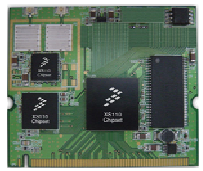
Digital Consumer Application of Ultra-wideband

DS-UWB Highlights

- Direct Sequence (DS-UWB) is the best technology for high rate WPAN
  - **Only current solution that easily scales to data rates well above 1 Gbps**
- Entering mass production of XtremeSpectrum™ chipset
  - **110 Mbps today, +500 Mbps 2005, +1 Gbps 2006**
  - **MiniPCI became available in September from top tier ODM's**
- Freescale XtremeSpectrum™ UWB received FCC approval!
  - **Delivering high performance with FCC compliant emissions**
- 1394 TA ratified PAL for DS-UWB's 802.15.3 MAC
  - **802.15.3 protocol adaptation layer to 1394 already ratified by 1394 TA**
- UWB Forum at 80 members
  - **Interoperability testing of DS-UWB solutions starting now**
- China UWB Forum launched 9/24 now at 40 members
- Freescale position on IEEE standards for UWB
  - **Time for compromise—ratify both proposals—let the market decide**
- FSL secured top tier product manufacturing partners for XS110
  - **Number 1 worldwide WLAN NIC manufacturer**
  - **Number 2 worldwide WLAN NIC manufacturer**
  - **Number 1 worldwide Projector and Display manufacturer**
  - **Leading manufacturers media PC's, adapters and displays**
- Most leading CE OEM's are engaged with Freescale DS-UWB



1394 TRADE ASSOCIATION

UWB FORUM

中国超宽带无线技术论坛 CUF China UWB Forum

DS-UWB Forum Is Growing Rapidly
Over 80 Companies Have Joined

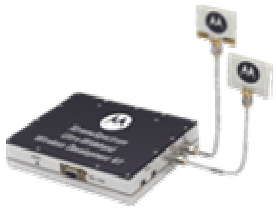
How Will UWB Products Rollout?

- The first round of products is modules based and has four stages
  - **Silicon, Module, System, Branding/Distribution**
- Silicon—complete connectivity solution of MAC, PHY, RF & SW drivers
  - **Enabling building block for consumer end products**
  - **Roadmap launched with completion of XS110**
  - **Expands & scales with XS220, XS500, XS1000 and derivatives**
- Modules—current stage
  - **Next building block for consumer end products**
  - **Roadmap launched with MiniPCI modules**
  - **Expands and scales with CardBus, 1394, USB, SDIO/CF, PCI Express**
- System ODM and OEM
  - **Completed end user products based on DS-UWB modules**
  - **First products: Flat panel displays, projectors, set top & PVR, DVD, media PC's, PC NIC's, Digital media adapters**
  - **Next products: Digital video cameras, digital still cameras/consumer camera phones, music players, media players, Smartphones**
- Branding/Distribution—starting 1Q05
  - **Branding and distribution of ODM white label products**

DS-UWB Products Timeline

2 HD Streams Demonstrated at CES

January 2003



XS110 CES Demos 3 HD Streams

January 2004

June 2004

XS110 Ships PCI to Alpha Customers

August 2004

FCC Certifies XS110

MiniPCI and 1394 Modules Available

Sept 2004

Nov 2004

Cardbus USB 2.0

Jan 2005

SDIO

Branded Consumer Mass Market Products 1Q2005

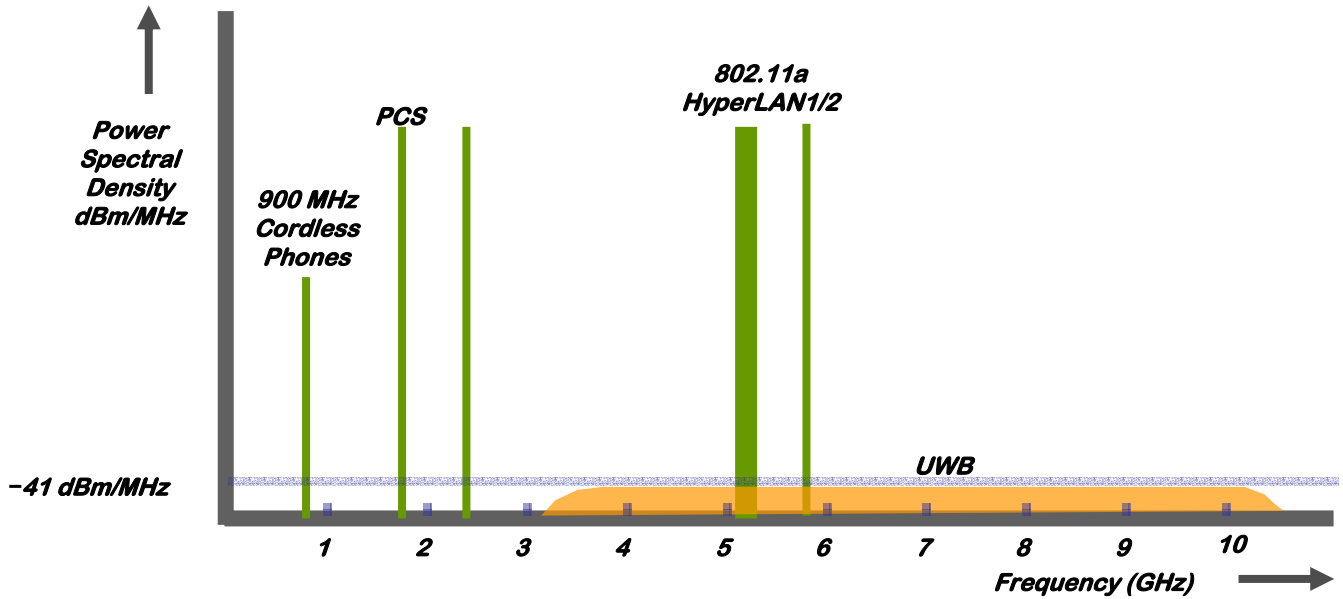
OEM System Designs Finalized

3rd Generation XS220 Silicon

March 2005

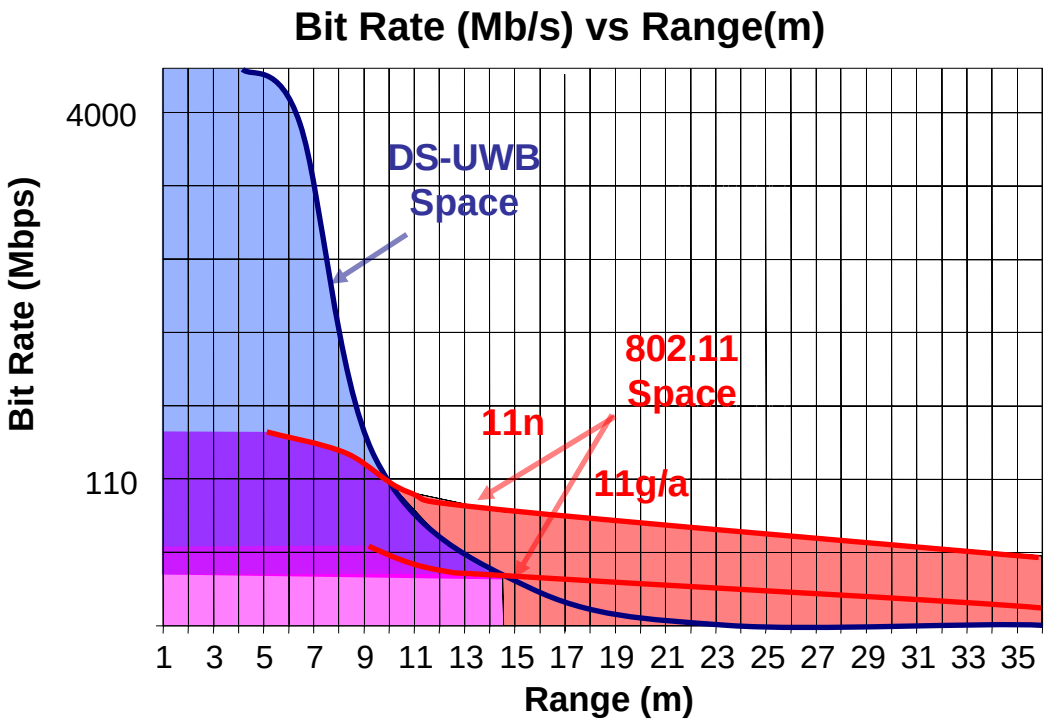
Launched by Motorola freescale semiconductor

What Is Ultra-Wideband?



