Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [MB-OFDM Proposal Update]
Date Submitted: [11 November, 2005]
Sources:

[J. Decuir] Company [MCCI]
Address [18814 SE 42nd St, Issaquah, WA 98027]
Voice:[+1 425 603 1188], FAX: [+1 425 603 0279], E-Mail:[joe@mcci.com]
[D. Leeper] Company [Intel Corporation]
Address [CH6-460, 5000 W Chandler Blvd., Chandler, AZ, 85226]
Voice:[+1 480 552 4574], FAX: [], E-Mail:[david.g.leeper@intel.com]
[See also MB-OFDM Contributor slides.]

Re: [MB-OFDM updates]

Abstract: [Overview and Updates to Original MB-OFDM Proposal]

Purpose: [To inform and persuade]

Agenda

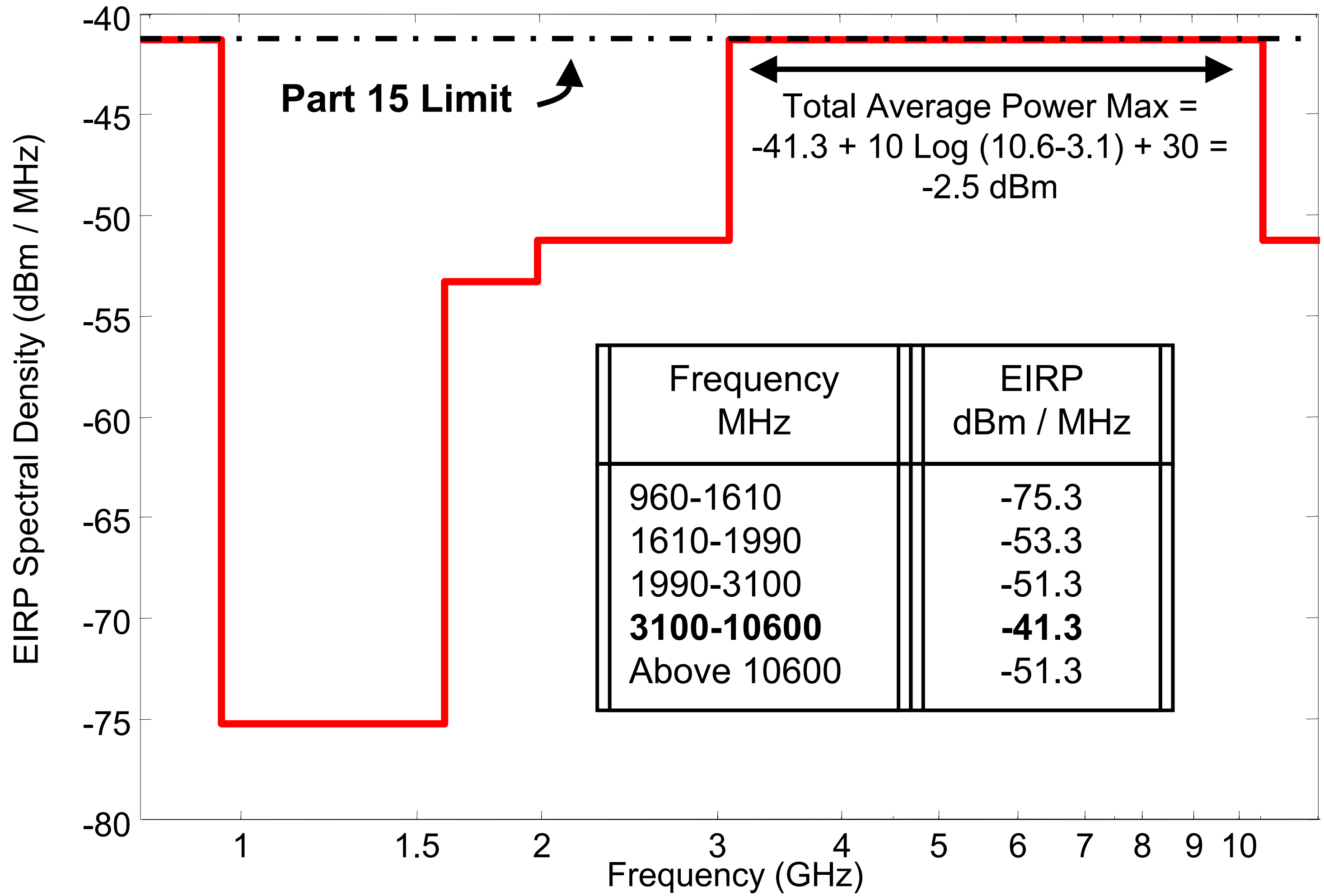
- Status and Prospects
- Introduction to MB-OFDM
- What’s New in MB-OFDM
- Regulatory Issues
- Why OFDM

Status within TG3a

- We started in 2002 with a spectral mask from the FCC (next slide)
- We rapidly converged on 2 distinct approaches, represented by Merged Proposal #1 and Merged Proposal #2
- We now have two designs that meet the terms of the original PAR, working with the FCC mask.
- We have been deadlocked since mid-2003

Common Constraint for All UWB Proposals

FCC Indoor Spectral Mask -- April 22, 2002



Frequency MHz	EIRP dBm / MHz
960-1610	-75.3
1610-1990	-53.3
1990-3100	-51.3
3100-10600	**-41.3**
Above 10600	-51.3

The situation has changed

- The US FCC has kept its word, and issued rules for devices to use their mask.
  - The FCC does not bind the rest of the world.
- However, the FCC and other administrations have been licensing some of that spectrum to system operators for other uses, e.g.:
  - Fixed wireless
  - Advanced cellular systems
- When these services are successful around the world, we can expect them to allocate more of the spectra that UWB is designed for.

New Incumbents Appear

- The same “Moore’s Law” that lets our chip geometries get smaller also enables cheaper radios at higher frequencies.
- This enables new services like 4G and WiMAX.
- Companies deploying networks for these services pay fees for rights to transmit on spectrum.
- The national regulators then protect them because there are expectations on the quality of the spectrum.
- UWB is proposed as unlicensed underlay service, so licensed services *always* have priority.

Perspective with other unlicensed radios

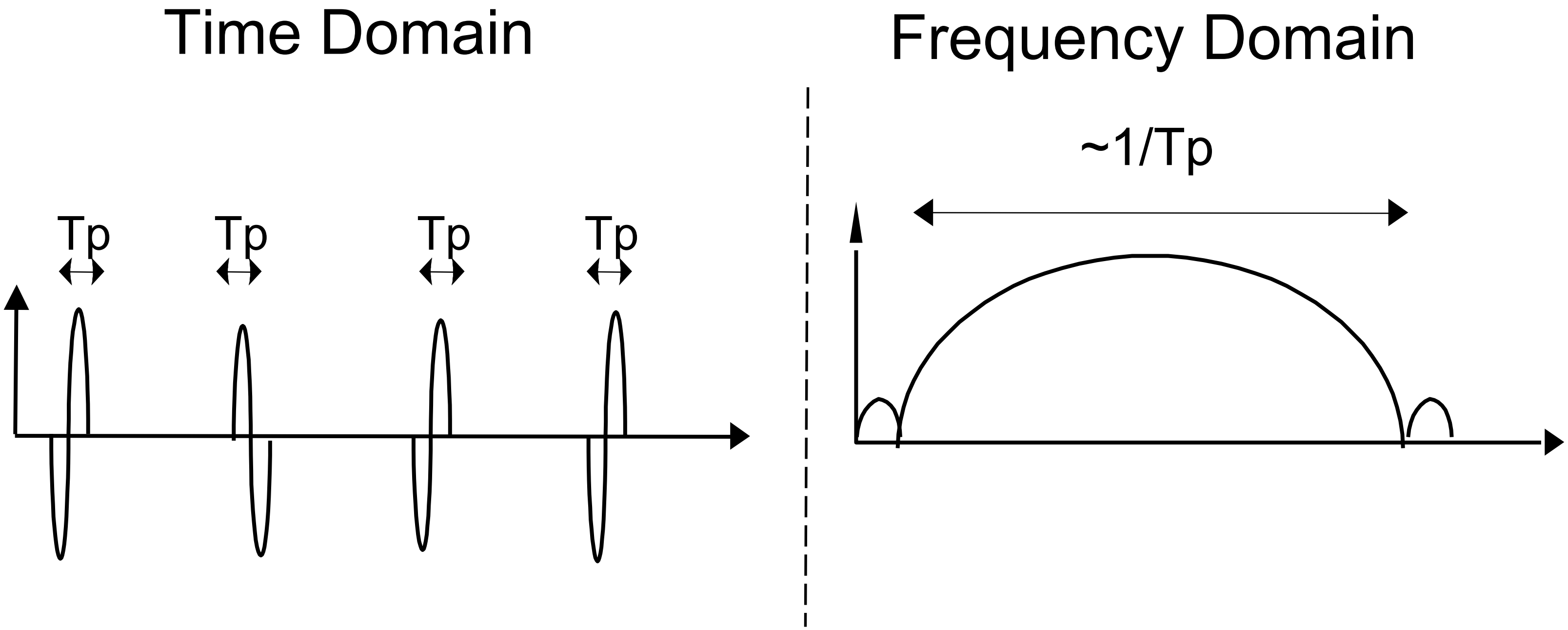
- Common unlicensed radios include:
  - IEEE 802.11 (20 MHz out of 2483 MHz)
  - IEEE 802.15.1 (Bluetooth™) (1 MHz/2483 MHz)
  - IEEE 802.15.3 (15 MHz out of 2483 MHz)
  - IEEE 802.15.4 (2 MHz out of 2483 MHz)
- What distinguishes them from UWB:
  - There are few licensed incumbents to contend with.
  - Their fractional bandwidth is tiny compared to UWB (e.g. 528 MHz or higher out of several GHz)
  - The ISM band radios have to coexist with each other, but don't need to worry about *new licensed* incumbents.
  - The UWB radios do have to accommodate new licensed incumbents, both now and in the future.

