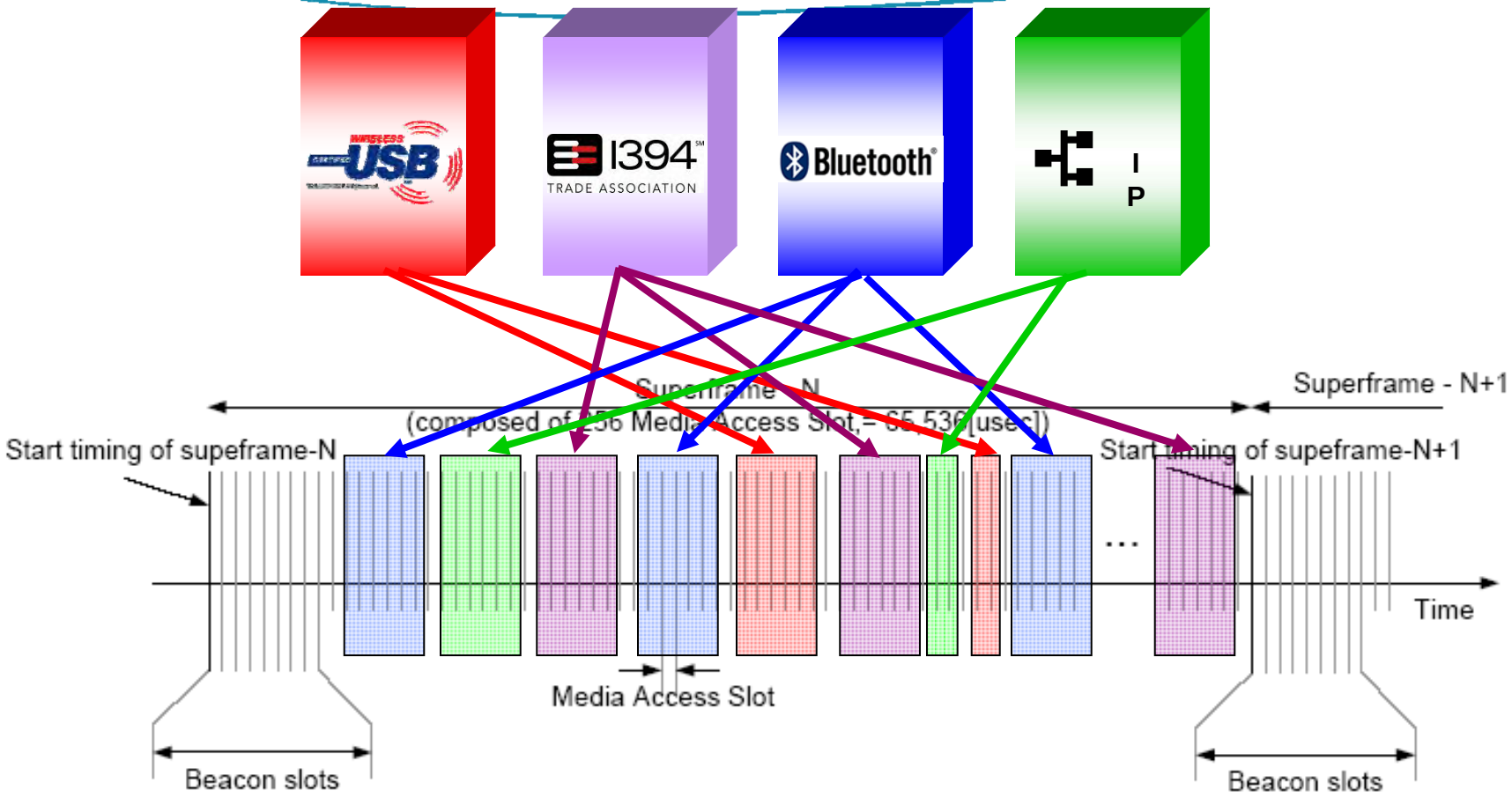


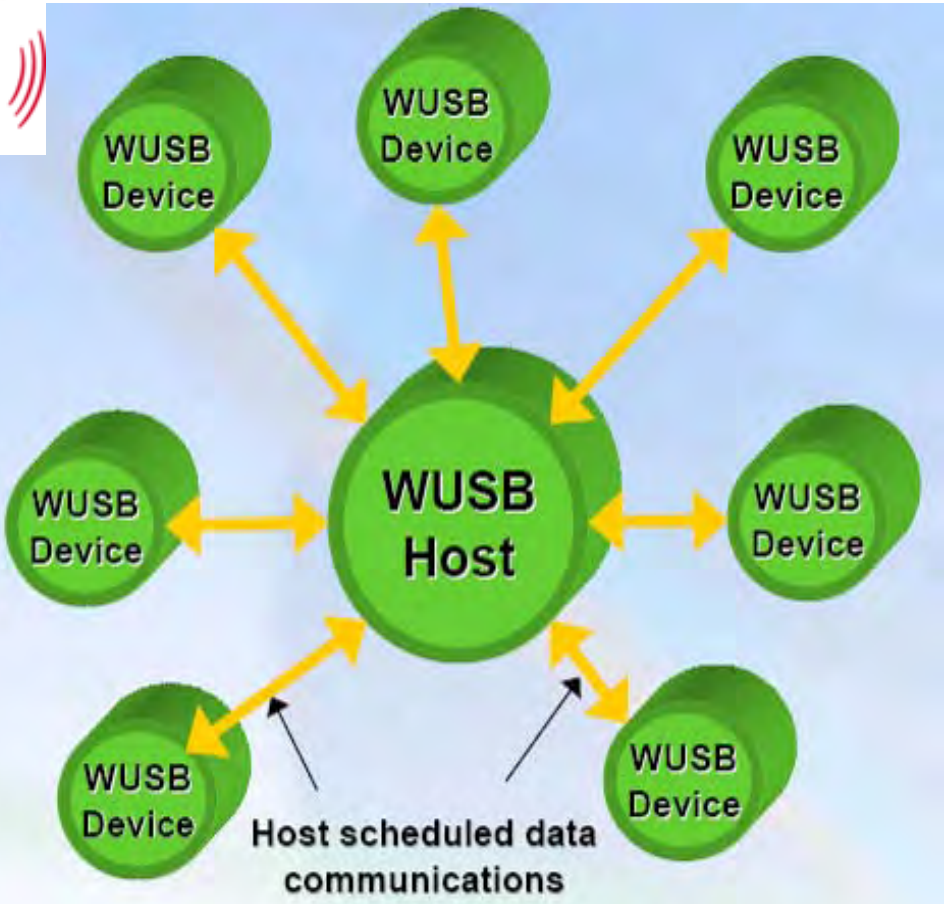
Figure 2 — MBOA MAC superframe structure

Any combination of protocols can be spread across a superframe

Wireless USB – first wave of products!