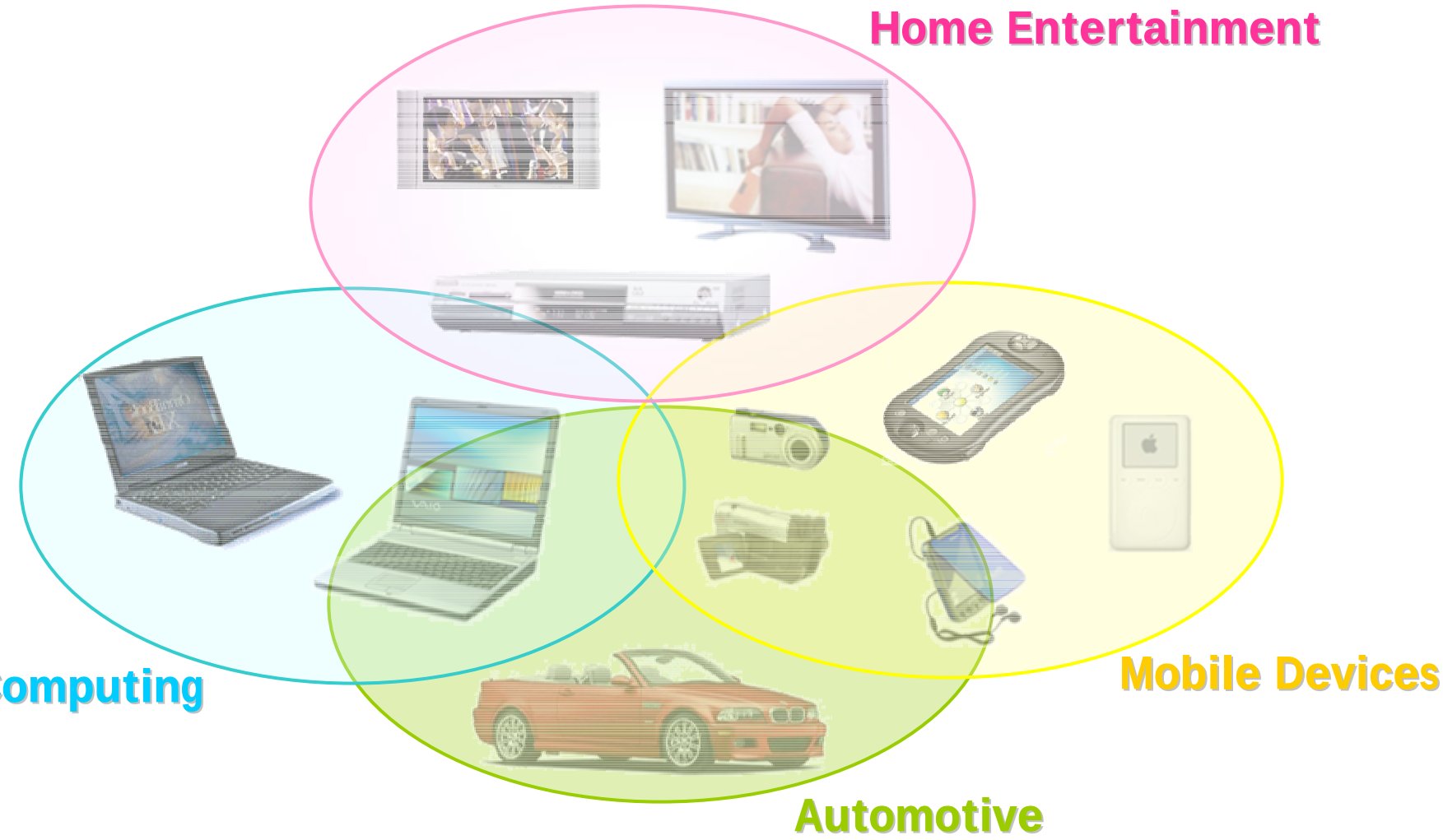
- Transmit power gives range and Bandwidth gives speed
- Traditional narrowband optimized for long range & low rates
- UWB is optimized for short range & high data rates
- Potential for best speed/power for short range applications
  - **Captured by DS-UWB**

Where Does UWB Fit Among Other Wireless?



- Wireless like 802.11 delivers longer range unlicensed radio performance
- Only UWB has the potential to deliver Gbps at short range
  - **Unique among wireless**
  - **Captured by DS-UWB**

Digital Consumer Application of UWB



Launched by Motorola
freescale semiconductor

Entertainment Applications

- Connect between sources and displays
  - **Drivers are wire elimination for install and freedom of component placement**
- Requirements
  - **Bandwidth**
    - **Each MPEG2 HD Stream 20-29 Mbps**
    - **Two full rate streams required for Picture-in-Picture (PIP)**
    - **Handheld can be used for PIP viewing or channel surfing Standard Definition (SD) stream**
  - **Range**
    - **Media center to display or handheld**
    - **Anywhere in the room (<10m)**
  - **QoS with low latency**
    - **Channel change, typing, gamers**
- Available Now—XtremeSpectrum™
  - **Being applied to both SD and HD**
  - **Good range performance**
  - **Much lower compression for better picture**
  - **Very low latency for good control**

Content Transfer for Mobile Devices

- Applications
  - **Smartphone/PDA, MP3, DSC**
  - **Media Player, Storage, display**
- Requirements
  - **Mobile device storage sizes**
    - **Flash 5, 32, 512, 2048 … MB**
    - **HD 4, …, 60+ GB**
  - **Range is near device (< 2m)**
  - **User requires transfer time < 10 sec**

Low Power Use Cases

Images from camera to storage/network

MP3 titles to music player

Low Power & High Data Rate Use

MPEG4 movie (512 MB) to player

Mount portable HD

Exchange your music & data

Print from handheld

Content Streaming for Mobile Devices

- Applications
  - **Digital video camcorder (DVC)**
  - **Smartphone/PDS, Media player**
- Requirements
  - **Range is in view of display (< 5m)**
  - **DV Format 30 Mbps with QoS**
  - **MPEG 2 at 12-20Mbps**
  - **Power budget < 500 mW**