Predictions for uncertain future

- Operators of future new services will buy spectrum rights in the upper band as well and become incumbents.
- The FCC is already licensing new incumbents in the US, too.
  - The proposed rules do not protect UWB
  - Interference cuts both ways
- So, we re-present a radio that can deal with that uncertain future.

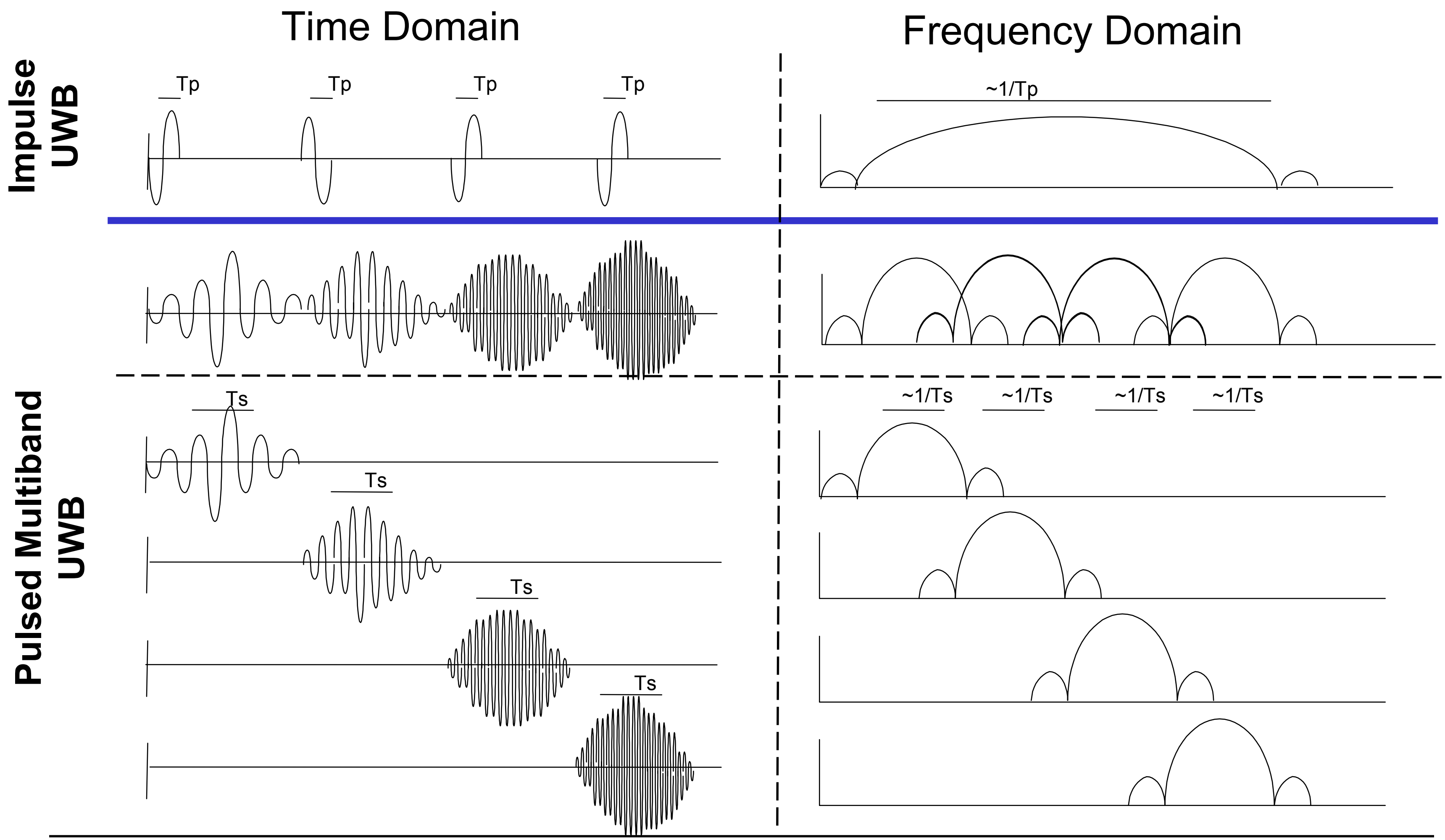
Introduction to MB-OFDM

UWB Evolution
Starting Point: Traditional "Impulse UWB"



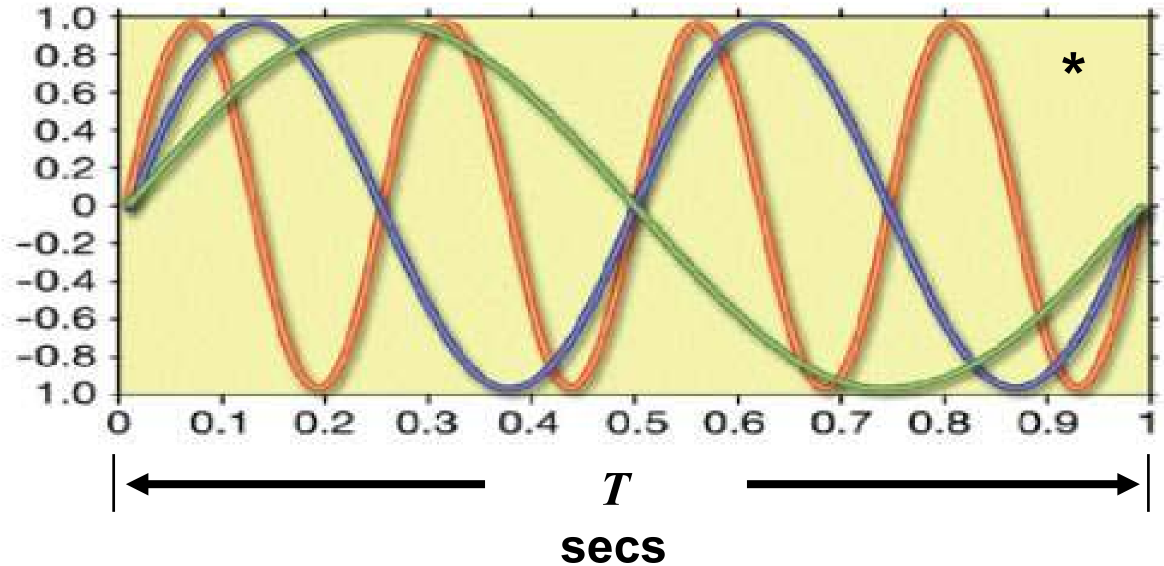
Tp < 1 nanosecond

UWB Evolution
Intermediate Form: “Pulsed Multiband” UWB



UWB Evolution: UWB via MB-OFDM

Original Proposal of Batra et al (Texas Instruments)**



$$Z(t) = \sum_{k=0}^{N-1} C_k e^{j2\pi(k-\frac{N}{2})t/T}$$

Symbol Statistics (Still Valid)

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

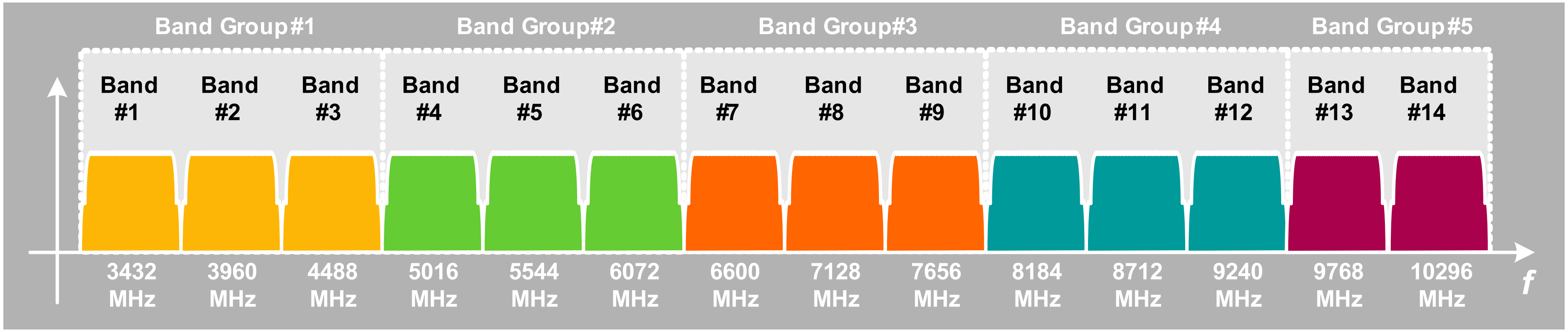
* http://www.iec.org/online/tutorials/ofdm/