Topology

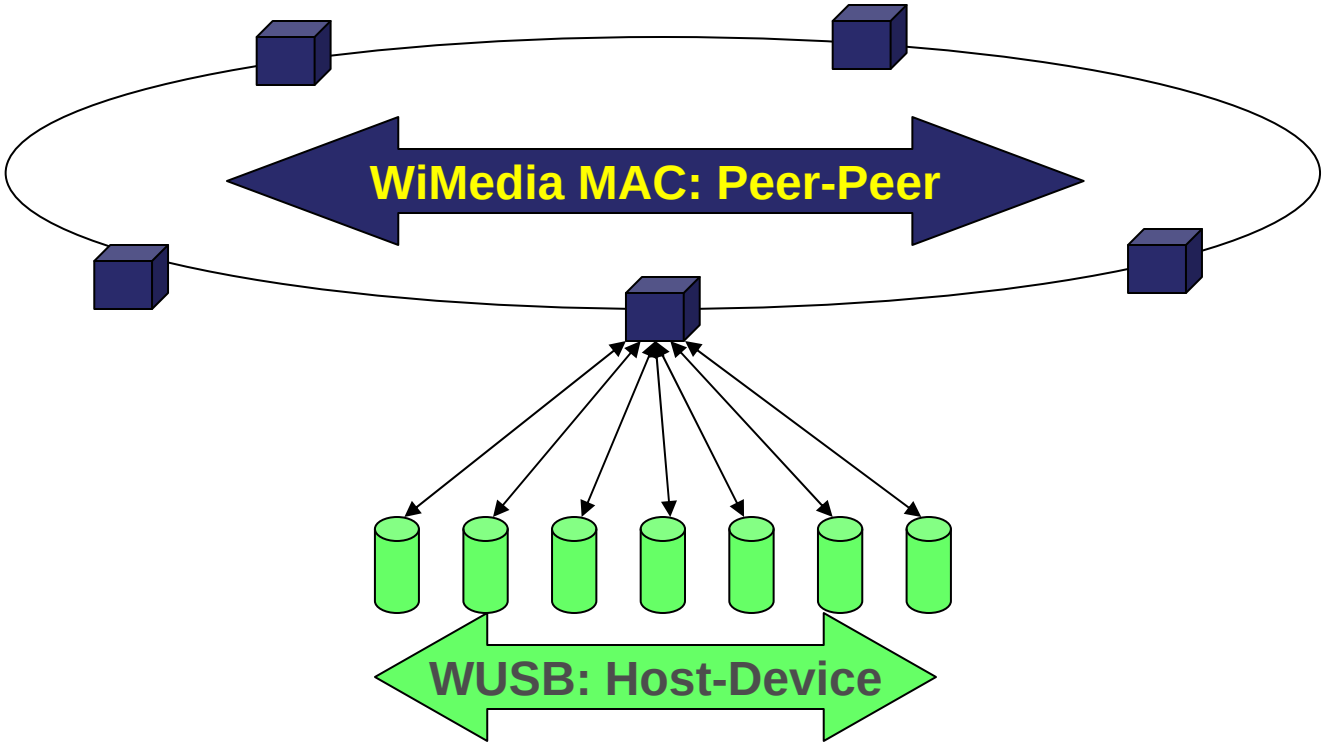
- Fundamental connection relationship is hub-and-spoke
- Connection model is a wire replacement
  - Connections are point to point between a WUSB host and a WUSB peripheral
- WUSB Cluster is a WUSB Host with one or more peripherals (up to 127)
- WUSB Clusters may co-exist within an overlapping spatial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



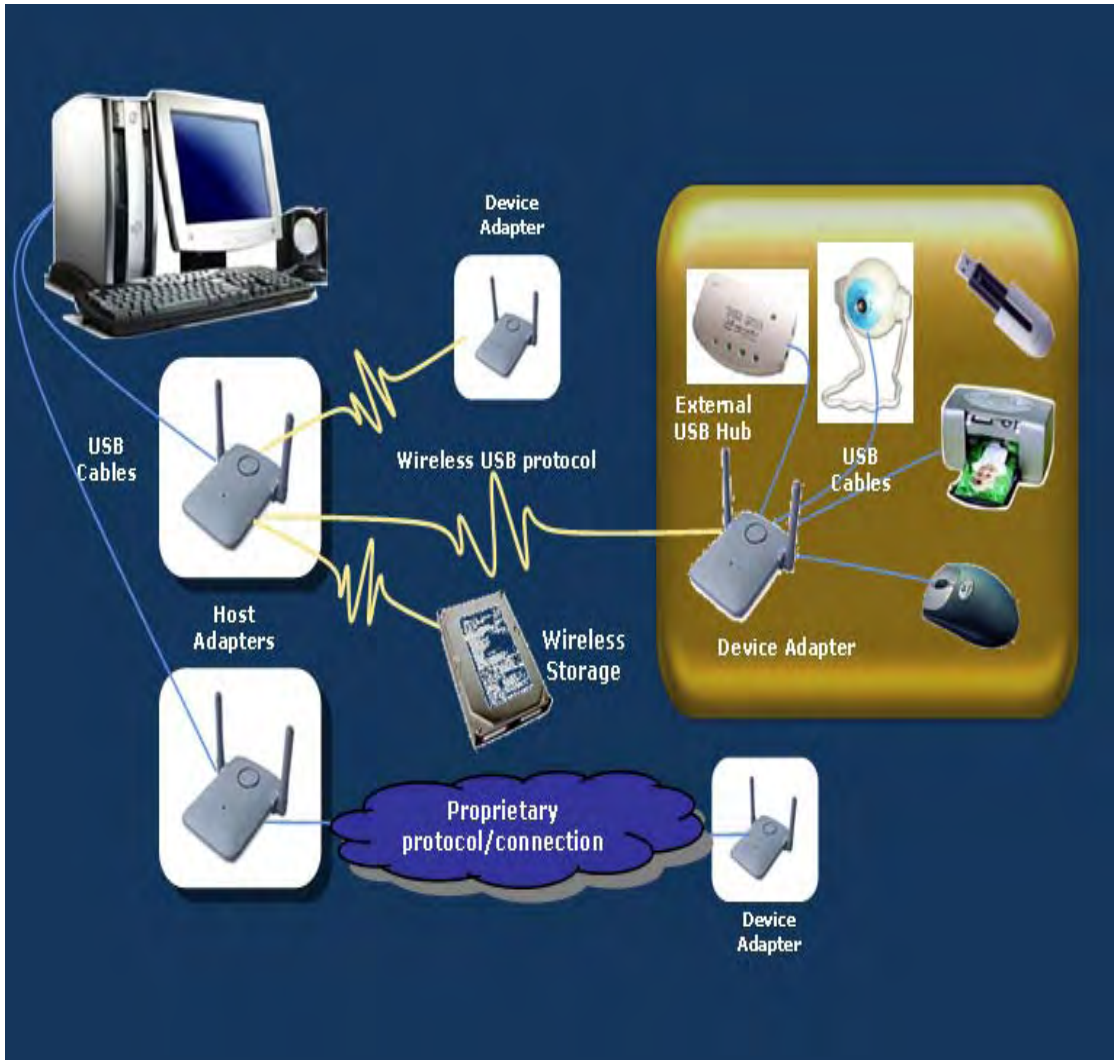
- Supports bridge to USB (wired) devices
- Dual Role Device