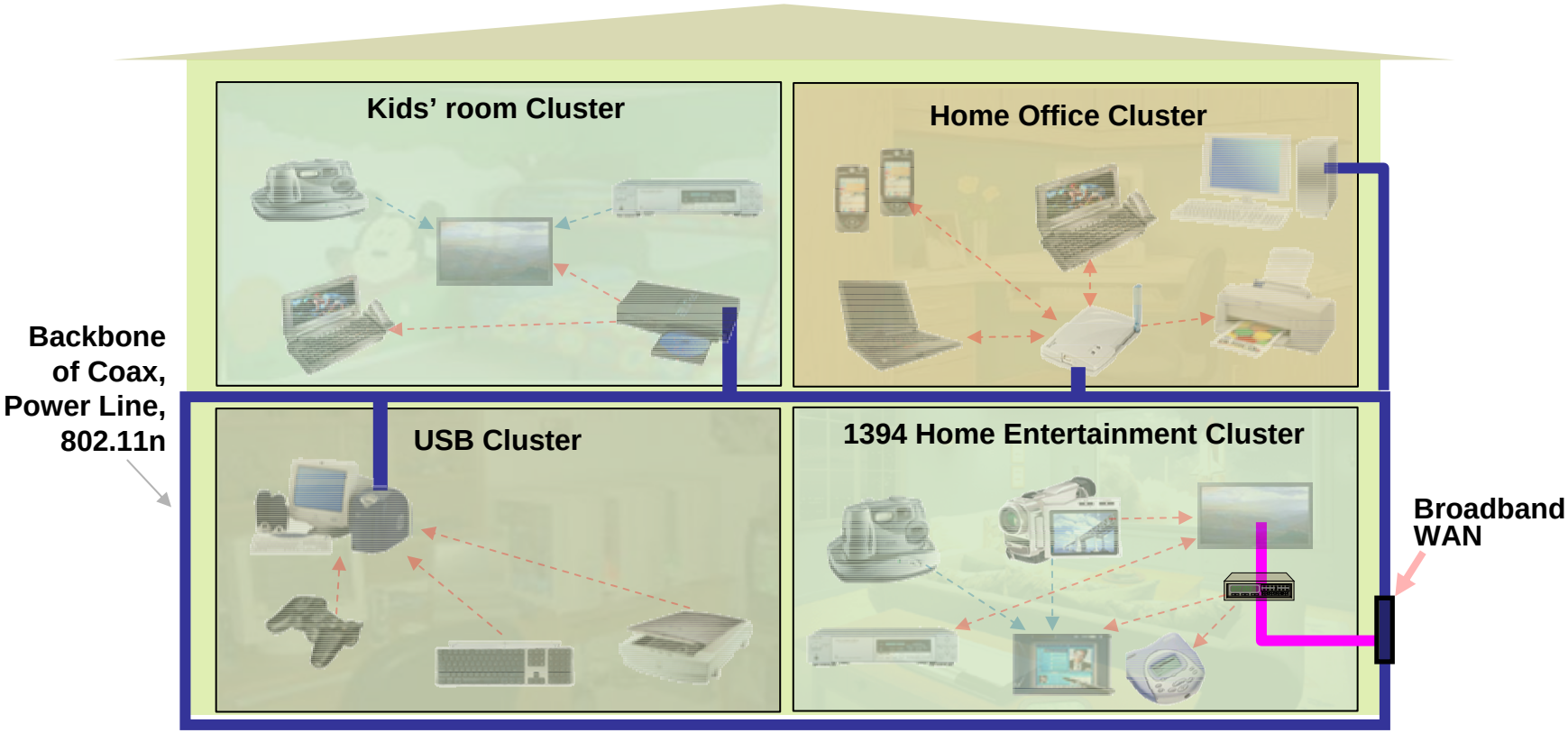
Use Cases

Stream DV or MPEG
DS-UWB is just a shift register
By far the most bits/Joule

Channel surf and PIP
to handheld

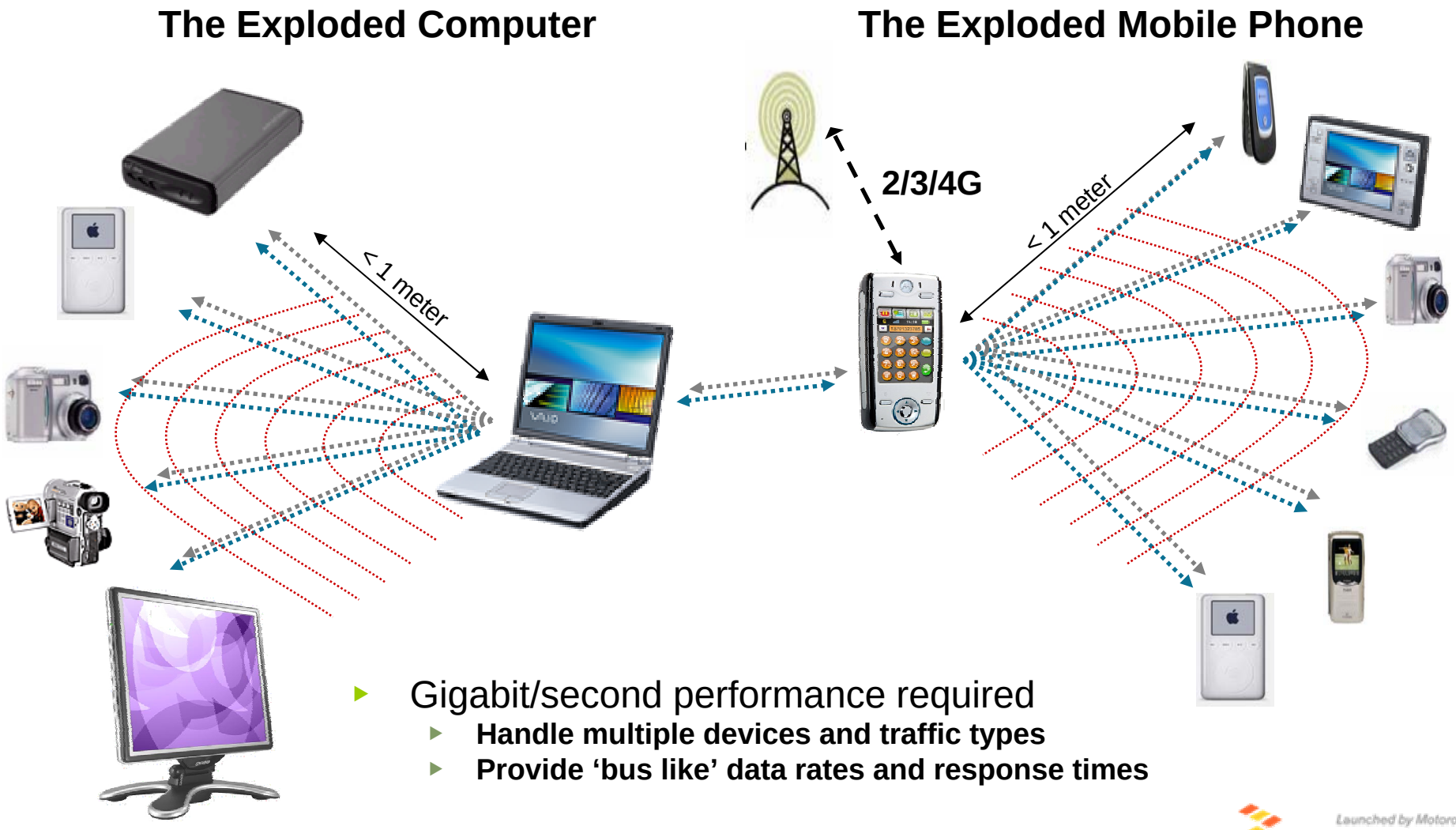
Stream presentation
from Smartphone/PDA to
projector

Your Entertainment, Information & Control Anywhere Is the Target …



- No wired solution can ever deliver freedom from jacks and wiring
- No wireless has ever delivered whole house coverage for all content
- A systems approach combining wired & wireless is the solution
  - **User experience is not just cutting the wire—personal mobile**

Exploded (Disaggregated) Devices
The Wireless Docking Station

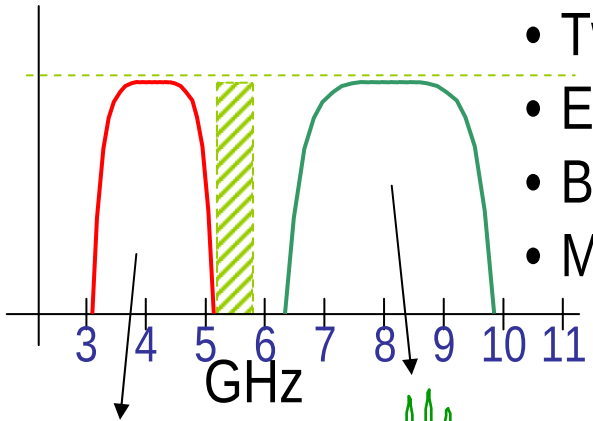


- Gigabit/second performance required
  - **Handle multiple devices and traffic types**
  - **Provide 'bus like' data rates and response times**

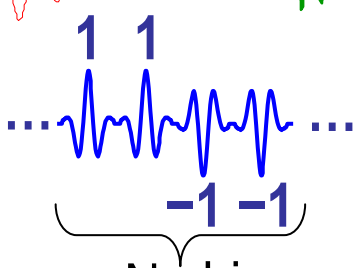
What Are The Technology Choices and What Are Their Relative Advantages

	MB-OFDM	DS-UWB
▸ Rates to 4 Gbps ▸ 10 meters & less ▸ Low Power	**HARD**	**EASY** ▸ Inherent immunity to fading ▸ Simple ▸▸ **FEC & ADC** ▸▸ **Few tap DFE** ▸▸ **Xmit is simple shift reg** ▸ Low bit-widths
▸ 110 Mbps & less ▸ 10 meters & greater	**EASY** ▸ Can mitigate fading ▸▸ **Frequency diversity** ▸▸ **Stronger FEC** ▸ Takes Advantage of FFT Efficiency ▸ Low bit widths	**HARD**

What is DS-UWB and Why Does It Scale?

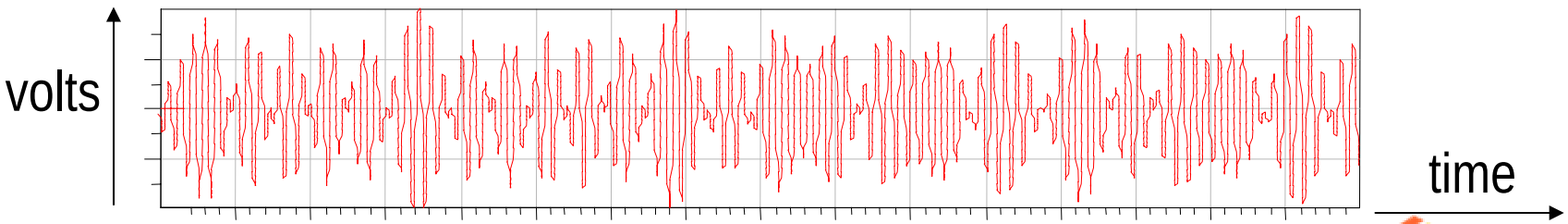


- Two wide ***50%-bandwidth*** contiguous bands
- Each captures unique propagation benefits of UWB
- Bandwidth and center frequency programmable
- Minimized potential for interference
  - Low band provides long wavelet
  - High band provides short wavelet
  - Wavelet = 3 cycles - packed back-to-back

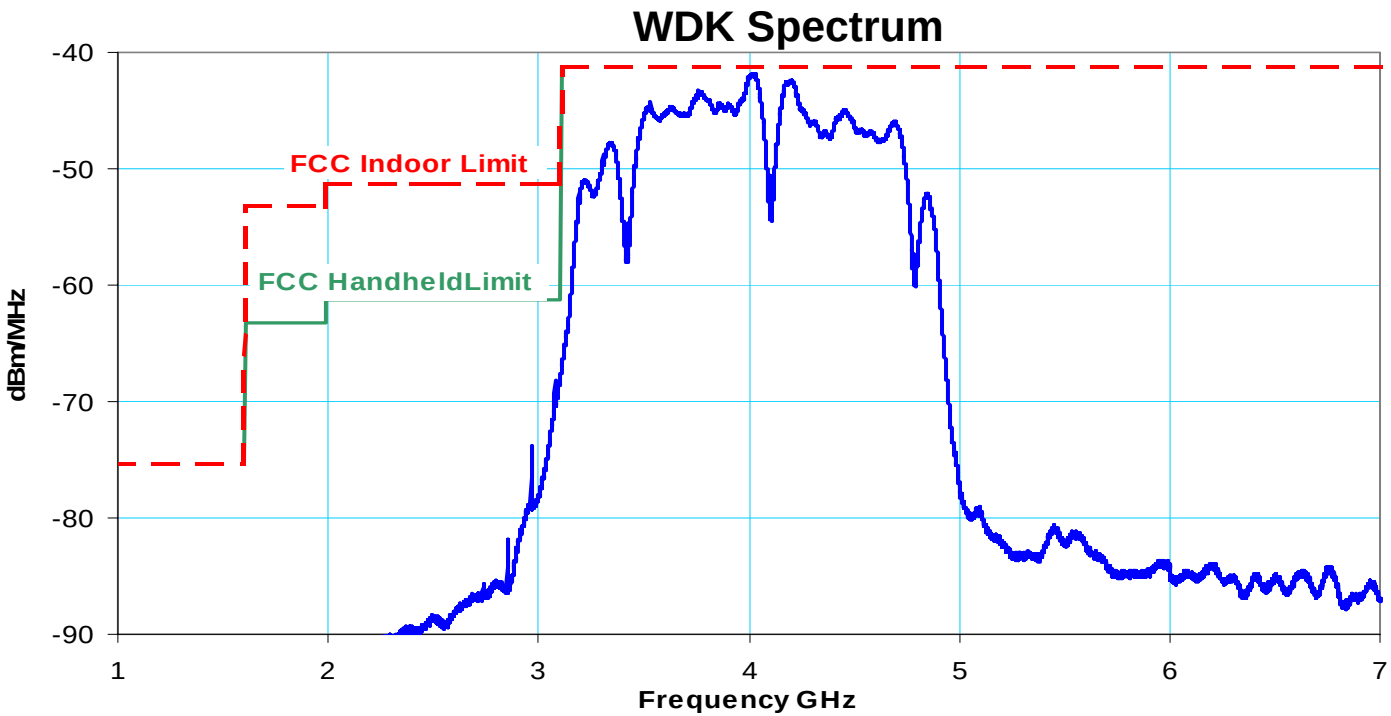


- Wavelets are modulated with BPSK or QPSK
- Symbol is made with an N-chip code sequence
- Code is ternary (+1, 0, -1)