** IEEE P802.15-03/268r1, October, 2003

*** Including 70.08ns zero prefix & guard times

Overview of Multi-Band OFDM

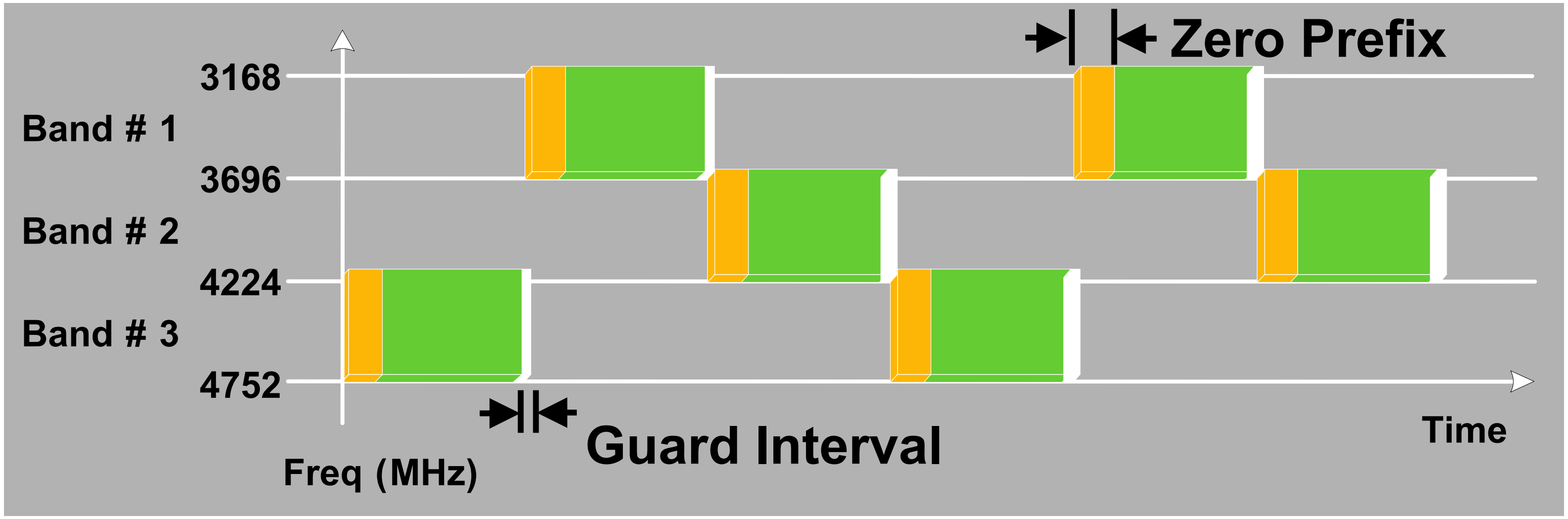
- Key Idea #1:
  - Divide the spectrum into 528-MHz-wide bands



- Advantages:
  - Transmitter and receiver process smaller baseband bandwidth signals (528 MHz).
  - Band groups can be rearranged to fit worldwide regulations

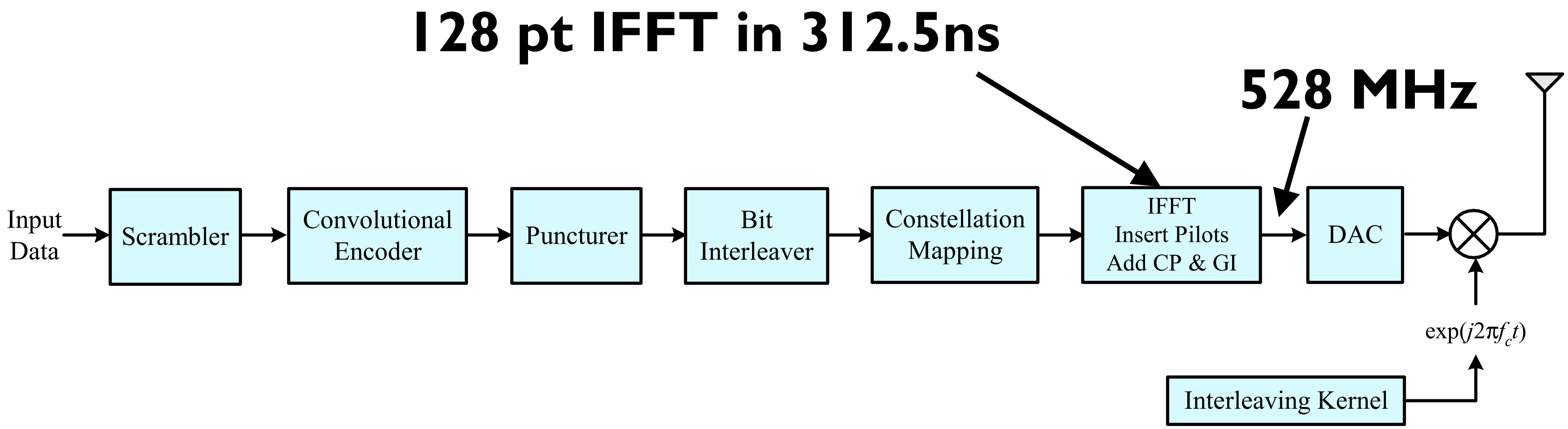
Overview of Multi-Band OFDM

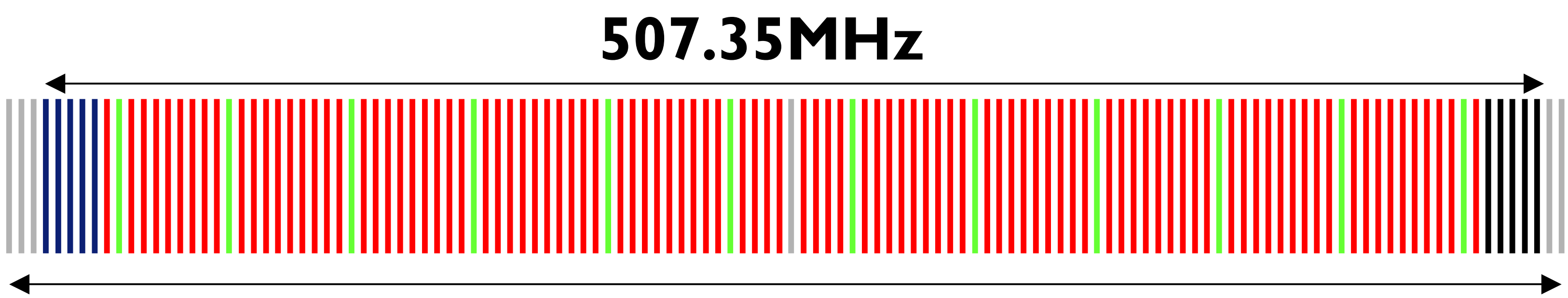
- Key Ideas #2, 3, 4:
  - Band Interleaving, Zero Prefixes, & Guard Intervals



- Advantages:
  - Frequency diversity, full allowable Tx power
  - Robustness to Multipath
  - Tx/Rx settling times

Example MB-OFDM UWB Tx chain





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

OFDM History

- Invented more than 40 years ago
- Adopted & proven many times over
  - Asymmetric DSL (ADSL)
  - IEEE 802.11a, 802.11g & 802.11 TGn
  - IEEE 802.16 (WiMax)
  - Power Line Networking (HomePlug and HomePlug A/V)
  - Digital Audio (DAB) & Video (DVB)
- A “natural” for the future
  - FCC’s Sought-After “*Cognitive Radios*”
  - Multimode Radios

What's New* in MB-OFDM?

- Fixed-Frequency Interleave (FFI) Codes
- 106.7 Mbps Data Rate
- Dual-Carrier Modulation (DCM)
- Transmit Power Control (TPC)
- Three-Stage Interleaver
- Explicitly Recommended OOB Limits

* Since 15-04-0493-00-003a (Batra)

System Performance with DCM and GT "Copy Over"

- The distance at which the Multi-band OFDM system can achieve a PER of 8% for a 90% link success probability is tabulated below*:

	AWGN	CM1	CM2	CM3	CM4
110 Mbps	21.5 m	New: 12.0 m Original: 11.4 m	New: 11.4 m Original: 10.7 m	New: 12.3 m Original: 11.5 m	New: 11.3 m Original: 10.9 m
200 Mbps	14.8 m	New: 7.4 m Original: 6.9 m	New: 7.1 m Original: 6.3 m	New: 7.5 m Original: 6.8 m	New: 6.6 m Original: 4.7 m
480 Mbps	9.1 m	New: 3.8 m Original: 2.9 m	New: 3.5 m Original: 2.6 m	N/A	N/A

* Includes losses due to front-end filtering, clipping at the DAC, ADC degradation, multi-path degradation, channel estimation, carrier tracking, packet acquisition, etc.