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

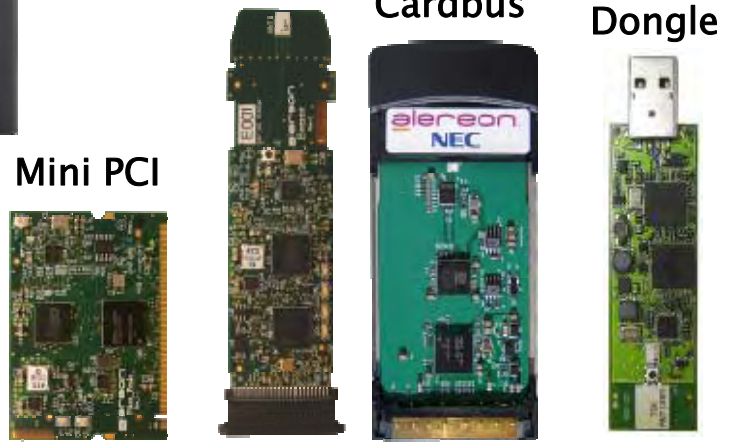
- Products are in production
  - FCC certification
  - WiMedia Certification
  - WUSB certification
- HWA/DWA products launched first
- Embedded products will be in the market later this year
- Eliminates the USB cable!

ExpressCard/34

Cardbus

Wireless USB Dongle

Mini PCI

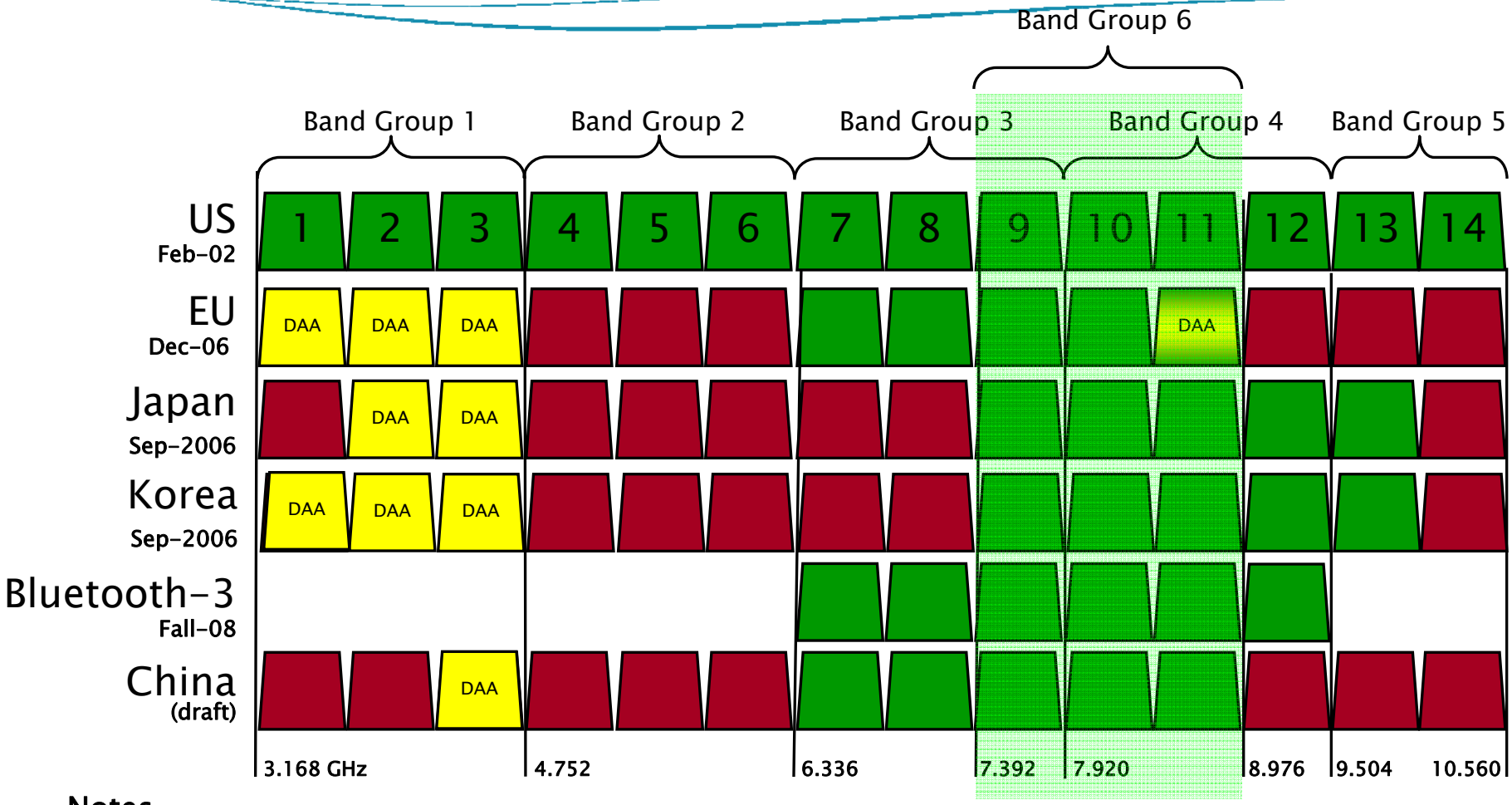


MiniCard

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

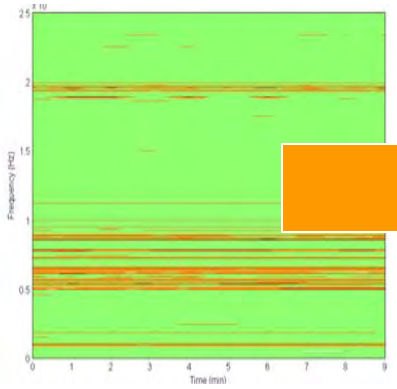


Notes

- 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 B11will 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?