- Result is Not-spiky in either Time or Frequency Domain



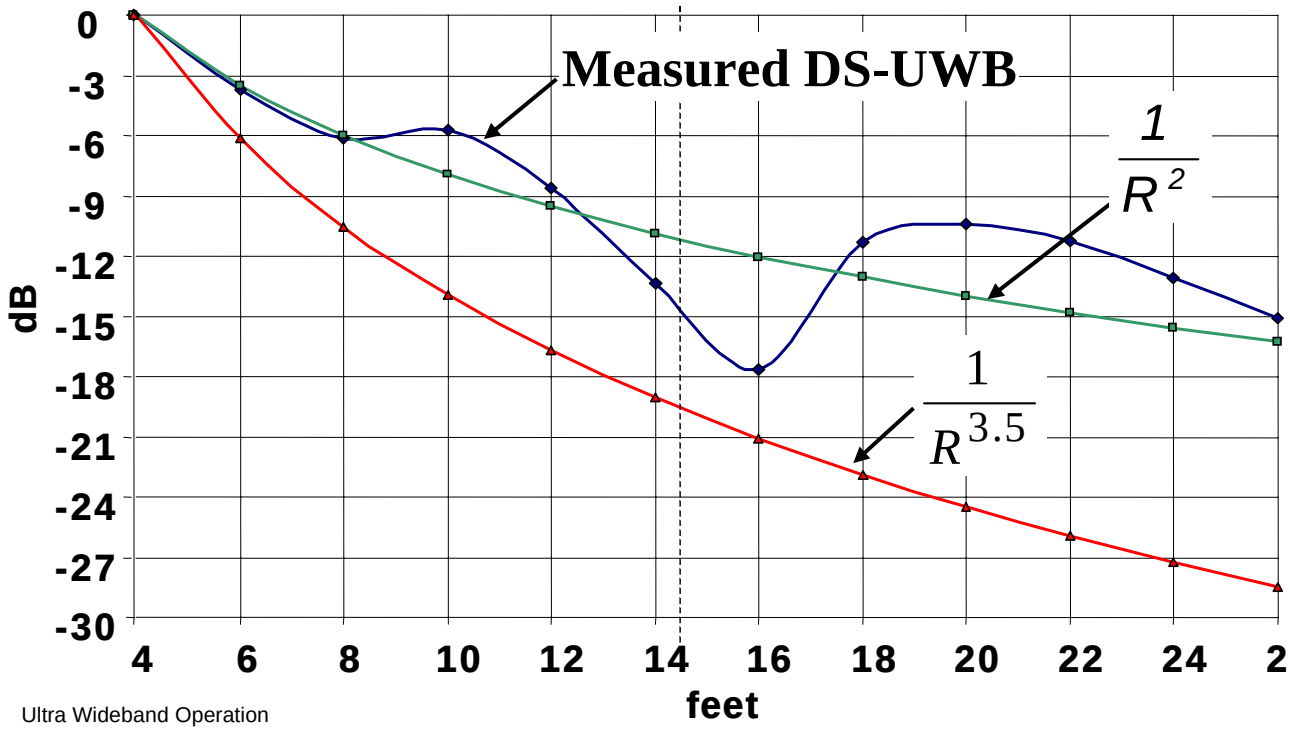
Current DS-UWB WDK Spectrum Easily Meets FCC Spectral Emission Limits



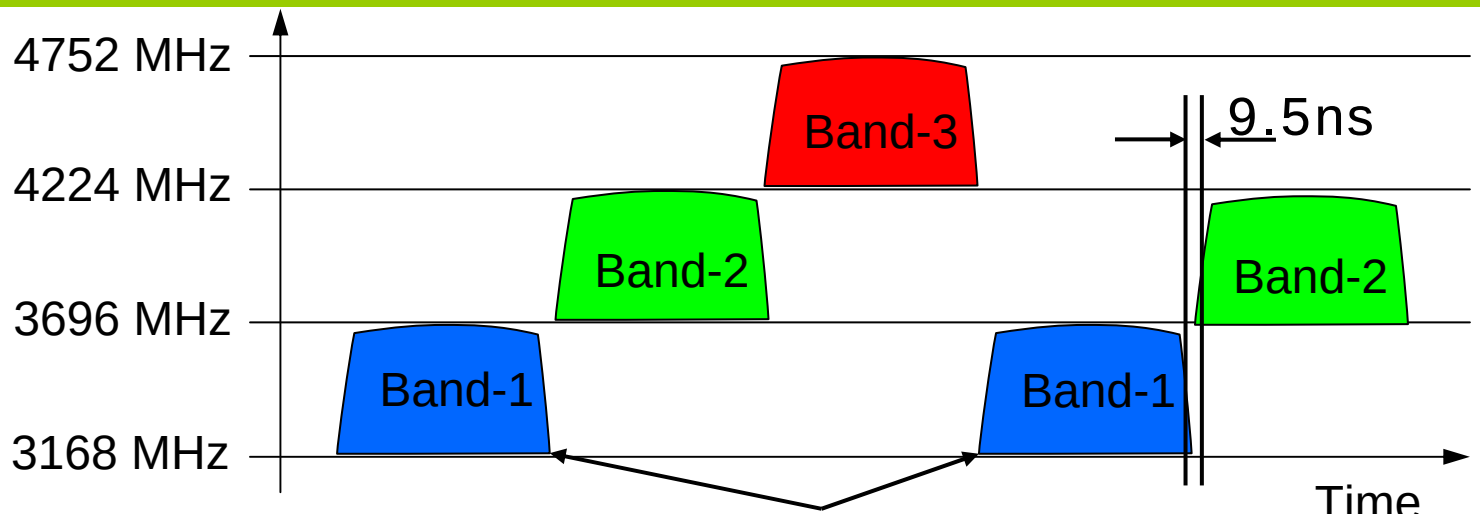
- Out of Band Emissions in GPS & cell phone bands are 30 dB better than required
- DS-UWB built for integration into cell-phones and GPS

Why Does DS Scale To High Data Rates At Low-Power/Cost? DS-UWB Is the First Radio With No Fading & Lots Of BW

- Real World Measurements Demonstrate Unique Benefits of DS-UWB
- Not on a $1/R^4$ curve -- Small dips, **no deep fades**
  - **= Very robust in highly cluttered environments**
  - **= Lower power and minimized potential for interference**

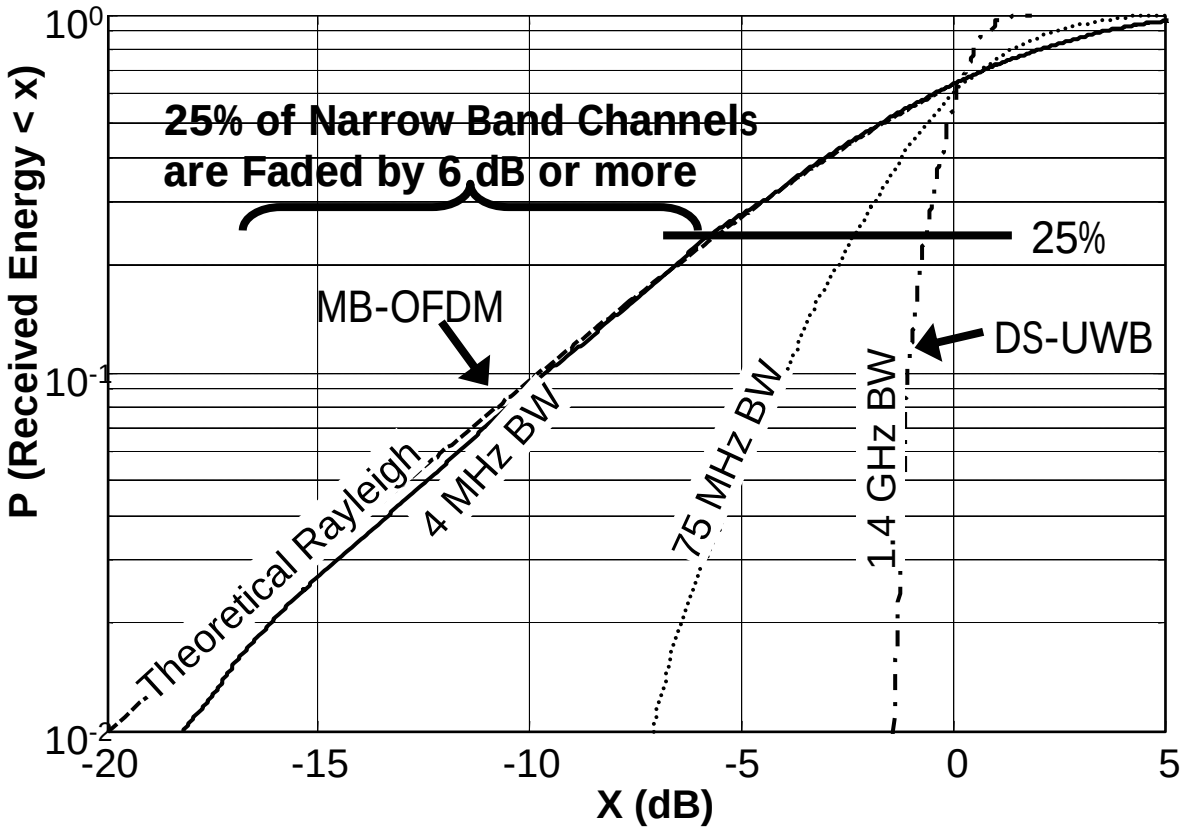


What Does MB-OFDM Look Like?