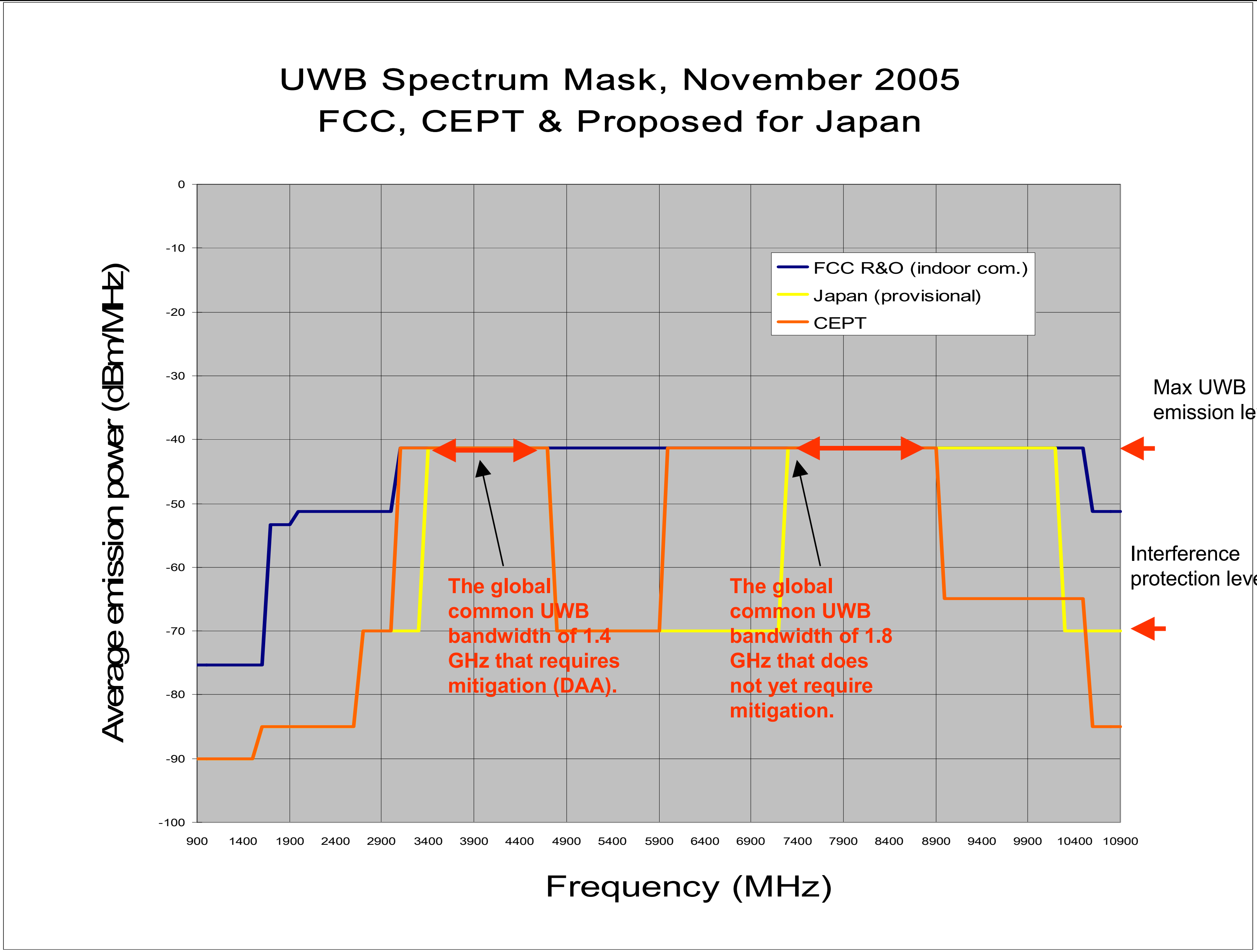
Performance Exceeds IEEE PAR Requirements

Regulatory Issues

Current* Regulatory Summary

- Mitigation will be required in the lower bands.
  - There may be temporary exemptions (e.g. 2010)
- Parts of the upper bands will not be available.
  - Different masks in different administrations
- Prospective result (next slide):
  - Mitigation required in the low bands
  - For the near term future, no mitigation required in the 7.25 – 9 GHz range

*There will likely be several presentations on the worldwide UWB regulatory situation.


UWB Spectrum Mask, November 2005
FCC, CEPT & Proposed for Japan
FCC R&O (indoor com.)
Japan (provisional)
CEPT
Average emission power (dBm/MHz)
Frequency (MHz)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
900
1400
1900
2400
2900
3400
3900
4400
4900
5400
5900
6400
6900
7400
7900
8400
8900
9400
9900
10400
10900
The global common UWB bandwidth of 1.4 GHz that requires mitigation (DAA).
The global common UWB bandwidth of 1.8 GHz that does not yet require mitigation.
Max UWB emission level
Interference protection level

MB-OFDM without Mitigation

- At this point, it looks like the band from 7.25 – 9 GHz might be available worldwide w/o mitigation required
- The existing band plan for MB-OFDM (slide 13) can be easily adjusted to fit:
  - Join sub bands 9 – 11 into a new band group: 7392 – 8976 MHz

Mitigation

- There are two types of mitigation under consideration by administrations:
  - Reduced duty cycle
  - Detect And Avoid (DAA)
- Reduced duty cycle might apply for TG4a UWB use cases (e.g. Zigbee)
- The TG3a UWB use cases have duty cycles high enough to require DAA

Detect and Avoid Requirements

- Step 1: Detect a victim incumbent service
- Step 2: Avoid interfering with that service
- Detection requires the ability to listen to other signals, with enough frequency and time granularity to actually hear them.
- Avoidance requires the ability to shape the transmit spectrum to avoid harmful interference:
  - How wide is the spectra to be vacated?
  - How deep is the notch?
  - How low must residual transmit energy be?

OFDM Facilitates Detection

- The demodulator uses FFT
- That directly provides detection with 4 MHz granularity – no extra hardware.
- The PHY layer design allows time intervals when energy can be detected.

Detection Challenges (1)

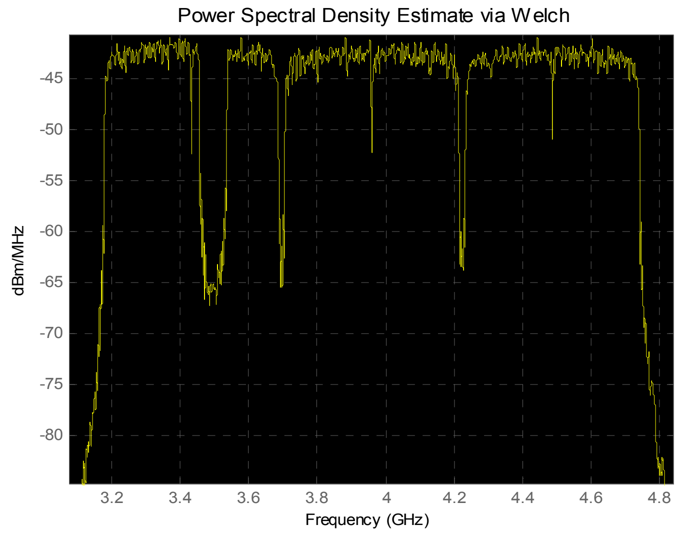
- For example services, e.g. WiMAX or cellular services, there are two radios to detect:
  - Uplink (UL) from nearby device
  - Downlink (DL) from remote device
- UL signals (from a nearby device) are stronger, but may have low duty cycle
- DL signals (from a remote tower) are weaker, but transmitting more often
- There are risks of false positives and of false negatives, such as:
  - the DL signal may be detected where there is no victim receiver nearby.
  - the UL signal may be strong enough to detect, but not on often enough to be detected easily.
  - The DL might be a different frequency than the UL.

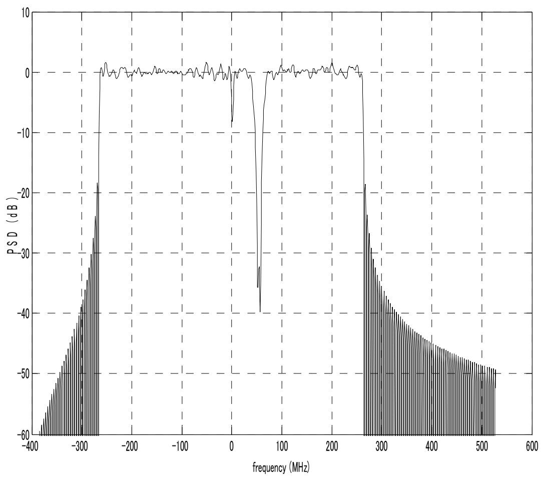
Detection Challenges (2)

- Some complexity is in the MAC layer:
  - When to shut up and listen, and how long
  - How to share detection results with other communicating devices
- None of these are insurmountable problems
  - The solutions are beyond the scope of this presentation
- There are no standards yet for detection

OFDM Facilitates Avoiding Interference

- Create notches around detected incumbents:
  - Channels and tones can be turned on/off dynamically to comply with changing regulations.
  - Can arbitrarily shape spectrum in software with a resolution of ~4 MHz.