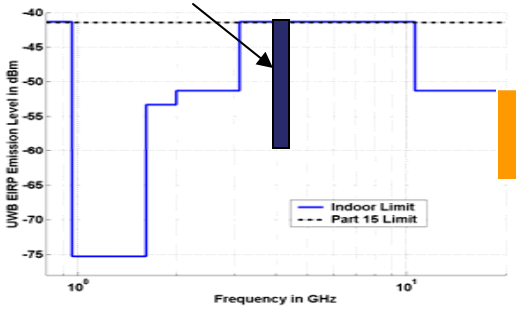
- FCC Chairman Powell: "Recent advances in smart radio technologies have the potential to provide more innovative, flexible, and comprehensive use of spectrum while at the same time minimizing the risk of harmful interference. On a real-time basis, smart radios determine their location or environment,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

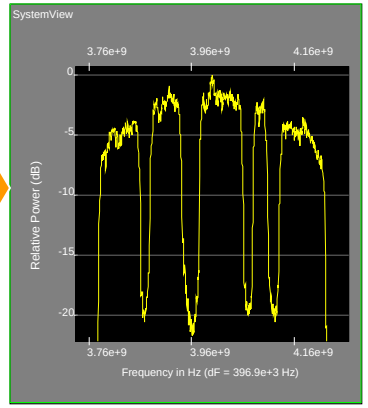


>99% of spectrum between 2.5 and 5GHz unused at any instant

Policy Based Cognitive Radio
- Measures local interference
- Observes local propagation
- Knows application requiremen
- Knows local regulatory policy
- >> Can Adjust Power, Spectrum, BW, and Throughput

"Notch" dictated by local regulations





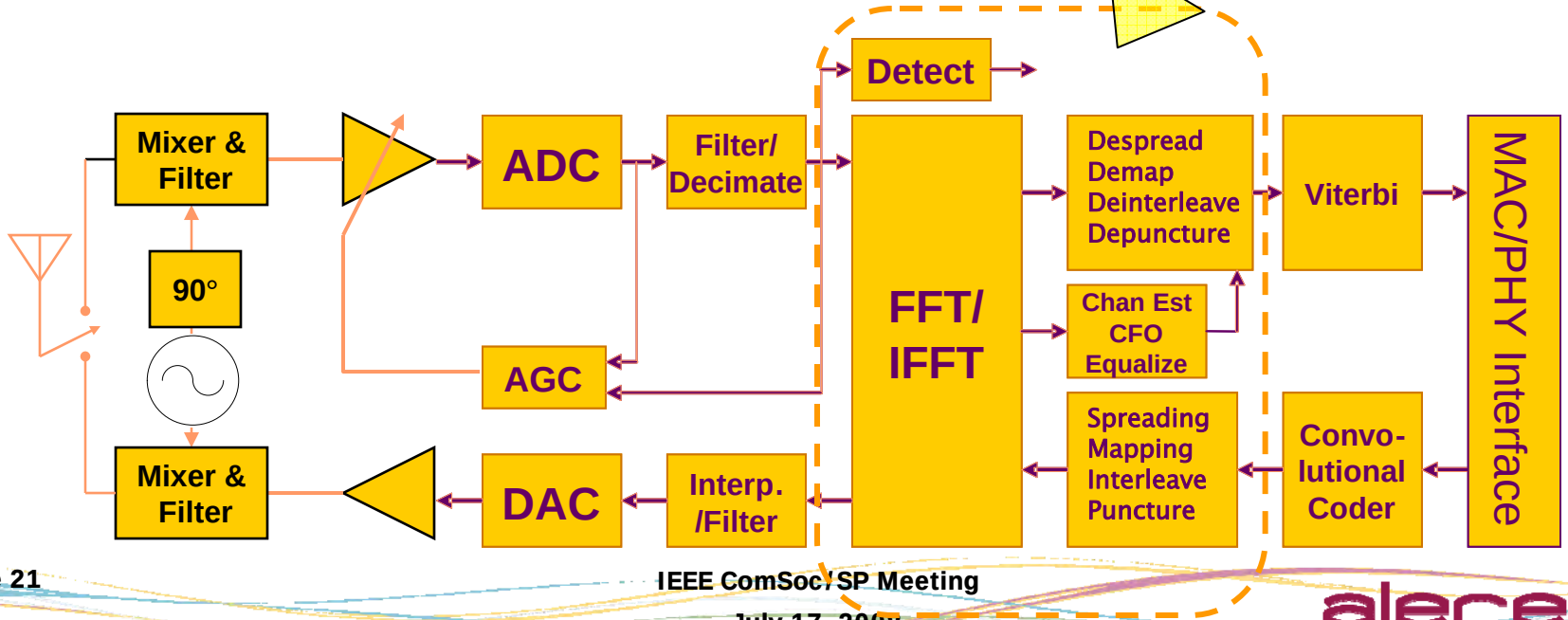
"Sculpted" spectrum

DAA is a form of Cognitive Radio

How does MB-OFDM implement DAA?

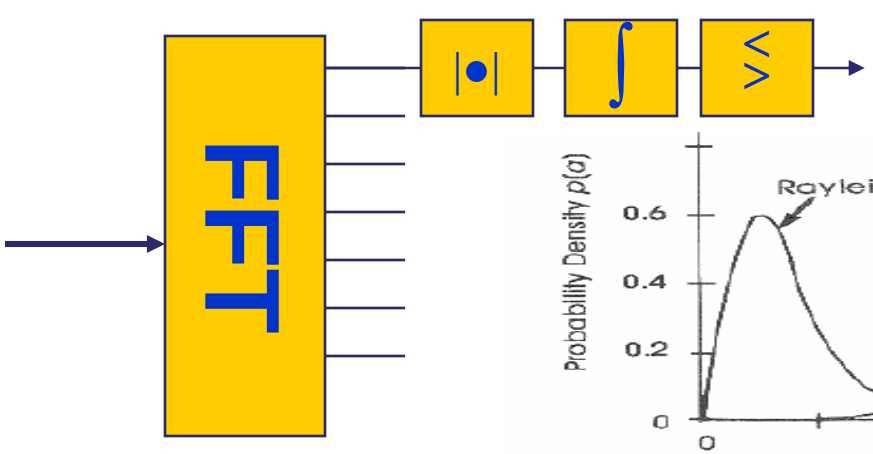
- Detect: Channelized radiometer
  - 128 channel FFT inherent in the design
  - Integrate spectra to achieve desired P_D
- Avoid: Bandstop filter (frequency domain)
  - 128 point IFFT
  - Additional signal processing techniques can increase notch depth, subject to RF linearity