- OFDM symbol uses 128, 4.125 MHz bandwidth carriers – 412 MHz Data BW
  - **Effectively 128 narrow-band radios**
  - **10 "Guard" tones emit useless energy – added noise to meet FCC 500 MHz BW requirement**
  - **12 pilot tones for tracking, + 1 null tone for DC**
- Symbols are frequency hopped
  - **Hopping causes bursts of interference into victim receivers**
  - **Sequences include 1,2,3,1,2,3 or 1,1,2,2,3,3 – could be others with longer strings of same freq**
- Symbol is long 242 ns plus 60.5ns cyclic prefix of zero's for 1,2,3,1,2,3 sequence
  - **long enough to capture a receiver and cause interference**
- Interference depends on sequence
  - **Burst is effectively 2X longer for 1,1,2,2,3,3 hop sequence**
  - **Interferes with lower bandwidth receivers**

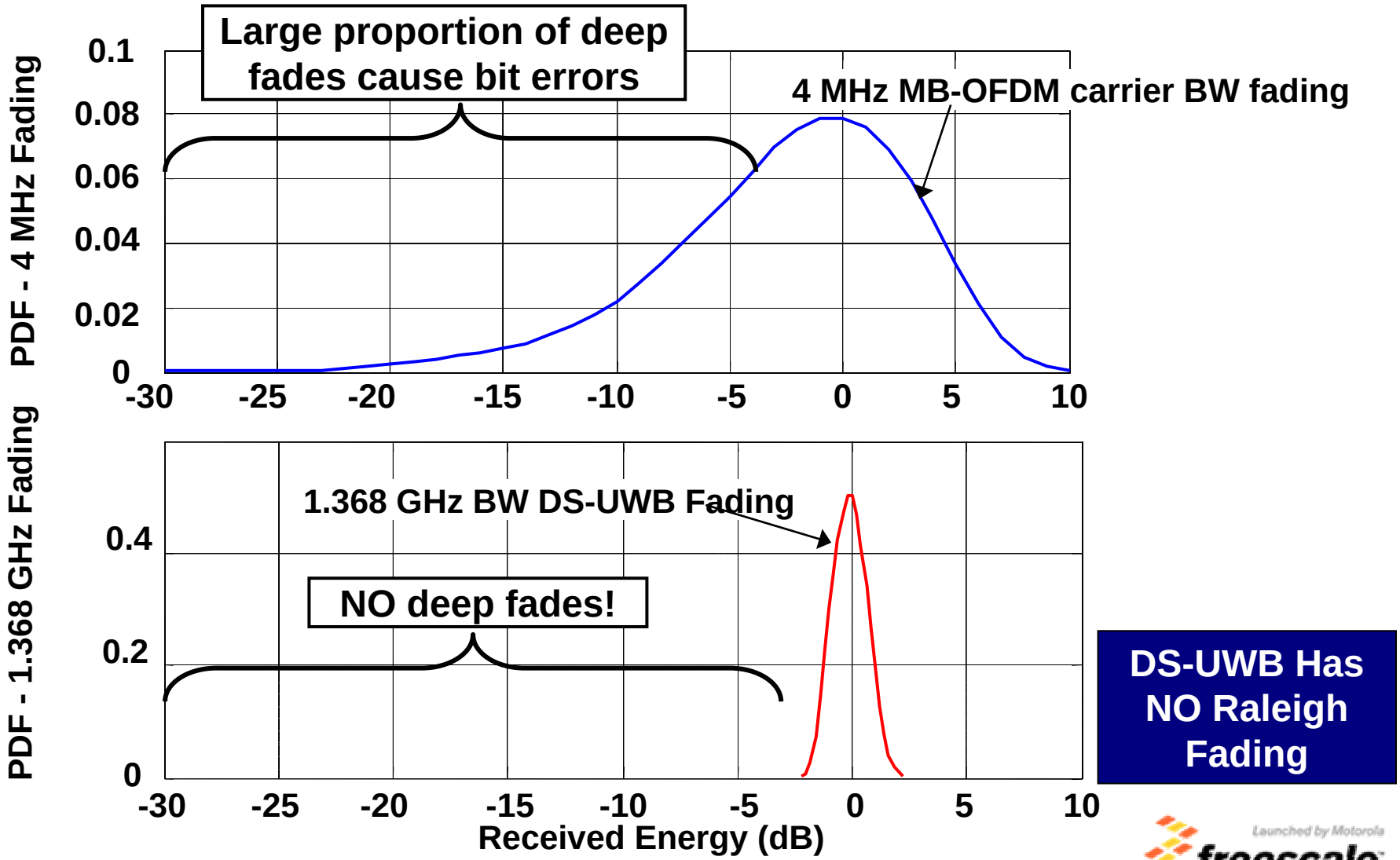
While DS-UWB is Fade Free
Many MB-OFDM Tones Suffer Heavy Fading



- DS-UWB takes full advantage of natural channel physics
- MB-OFDM tones suffer heavy fading
- MB-OFDM does not coherently process the bandwidth
  - **FEC across tones is used**

- Large coherent relative BW enables radios with no fading
  - **This is a first for wireless**
  - **Allows FEC to be turned off, or left out for short range apps**

UWB Fading Distributions Are Key
Histogram of what amplitude any sub-carrier might have

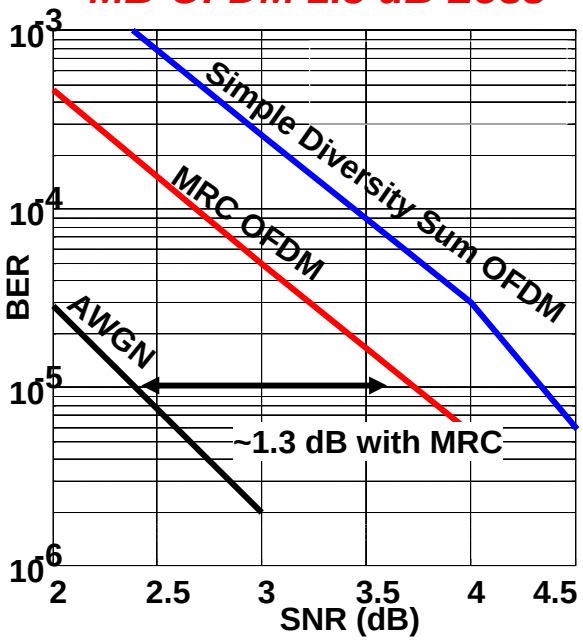


DS-UWB Has NO Raleigh Fading

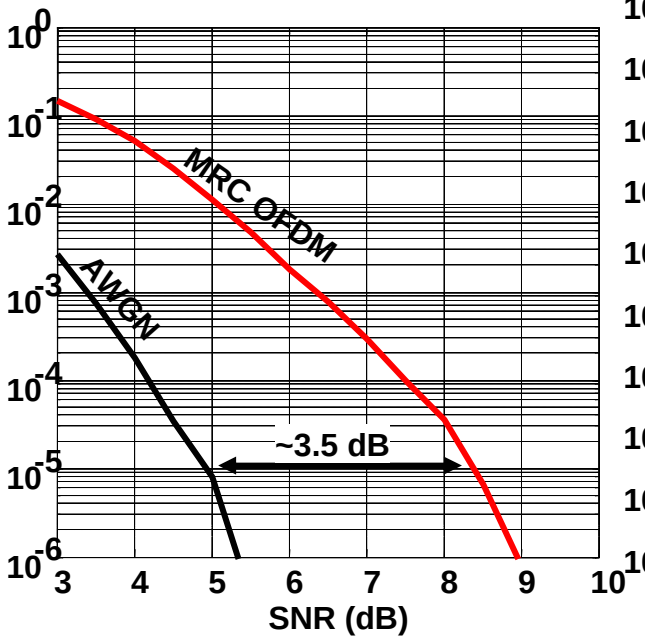
DS-UWB versus MB-OFDM Performance Loss Due to Fading

- **MB-OFDM performance worsens as data rate increases- frequency diversity is lost**
  - "Energy Capture" ≠ Energy Utilization
- **DS-UWB maintains performance within 1 dB of optimal with low complexity RAKE**