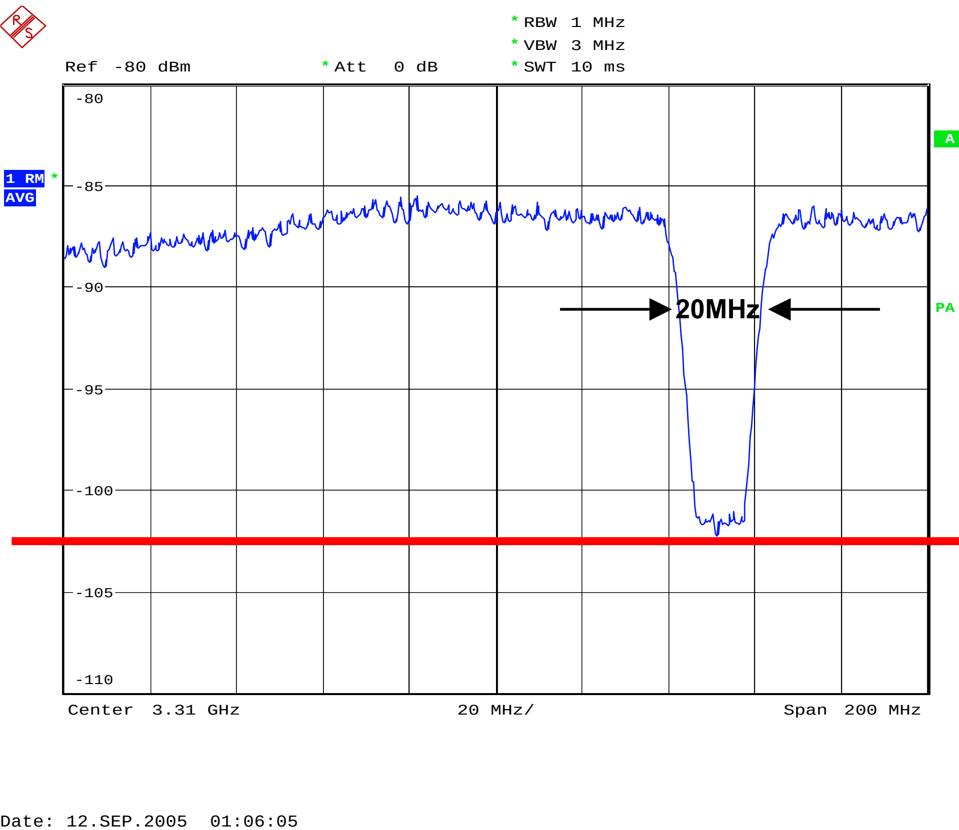




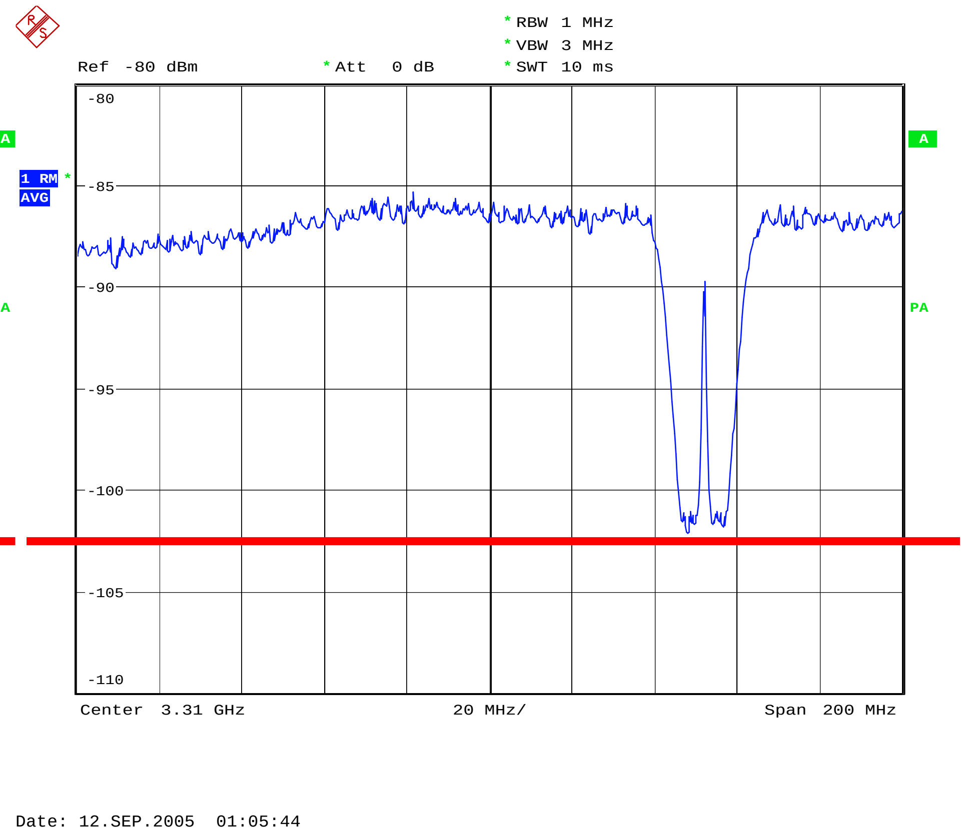
Notch bandwidth: 7.25 MHz
Notch depth: 30 dB
AIC tones: 2(left) + 2(right)
In-band tones: 3 (zeros)
AIC coef. quantization: 5 bit (see below)
Interference cancellation: 6 bit
Transmitter DAC: 6 bit
Total tones used for mitigation: 7
Total number of computed AIC tones: 4

- Additional notch depth via “Active Interference Cancellation” (AIC)
  - Under consideration for inclusion in the MB-OFDM spec
  - Modest addition to system complexity
  - Reference: H. Yamaguchi (TI), 10th ECC TG3 Meeting, Copenhagen, July 11, 2005

Demonstrate Avoidance (recording)

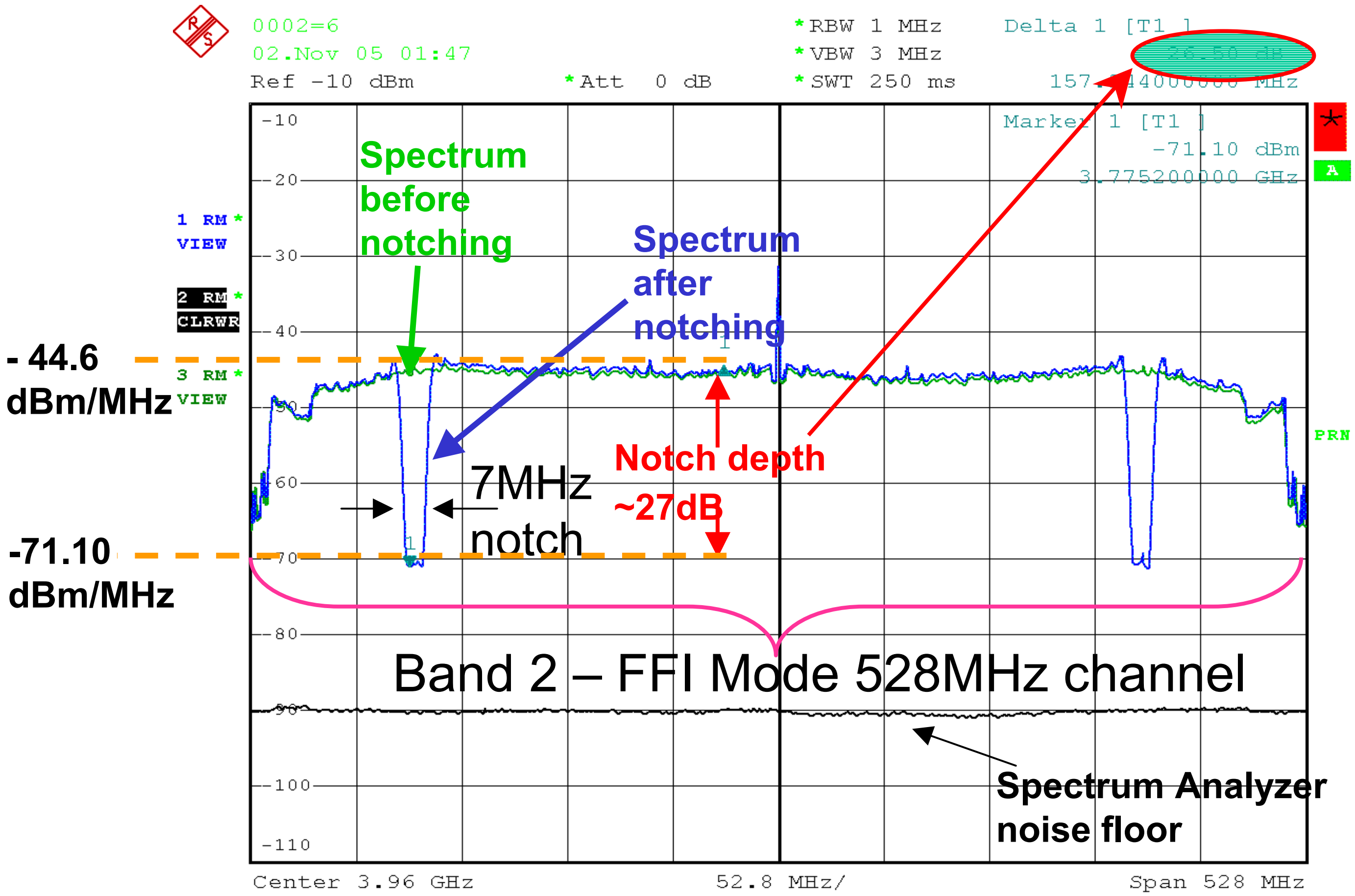


MB-OFDM signal with 20MHz notch (5 tones)