Alereon's CogniPHY™ Technology

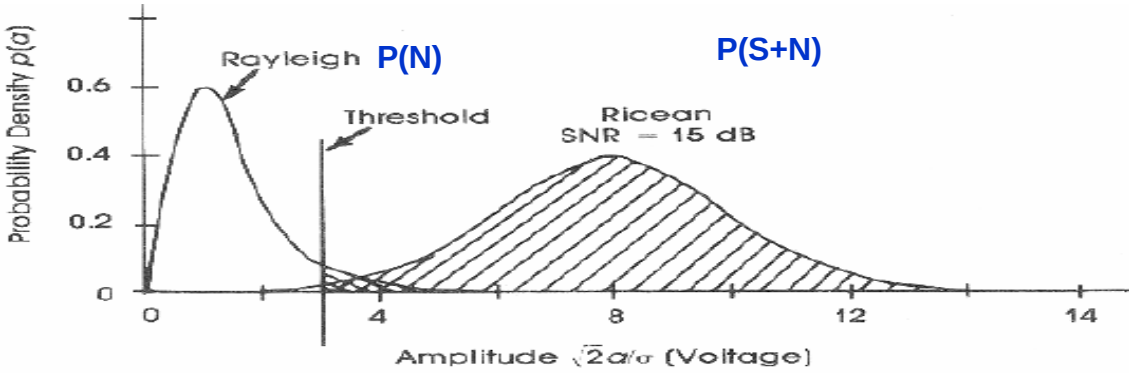


Detection

- 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



Per tone: 4.125MHz resolution,
~ -101dBm noise floor



DAA in a WiMedia TDMA MAC

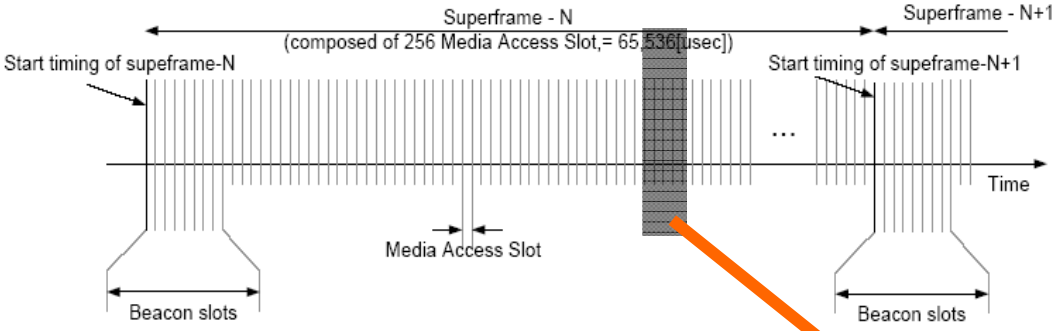
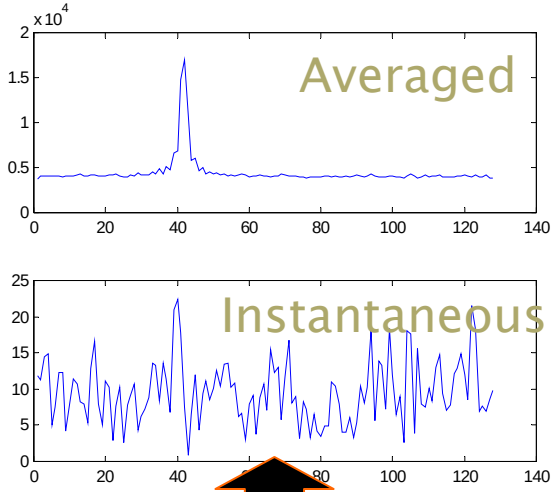
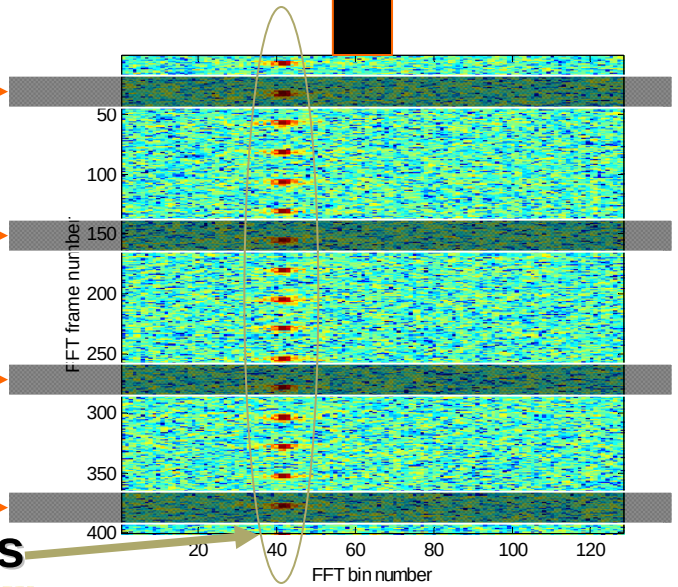


Figure 2 — MBOA MAC superframe structure



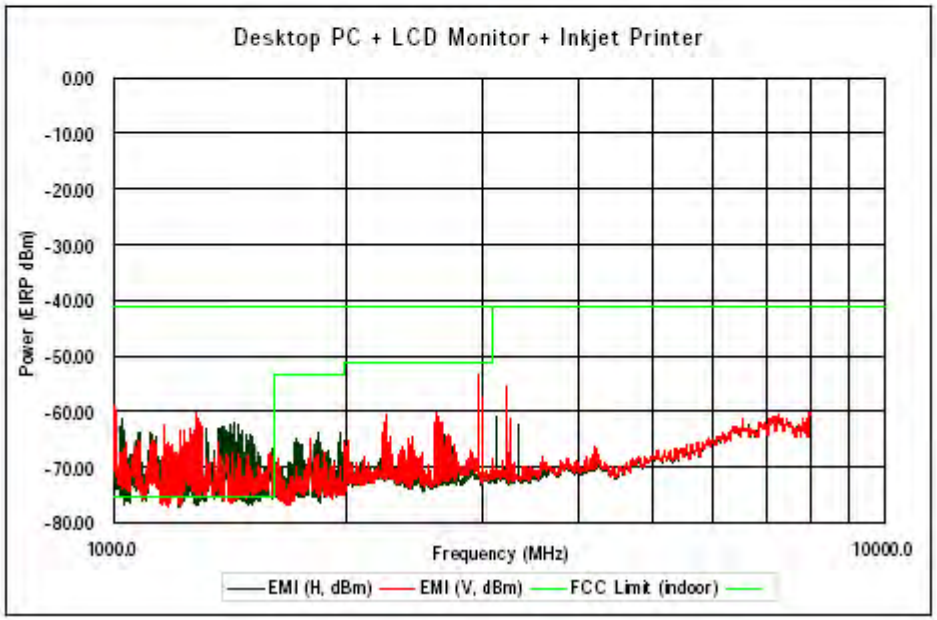
- WiMedia MAC is TDMA
- Slots can be reserved for spectrum sampling ("silent periods")
  - All network Tx shut off
- Larger number of slots increases probability of detecting beacon
  - But reduces UWB data throughput
- Work continues to explore cyclostationary signals