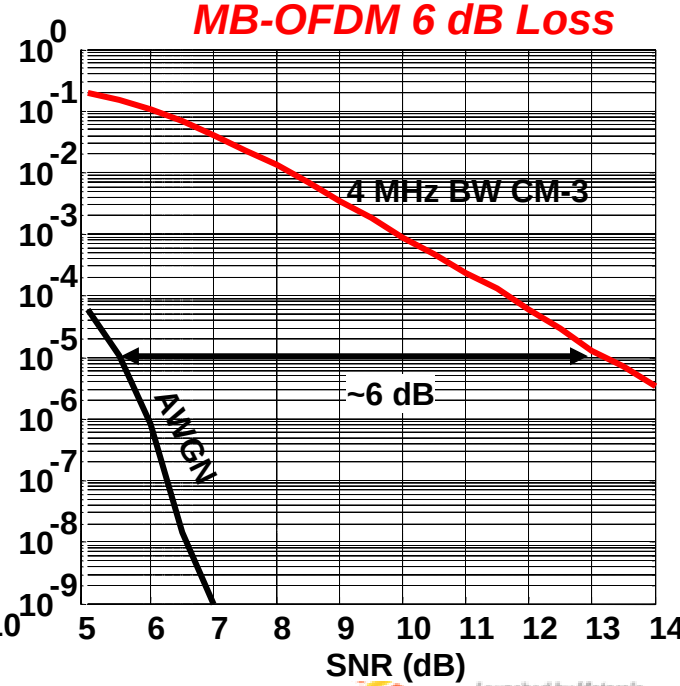
110 Mbps
Rate 11/32 FEC
with 2x Diversity
MB-OFDM 1.3 dB Loss



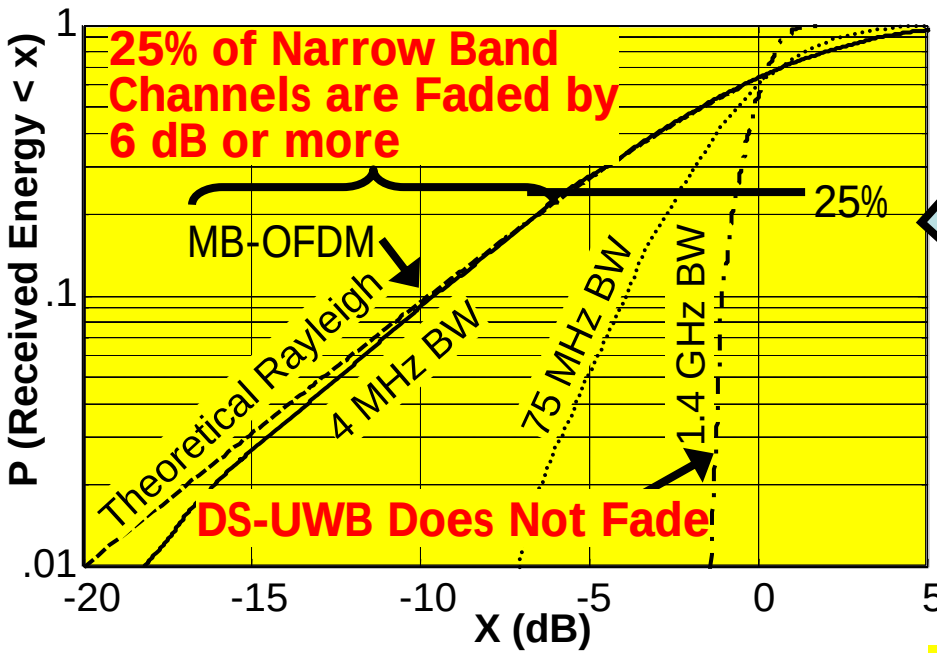
200 Mbps
Rate 5/8 FEC
with 2x Diversity
MB-OFDM 3.5 dB Loss



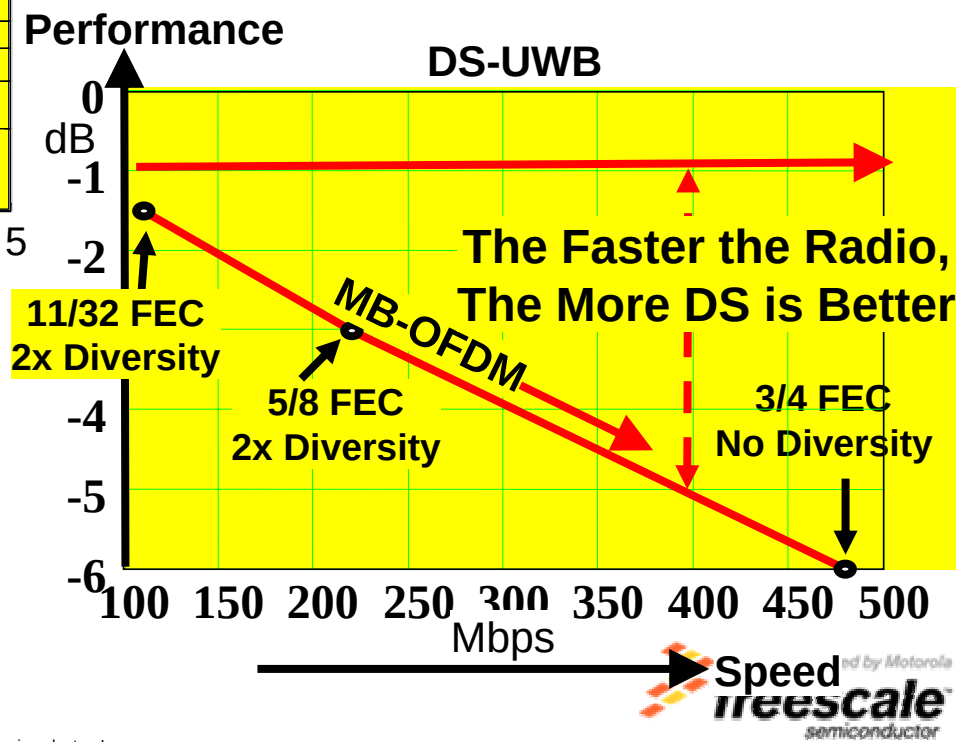
480 Mbps
Rate 3/4 FEC
with No Diversity
MB-OFDM 6 dB Loss



DS-UWB Takes Full Advantage of UWB Propagation
DS-UWB Performance Differential Gets Wider As Speed Goes Up



Performance Difference is Natural Consequence of Channel Physics



DS-UWB Naturally Fits Needs of Multi-Media & Handheld Devices

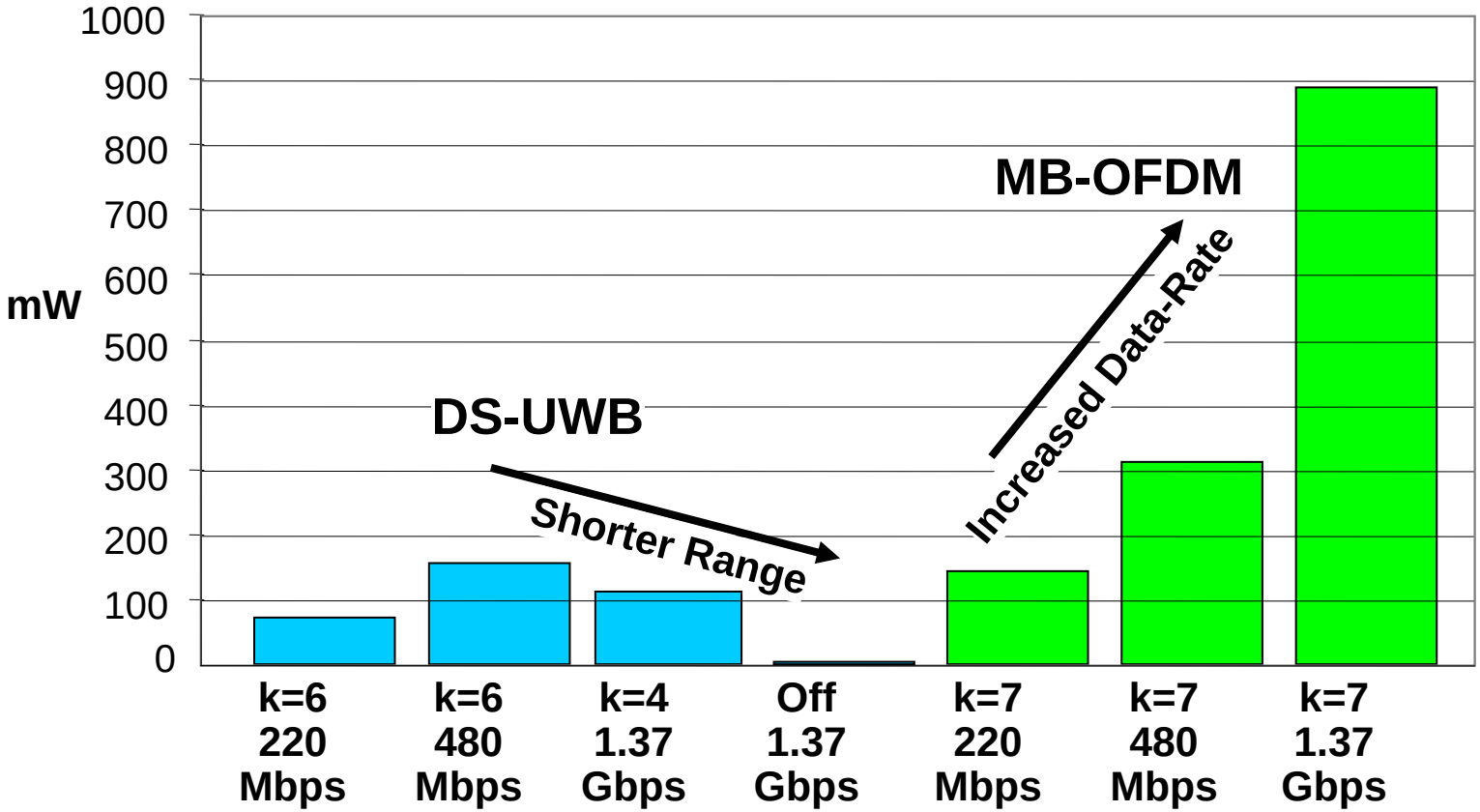
Fading Drastically Changes The Ability To Scale To High Rates At Low Complexity & Low Power