MB-OFDM signal plus “FWA” inside 20MHz notch

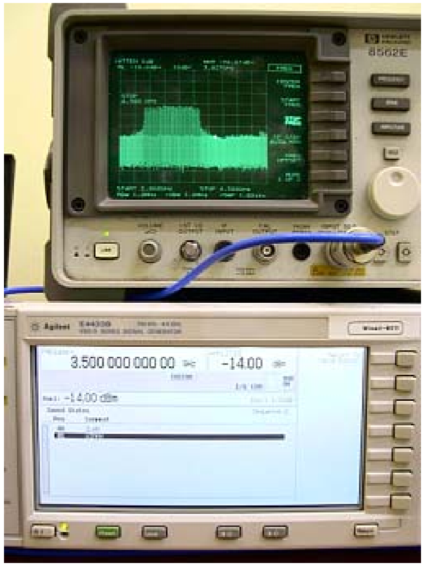
7MHz notch – Real Measurement

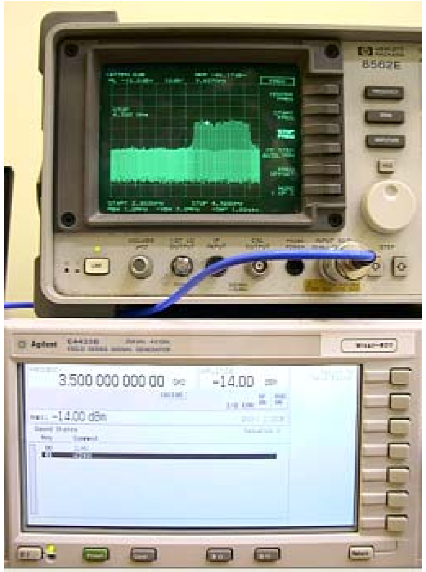


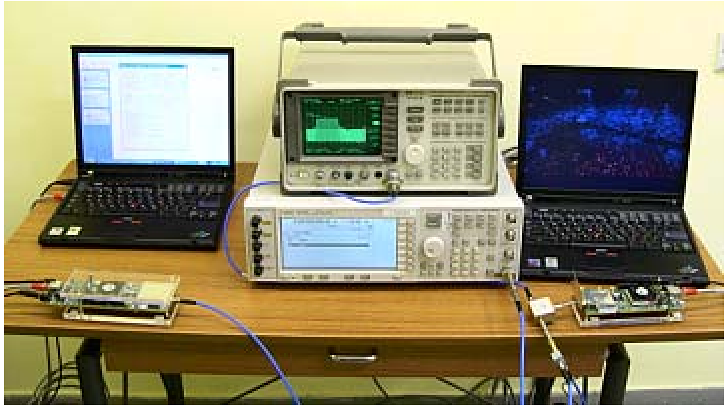
Source: Staccato Communications

Detect And Avoid (DAA) Demonstration

- DAA is the base for Europe and Japan regulation proposals
- Wisair demonstrated DAA capability in Europe CEPT TG3 Meeting
- Avoid usage in bands used by
  - Mobile 3G / 4G
  - WiMax
  - European WLL







Product Design Philosophy

- I don't like having to replace my equipment frequently
  - Most customers don't have the discretionary income of engineers, let alone marketing people…
- We accept product obsolescence, but:
  - 32 year old 'classic cars' still work
  - NTSC (and PAL) TVs still work (until 2010)
  - DOS PCs, Classic MACs and Windows 3.1 PCs still work
  - AMPS cell phones still work in US networks
  - my LaserJet printer bought in 1996 still works
- We should be designing products that can be expected to work for 10 years.

Design to Last

- The lower frequency band looked clear in 2002, but in 2006 it will require mitigation.
- The upper frequency band looked clear in 2002, but in 2006 it will be narrower.
  - And the remains may need mitigation someday
- Interference works both ways:
  - Unforeseen future incumbents may interfere with a radio sold in 2006, causing unexpected failures
- We should anticipate that risk and design an adaptive and agile IEEE standard radio.

Why is OFDM Essential:

- Worldwide regulatory compliance
  - Next year (2006)
  - Farther in the future (e.g. after 2010)
- Design to Last
  - It should not surprise the customers by failing when new incumbents appear.

MB-OFDM -- Conclusions

- Has performance that exceeds IEEE PAR requirements.
- Now offers even more robust performance in presence of multipath & interference (DCM, GT, Interleaving, …)
- Offers digitally generated signal / spectrum that
  - can accommodate differing world-wide regulations and “on-the-fly” interference scenarios
  - has degrees of freedom for the future
- Has garnered support of hundreds of companies in silicon, telecom, computing, and entertainment electronics
- Has multiple companies announcing silicon availability
  - Several have already demonstrated DAA

Call To Action

- Break the deadlock.
- Choose a design which facilitates mitigation.
- Choose a design which is flexible enough to keep working long after the customers bought it.
- Vote to select and confirm Merged Proposal #1.

Backup

Fixed-Frequency Interleaving

- Added three new time-frequency codes (TFCs):
  - New codes are equivalent to transmitting on a single frequency band (FDMA).
  - These new modes are referred to as Fixed-Frequency Interleaving (FFI).
  - Summary of all TFCs is shown below

TFC Number	Type	Preamble	BAND_ID					
1	TFI	1	1	2	3	1	2	3
2	TFI	2	1	3	2	1	3	2
3	TFI	3	1	1	2	2	3	3
4	TFI	4	1	1	3	3	2	2
5	FFI	5	1	1	1	1	1	1
6	FFI	6	2	2	2	2	2	2
7	FFI	7	3	3	3	3	3	3

- Support for TFI and FFI is mandatory within the standard:
  - No hardware penalty for supporting FFI modes in addition to TFI modes.

- Advantages of FFI modes:
  - Improved SOP performance.
  - Use TFC 7 to operate w/o mitigation in CEPT areas before 2010

New Data Rate of 106.7 Mbps

- MB-OFDM authors continue to maintain 110 Mbps data rate to allow direct comparison against the TG3a selection criteria (≥10m range @ ≥110Mbps)
- However, from a practical point of view, the required code rate of 11/32 is not particularly elegant or necessary
- We prefer to use a 1/3 rate code with no puncturing and provide a slightly lower data rate
- The legacy 110Mbps rate will continue to be part of the proposal for purposes of comparison with other contending proposals, and to demonstrate compliance with the original selection criteria
    - Silicon implementation of the legacy 110Mbps rate is optional.

Updated Data Rate Table

Note: Over-the-Air "Chip" Rate = 640 Mcps in All Cases

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

FDS = Frequency Domain Spreading, TDS = Time Domain Spreading

Dual Carrier Modulation (1)

- Previous modulation approach for 320, 400, 480 Mbps:
  - Map 2 interleaved bits onto a QPSK constellation and then map symbol onto the appropriate IFFT tone.

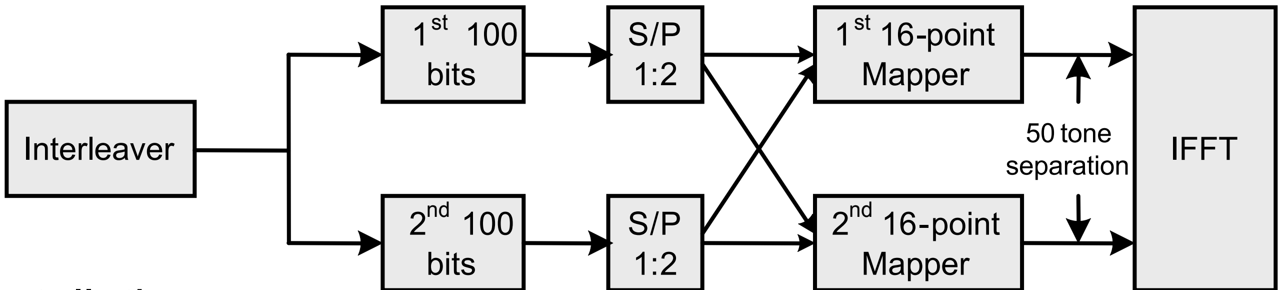
  - When there is a deep fade on the tone, the system has to rely solely on strength of error correction code to recover lost information.
- As the code strength decreases, the performance gap from AWGN starts to increase (also known as loss in diversity).
- Some have suggested that this loss in diversity is “fundamental” and can never be recovered.
- We have shown in the past that Guard Tone mapping is one way to reduce this loss. In the following slides, we will show another simple technique to reduce the loss even further.