WiMax beacons

DAA's Problem: Acceptable P_{FA}

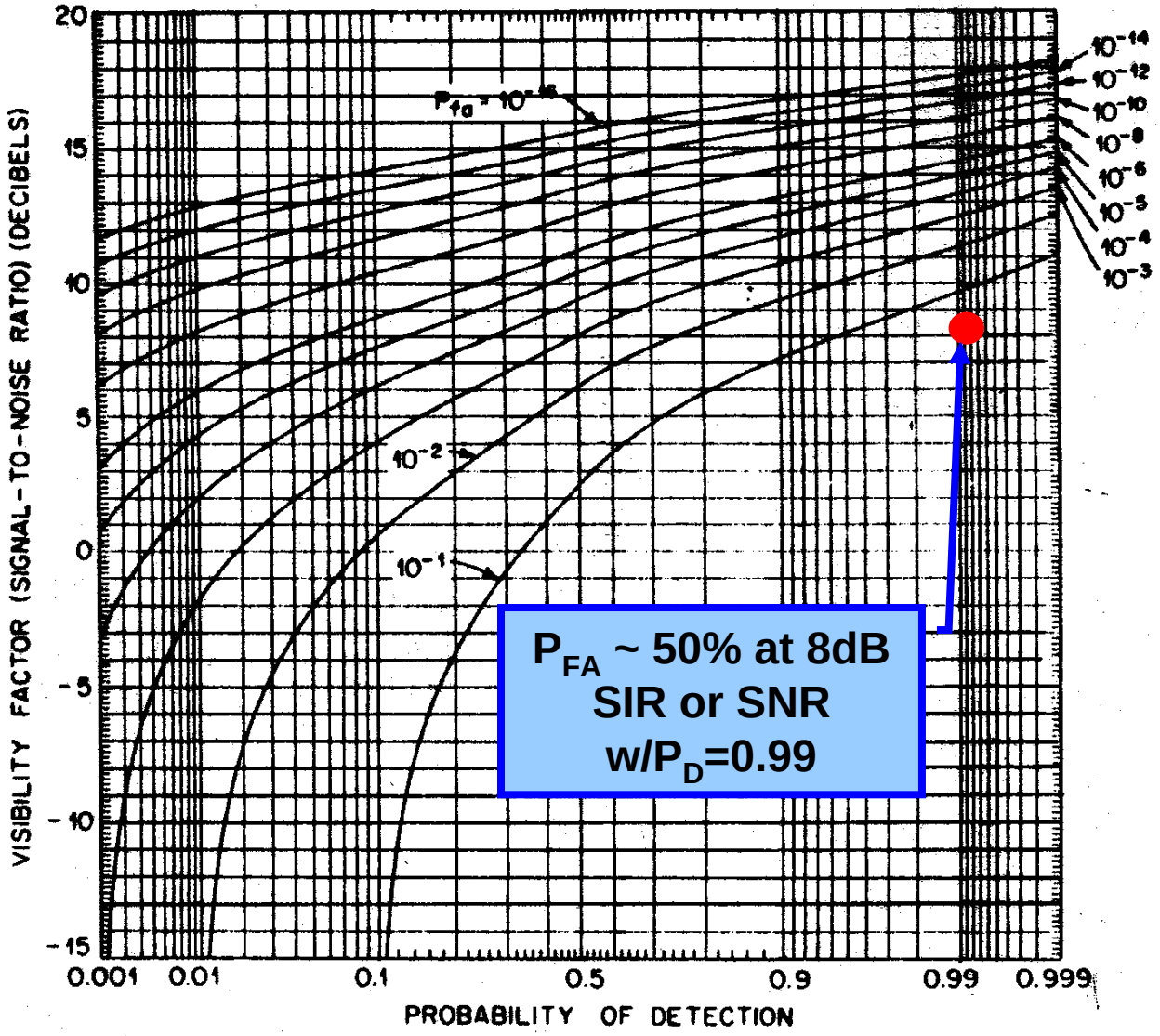
Desktop PC with flat panel display and inkjet printer attached.



Source: TDK RF Systems

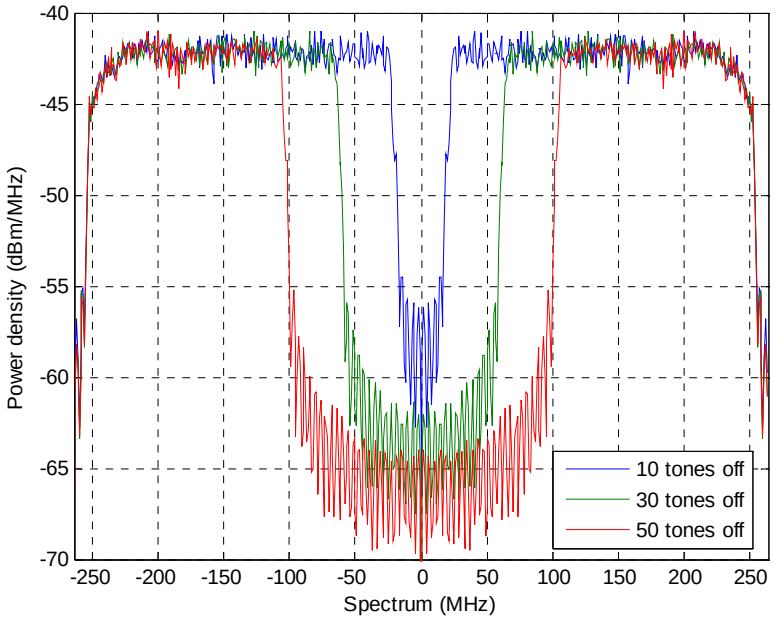
- Ambient noise levels around typical PC are high
- Radiometer detection may not be able to successfully yield acceptable P_D without unacceptable P_{FA}
  - Radiometer is not "smart" enough to discriminate WiMax from spurs/noise
- More exotic signal processing will be required
- Use of upper bands may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