- Three approaches to achieve > 480 Mbps proposed by MBOA
  - **Shift from QPSK to 16-QAM in order to reach 960 Mbps**
    - **Needs 3.9 dB higher Eb/No for acceptable performance**
    - **Gain in frequency diversity does not offset the higher Eb/No requirement**
      - **i.e. it's a loosing battle**
    - **More Complex - Needs higher precision (7-bits) ADC and FFT processing**
      - TI reports that 801.11a requires 10-bit ADC for 64-QAM
  - **Use MIMO techniques**
    - **Like 11.n - Requires multiple Rx & Tx chains (> N times the complexity)**
    - **Requires uncorrelated RF channels at short range for MIMO gain**
  - **Use all three bands simultaneously**
    - **Eliminates the frequency hop**
    - **3 X more ADCs or ADC at 3X clock**
    - **Increased FFT complexity -- 4x or more**
- All approaches require Big FEC to combat fading in 4 MHz channel
  - **k=7 Viterbi decoder running at >1 GHz**
  - **~1 Watt at 90nm**

FEC Power Requirements & Scaling

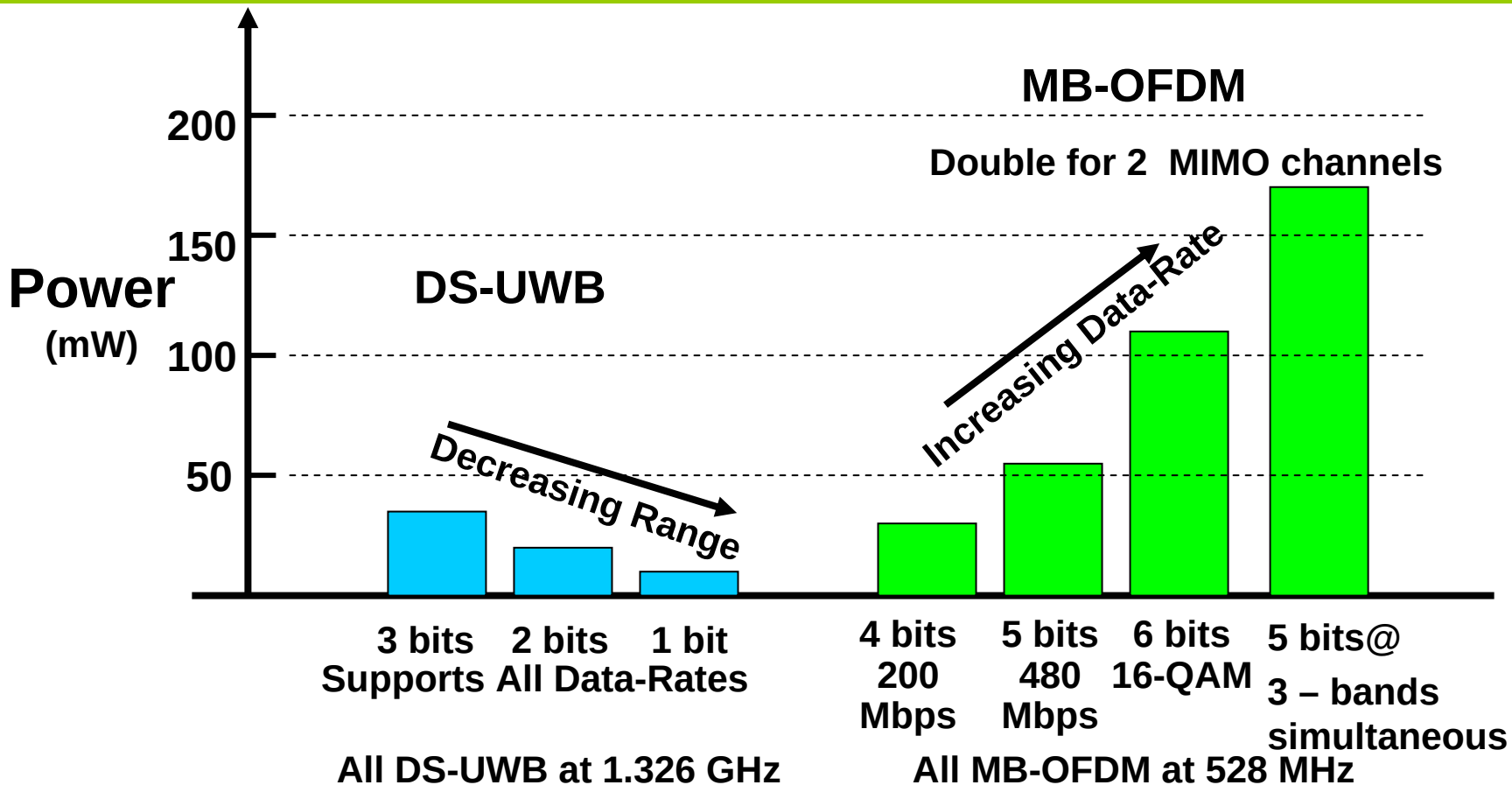
Power ~ $2^k * f$

Assumes 90nm CMOS -- scaled from Viterbi operating in .18μ



* Delta relative to Un-coded DS – un-coded MB-OFDM fails due to fading

ADC Power Requirements & Scaling

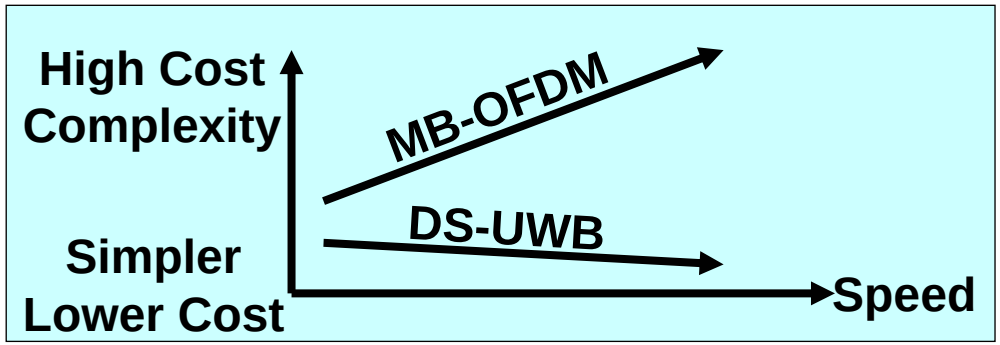


Down stream processing shrinks/expands with ADC bit width

Bit Width growth = downstream processing growth too!

DS-UWB Complexity Takes Advantage Of Propagation
DS-UWB Power Excels More & More As Data Rate Goes Up

- **As UWB Gets Faster**
  - DS – Gets Simpler
  - MB-OFDM Requires More Complexity



As Range ↓ & Speed ↑	DS (Gets Simpler)	MB-OFDM (Gets More Complex)
Signal gets Big	Adapts: Uses less processing Gain ▸ Shorter codes ▸ 3►2►1 bits ADC as speed ↑ ▸ Less bits in processing	Frozen: Req's more processing gain to get to high data rate regardless of SNR ▸Higher order QAM ▸More bits in ADC/DAC, FFT/IFFT
Rayleigh Fading	Adapts: Turn FEC Off, (or leave it out) or Use Small (k=4) FEC	Frozen: Serious FEC Required ▸ Speed of K=7 FEC at high rates **killer power & space @ 1Gbps**
Delay Spread goes Down	Adapts: DFE covers less time	Frozen: Band Plan Fixed