Dual Carrier Modulation (2)

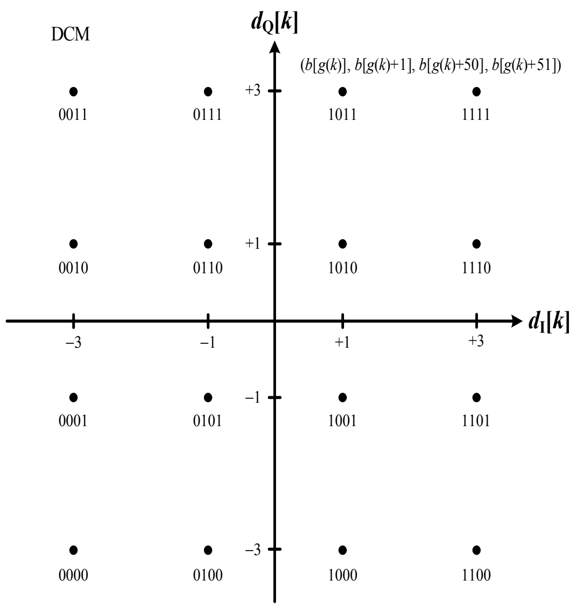
- Basic idea behind DCM:
  - Map 4 interleaved bits onto *two* 16-point symbols using two fixed but different mappings. This yields a 16-QAM-like constellation (see backup).
  - Map the resulting two 16-point symbols onto two different IFFT tones separated by 50 tones.
- Advantage of DCM:
  - The same 4 bits of information are mapped onto two tones that are separated by at least 200 MHz.
  - The probability that there is a deep fade on both tones is QUITE SMALL.
  - Even if there is a deep fade on one of the two tones, the 4 bits of information can be recovered using simple detection schemes.
  - Therefore, the loss in diversity will be much smaller.
- <u>Benefit:</u> Reduce diversity loss (by ~1.5 dB) for the higher data rates, where there is no frequency-domain or time-domain spreading.
- <u>No change</u> to PSD, no change to interference potential of Tx signal.

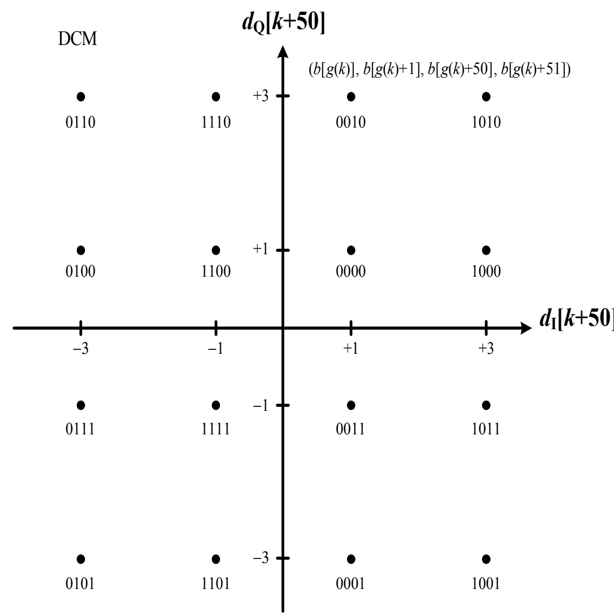
Dual Carrier Modulation (3)

- Block diagram of DCM:



- 16-point constellations:





System Performance with DCM and GT “Copy Over”

- The distance at which the Multi-band OFDM system can achieve a PER of 8% for a 90% link success probability is tabulated below*:

	AWGN	CM1	CM2	CM3	CM4
110 Mbps	21.5 m	New: 12.0 m Original: 11.4 m	New: 11.4 m Original: 10.7 m	New: 12.3 m Original: 11.5 m	New: 11.3 m Original: 10.9 m
200 Mbps	14.8 m	New: 7.4 m Original: 6.9 m	New: 7.1 m Original: 6.3 m	New: 7.5 m Original: 6.8 m	New: 6.6 m Original: 4.7 m
480 Mbps	9.1 m	New: 3.8 m Original: 2.9 m	New: 3.5 m Original: 2.6 m	N/A	N/A

* Includes losses due to front-end filtering, clipping at the DAC, ADC degradation, multi-path degradation, channel estimation, carrier tracking, packet acquisition, etc.

Performance Exceeds IEEE PAR Requirements

Improvement with DCM + GT

- System performance improves for both channel models:
  - CM1: 2.9 m → 3.8 m (+2.4 dB improvement).
  - CM2: 2.6 m → 3.5 m (+2.6 dB improvement).
- Using the fact that shadowing contribution is ~3.9 dB to the overall degradation, the gap from AWGN to the 480 Mbps mode using DCM + Guard Tone Mapping has already been reduced by ~2.5 dB!
- This analysis shows that the Rayleigh fading for MB-OFDM can be mitigated by additional signal processing.

Gap of 6 dB in fading is *NOT* a fundamental issue

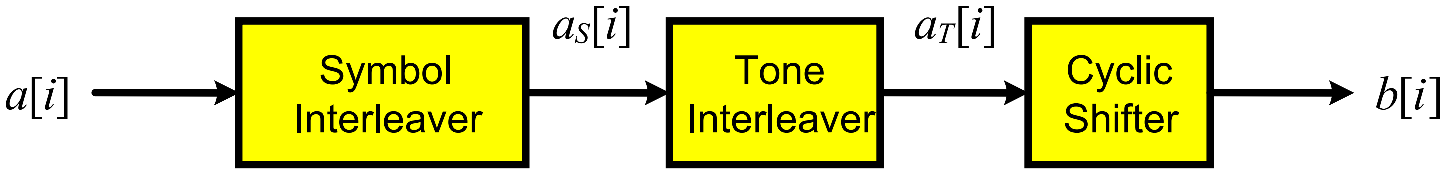
Transmit Power Control

- Mapping between TXPWR_LEVEL and Transmit Power Attenuation

TXPWR_LEVEL	TX Power Attenuation for TFI Modes	TX Power Attenuation for FFI Modes
0	0 dB	0 dB
1	2 dB	2 dB
2	4 dB	4 dB
3	6 dB	6 dB
4	8 dB	8 dB
5	10 dB	RESERVED
6	12 dB	RESERVED
7	RESERVED	RESERVED

- Relative accuracy of the transmit power attenuation shall be the maximum of ±1 dB or ±20% of the change in attenuation (dB scale).

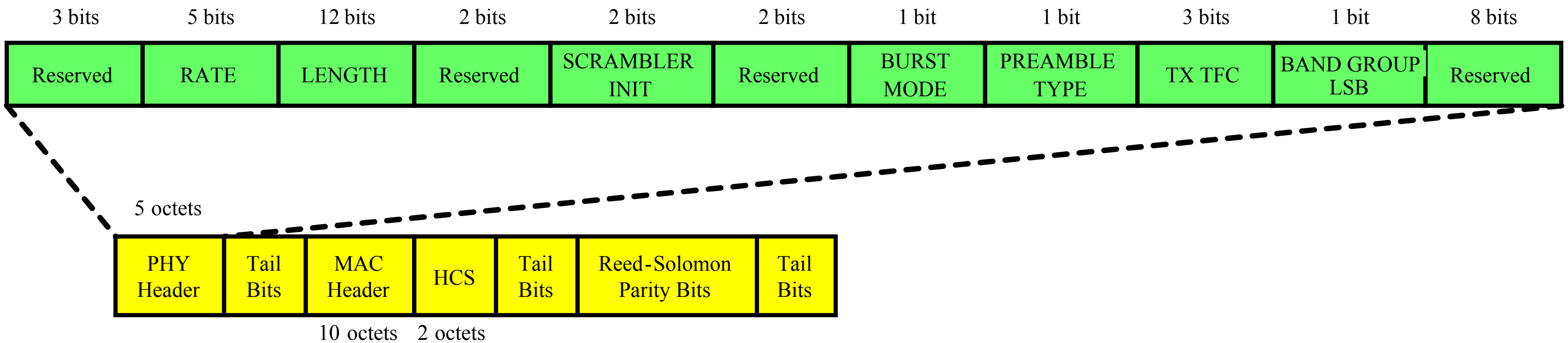
Three-Stage Interleaver



1. The **symbol interleaver** permutes the bits across 6 consecutive OFDM symbols enables the PHY to exploit frequency diversity within a band group.
2. The intra-symbol **tone interleaver** permutes the bits within an OFDM symbol to exploit frequency diversity across subcarriers and provide robustness against narrow-band interferers.
3. The intra-symbol **cyclic shifter** shifts the bits in successive OFDM symbols by deterministic amounts to better exploit frequency diversity for modes that employ time-domain spreading and fixed-frequency interleaving.