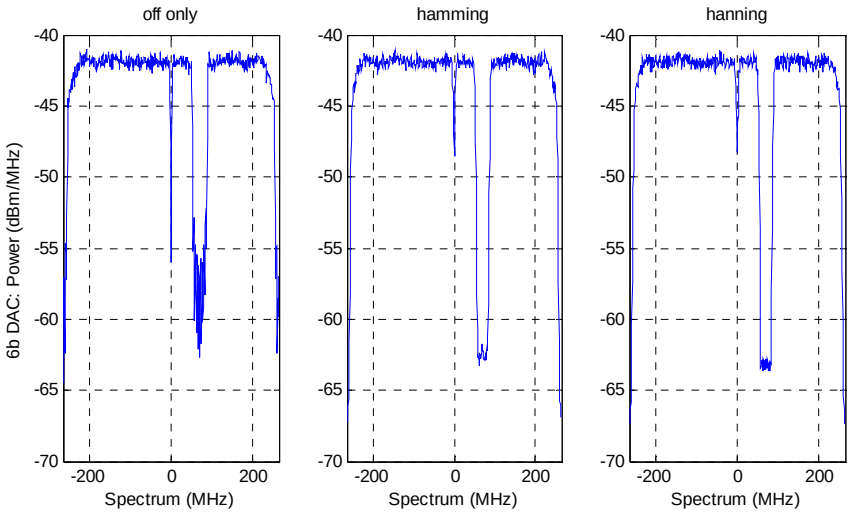
Radiometer detection – P_D vs P_{FA}



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

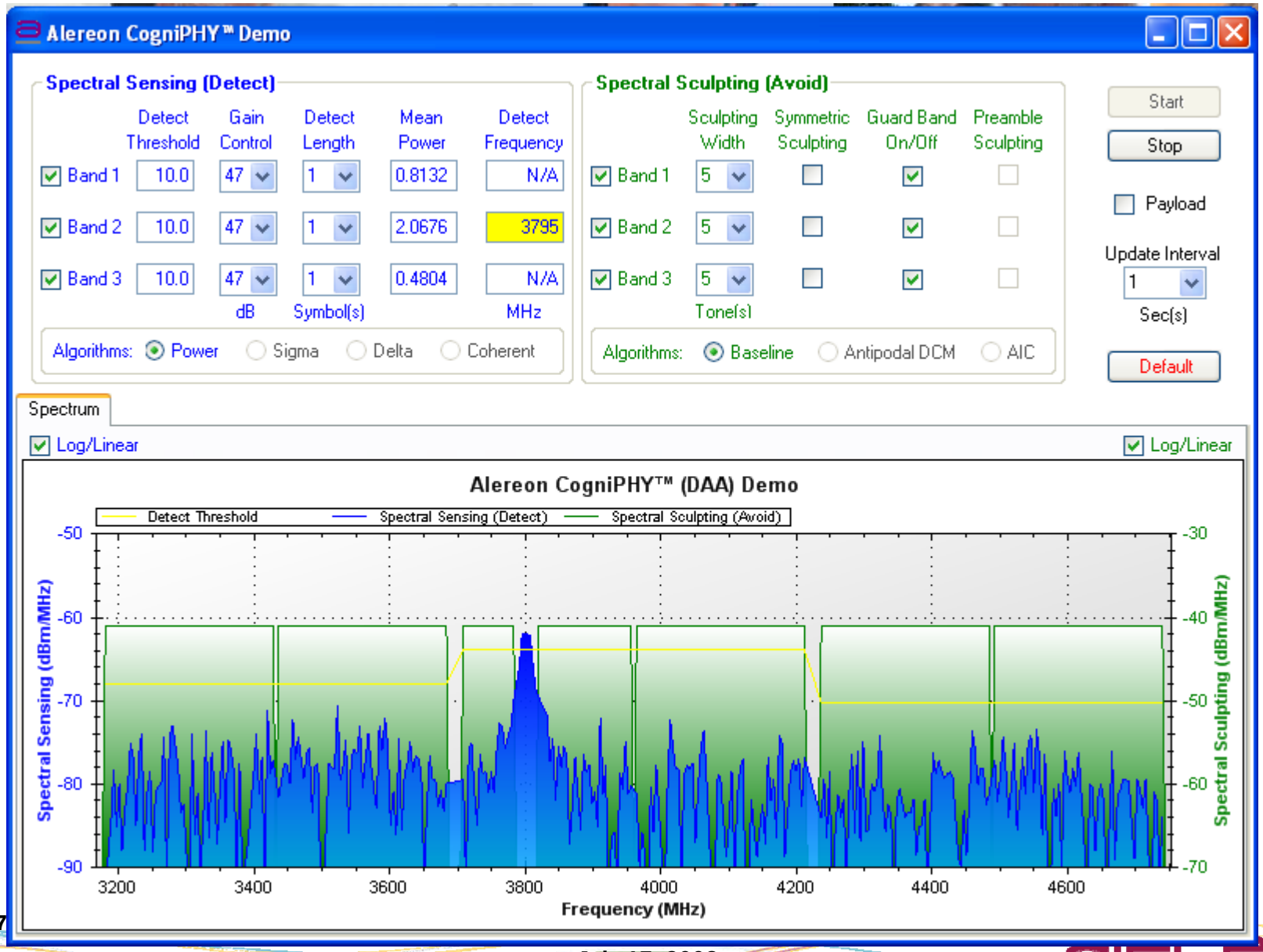
Spectral Sculpting Techniques



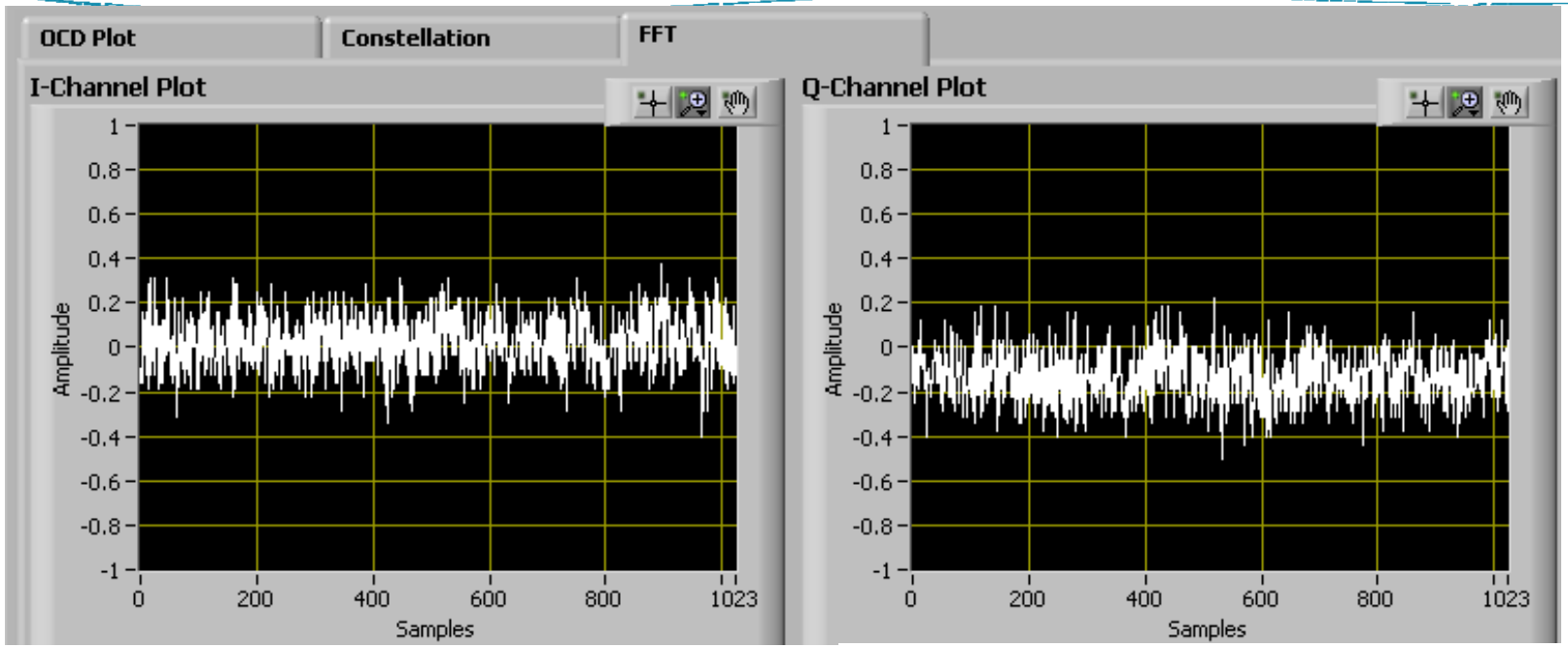


- Notches created by applying weight vectors to IFFT
- Depth a function of:
  - DAC bit resolution
  - RF EVM
  - Sin(x)/x limits (with weighting)