DS-UWB Power Profile Compared To Bluetooth

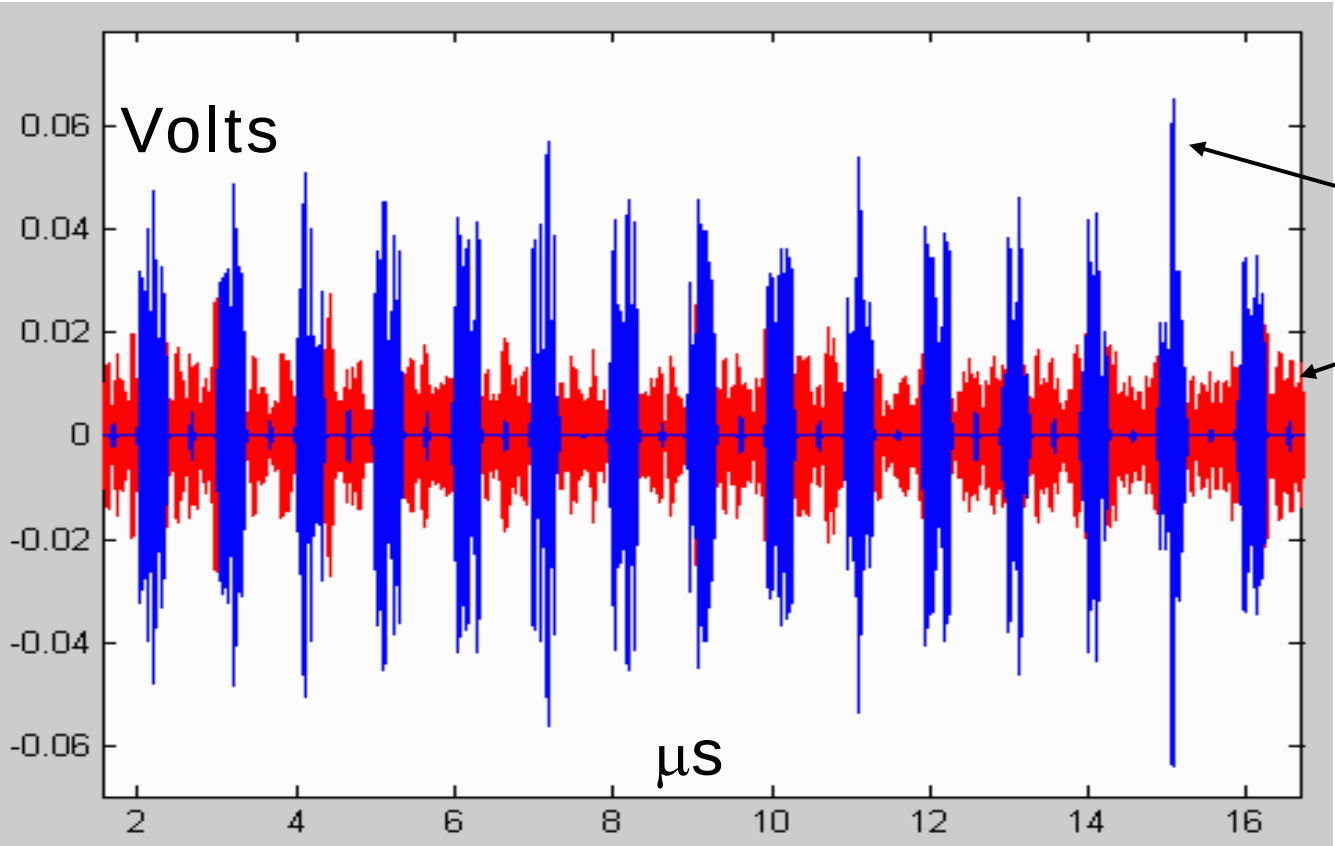
Only DS-UWB meets both the power needs and the transfer-time user-experience required of handhelds

size (MB)	Transfer time (sec)			Energy (Joules)			Power Ratio	
	BT	DS-220	DS-1Gbps	BT joules	DS-220	DS-1Gbps	BT/220	BT/1Gbps
5	57.3	0.5	0.3	5.7	0.2	0.1	24	45
32	365.9	2.0	0.5	36.6	1.0	0.3	37	135
512	5851.6	28.6	5.7	585.2	14.3	2.8	41	207

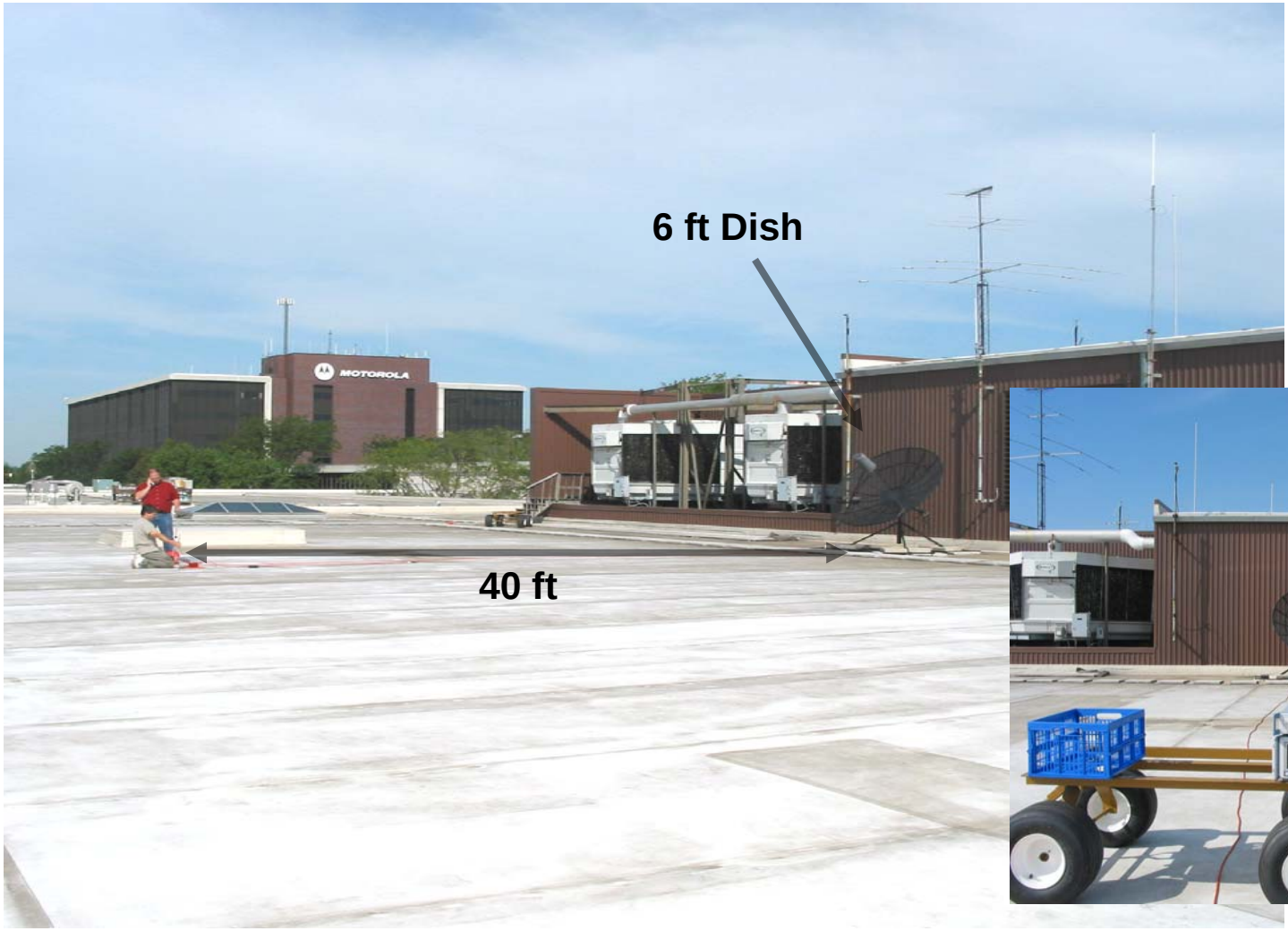
- Model Parameters:
  - **Flash Storage**
    - **5 MB, 32 MB (next gen smart-phone w/camera), 512 MB (MPEG-4 Movie)**
  - **DS-UWB (total solution MAC/BB/PHY) is 500 mW**
  - **Bluetooth 100 mW (low-power ver) (BT xmit power alone can go to 100 mw)**
  - **Includes Overhead for preambles, headers etc. for 802.15.3 MAC**
  - **Assumes .2 sec overhead to wake, scan, pass security, associate & get started**
  - **DS-UWB effective throughput rates of 165 Mbps and 1 Gbps used for 220 Mbps & 1.32 Gbps tx/rvc rates respectively after rate 3/4 FEC**
  - **Modes with No FEC improve speed and battery life even more**

What About Interference?
30 MHz BW C-band Victim Receiver – Pre Detection

- DS-UWB has the highest safety margin for no interference
- Plot illustrates the difference as seen by 30 MHz BW receiver
- 1/3 rd duty cycle bursts of 242ns are easily observed



C-band Tests Done In Normal Operating Conditions



C-Band System Test Results

- MB-OFDM had ***substantially*** less safety margin
  - **5 dB worse for baseline 3-hop with 1,1,2,2,3,3 sequence**
  - **4 dB worse for 3-hop with 1,2,3 sequence**
  - **9 dB worse for 7 hop**

Digi-Cipher	"Theory" Duty Cycle	MB-OFDM	Gated Noise	DS
	dB	dB	dB	dB
Continuous		0.0	0.0	0.0
3,1 hop	5.7	4.6	3.0	
3,1 hop w/CP	4.9	3.6		
3,2 hop	5.7	5.2	5.4	
7,1 hop	9.4	7.7	7.7	
7,1 hop w/CP	8.6	7.2		
7,2 hop	9.4	9.4	10.6	
13,1 hop	12.1	10.0	10.8	
13,2 hop	12.1	11.5		

Actual Measured

Results & Trends Matched "Theory"

- Noise, non-hopped continuous-OFDM, and DS were ~ equal
- Affect was less than duty-cycle for short bursts (e.g. 1,2,3 sequence)
- Affect moved upward toward duty-cycle with longer bursts (e.g. 1,1,2,2,3,3)
- Results are consistent with other measurements using Video Cipher (analog) receiver

Summary

	MB-OFDM	DS-UWB
▸ Rates to 4 Gbps ▸ 10 meters & less ▸ Low Power	**HARD**	**EASY** ▸ Inherent immunity to fading ▸ Simple ▸▸ **FEC & ADC** ▸▸ **Few tap DFE** ▸▸ **Xmit is simple shift reg** ▸ Low bit-widths
▸ 110 Mbps & less ▸ 10 meters & greater	**EASY** ▸ Can mitigate fading ▸▸ **Frequency diversity** ▸▸ **Stronger FEC** ▸ Takes Advantage of FFT Efficiency ▸ Low bit widths	**HARD**