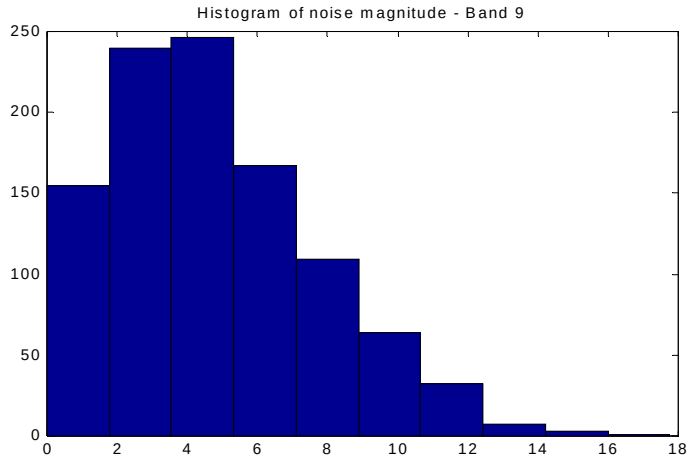
Alereon's CogniPHY™ Technology (Band Grp 1)

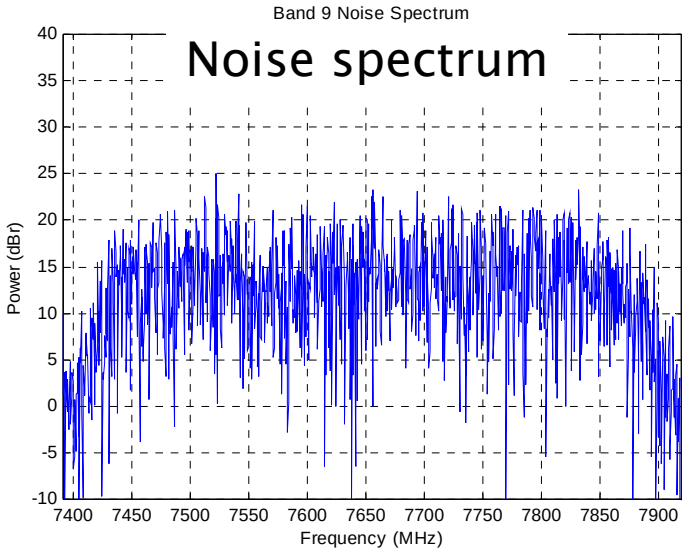


More data from CogniPHY™ (Band 9)



Histogram of FFT magnitude



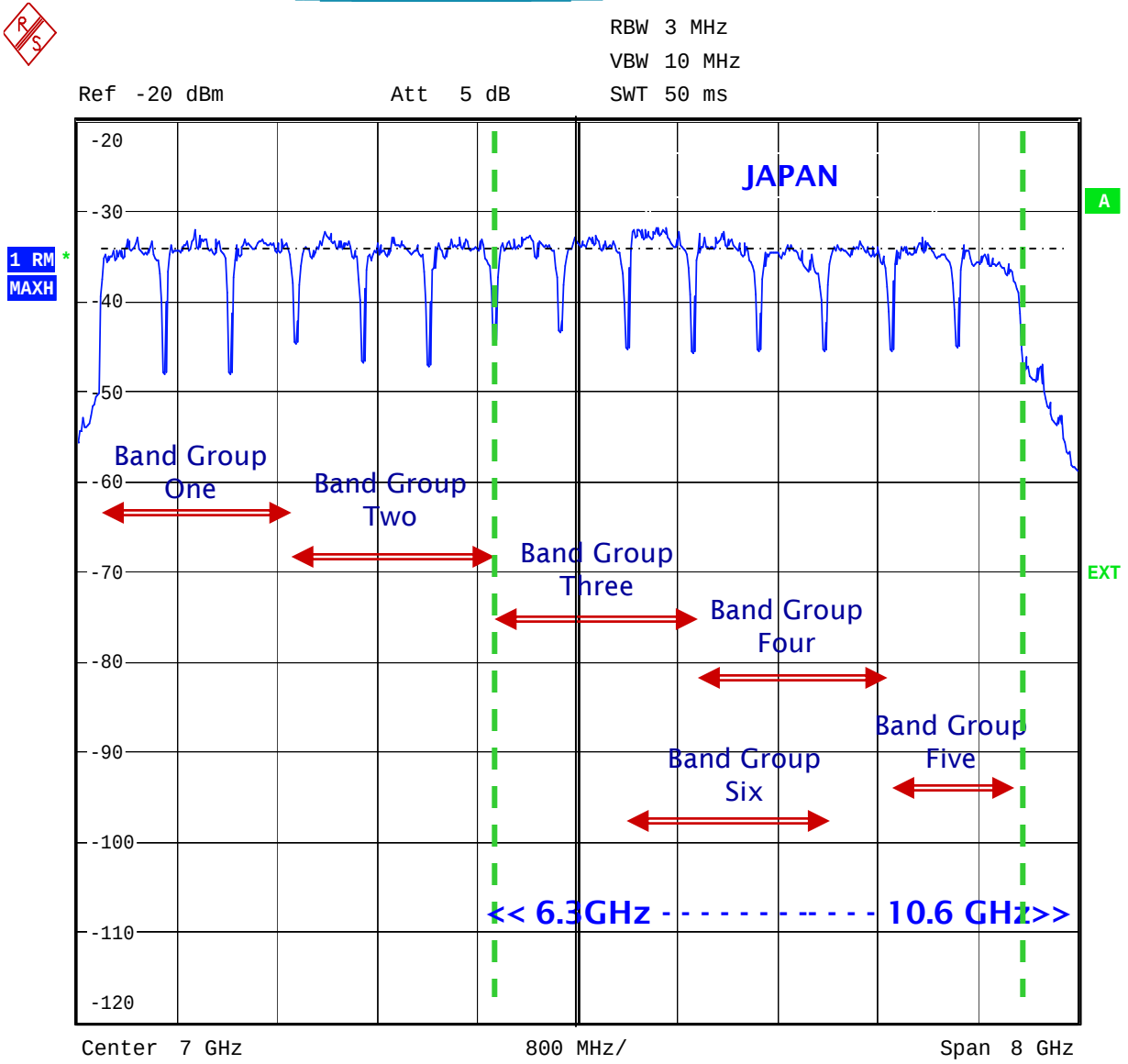


Going forward: C-Band+DAA vs X-Band

- 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, P1dB)
  - CMOS very difficult
- Baseband
  - Similar complexity
  - +/-20ppm 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