Changes to PLCP Header (1)

- New PLCP Header format:



PLCP Header

- Changes to the PHY Header:
  - Added two bits to support burst mode capabilities. (1) Burst Mode bit specifies whether next packet is part of the burst, (2) Preamble Type bit specifies whether next preamble is a standard preamble or burst preamble. (Burst Mode supports streaming with shorter preamble.)
  - Added two bits to mitigate potential problems from adjacent channel interference: (1) TX_TFC specifies the TFC used for transmission, (2) BG_LSB specifies the LSB of the BG used for transmission.

Changes to PLCP Header (2)

- Changes to the PLCP Header:
  - Replaced PAD bits with Reed-Solomon (RS) parity bits.
  - A (23,17) systematic Reed-Solomon outer code is added in order to increase the robustness of the PLCP header.
  - RS protects only the PHY header, MAC header, and HCS (total = 17 bytes).
  - Encoding of RS parity bits is mandatory at the transmitter (additional complexity is quite small).
  - Since RS code is systematic, a RS decoder is optional at the receiver.
- Reasons for adding RS outer code:
  - Increases robustness of the PLCP header.
  - "Future proofs" standard $\Rightarrow$ PLCP header will not be the limiting factor for packet error rate.
  - This means that we can add advanced coding schemes to the standard in the future without having to change packet structure.
- RS (23, 17) code is derived from a shortened RS(255, 249) code.

Complexity (numbers supplied by TI)

- Die size for PHY core:

Process	Complete Analog*	Complete Digital
90 nm	3.0 mm^2	1.9 mm^2
130 nm	3.3 mm^2	3.8 mm^2

* Component area.

- Active CMOS power consumption for PHY core:

Process	TX 55 Mb/s	TX 110, 200 Mb/s	RX 55 Mb/s	RX 110 Mb/s	RX 200 Mb/s
90 nm	85 mW	128 mW	147 mW	155 mW	169 mW
130 nm	104 mW	156 mW	192 mW	205 mW	227 mW

Recommended Out-of-band Emissions (1)

- For cases, when UWB devices will be in close proximity to cellular devices and GPS downlink devices, the authors of Merged Proposal #1 recommended tighter out-of-band (OOB) emissions.
- The OOB emissions mask is specified for average power emissions and excludes possible narrowband spectrum spikes or spurs.
- Assumptions for new OOB emissions mask:
    1. Device separation of 60 cm.
    2. Noise figure of 7 dB for cellular devices, and 3.5 dB for GPS devices
    3. Allowed noise floor increase of 1 dB for cellular devices, and 0.5 dB for GPS devices.
    4. Victim gain antenna of –3 dBi.
    5. Free space path loss model (frequency used in path loss model is defined to be the lowest frequency of victim's operating band).

Recommended Out-of-band Emissions (2)

- Recommended OOB mask:

Frequency Band (MHz)	FCC Handheld Limit (dBm/MHz)	Recommended limit (dBm/MHz)
869-894	§15.209	-83.3
925-960	§15.209	-82.5
1570-1581	-75.3	-84.7
1805-1880	-63.3	-76.8
1930-1990	-63.3	-76.2
2110-2170	-61.3	-75.4

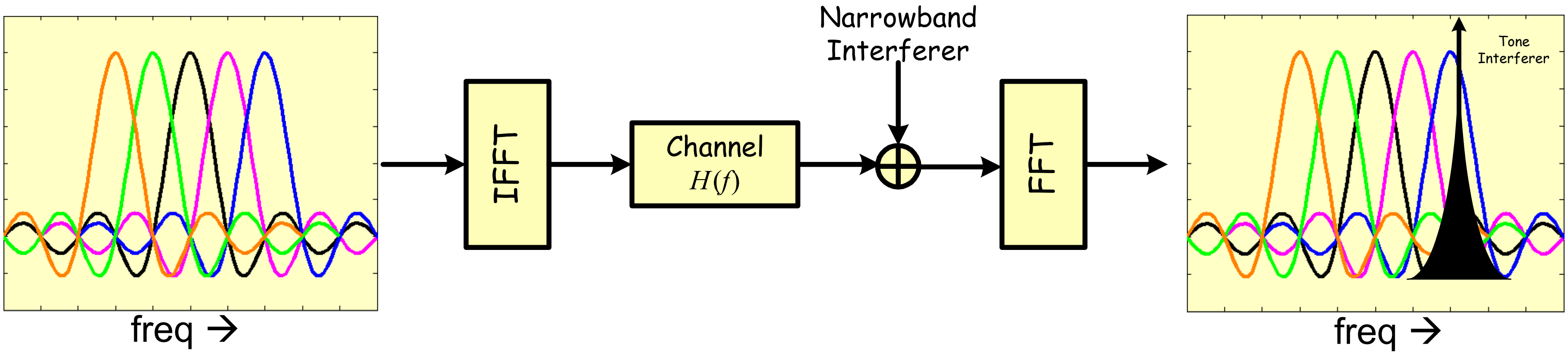
- These new recommended emission limits should help to address some of the concerns that are being raised within the ITU.

Why OFDM?

Why OFDM is Preferred (1)

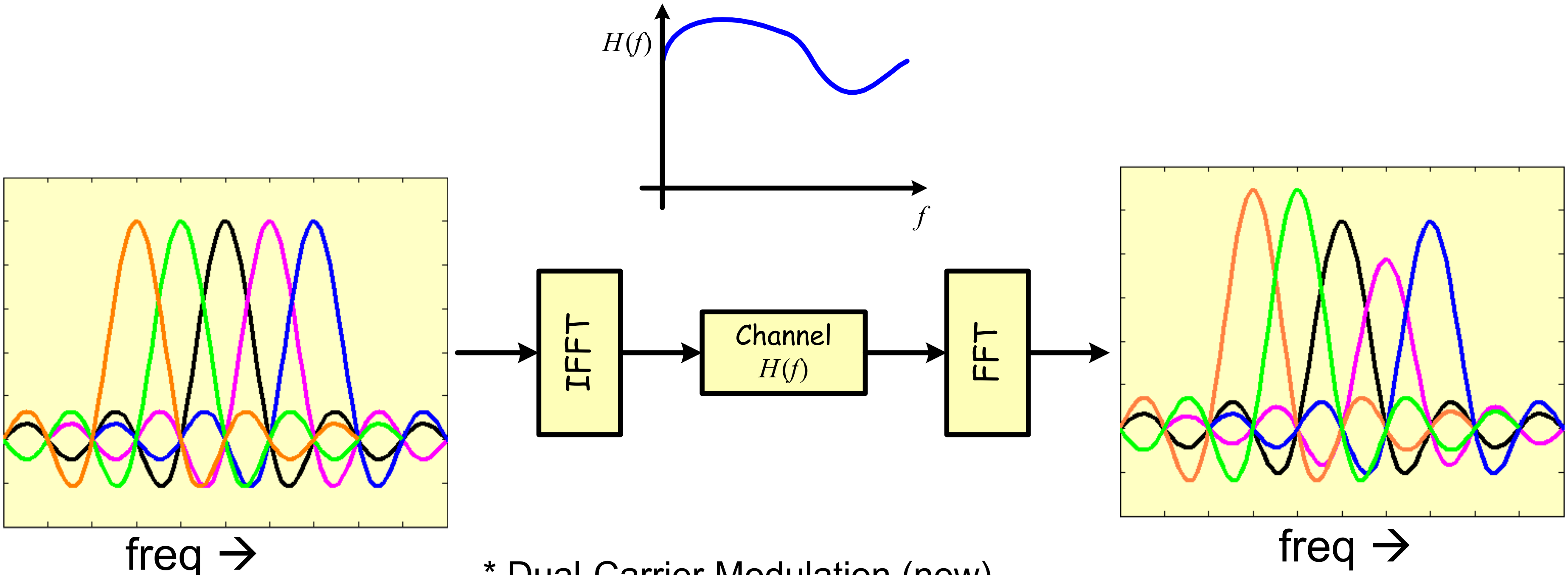
- OFDM is spectrally efficient:
  - IFFT/FFT operation ensures that sub-carriers do not interfere with one other.
  - Since the sub-carriers do not interfere, the sub-carriers can be brought closer together ⇒ High spectral efficiency.

- OFDM has an inherent robustness against narrowband interference:
  - Narrowband interference will affect at most a couple of tones.
  - ⇒ Do not have to drop the entire band because of narrowband interference.
  - ⇒ Erase information from the affected tones, since they are known to be unreliable. Already-present FEC recovers lost information.



Why OFDM is Preferred (2)

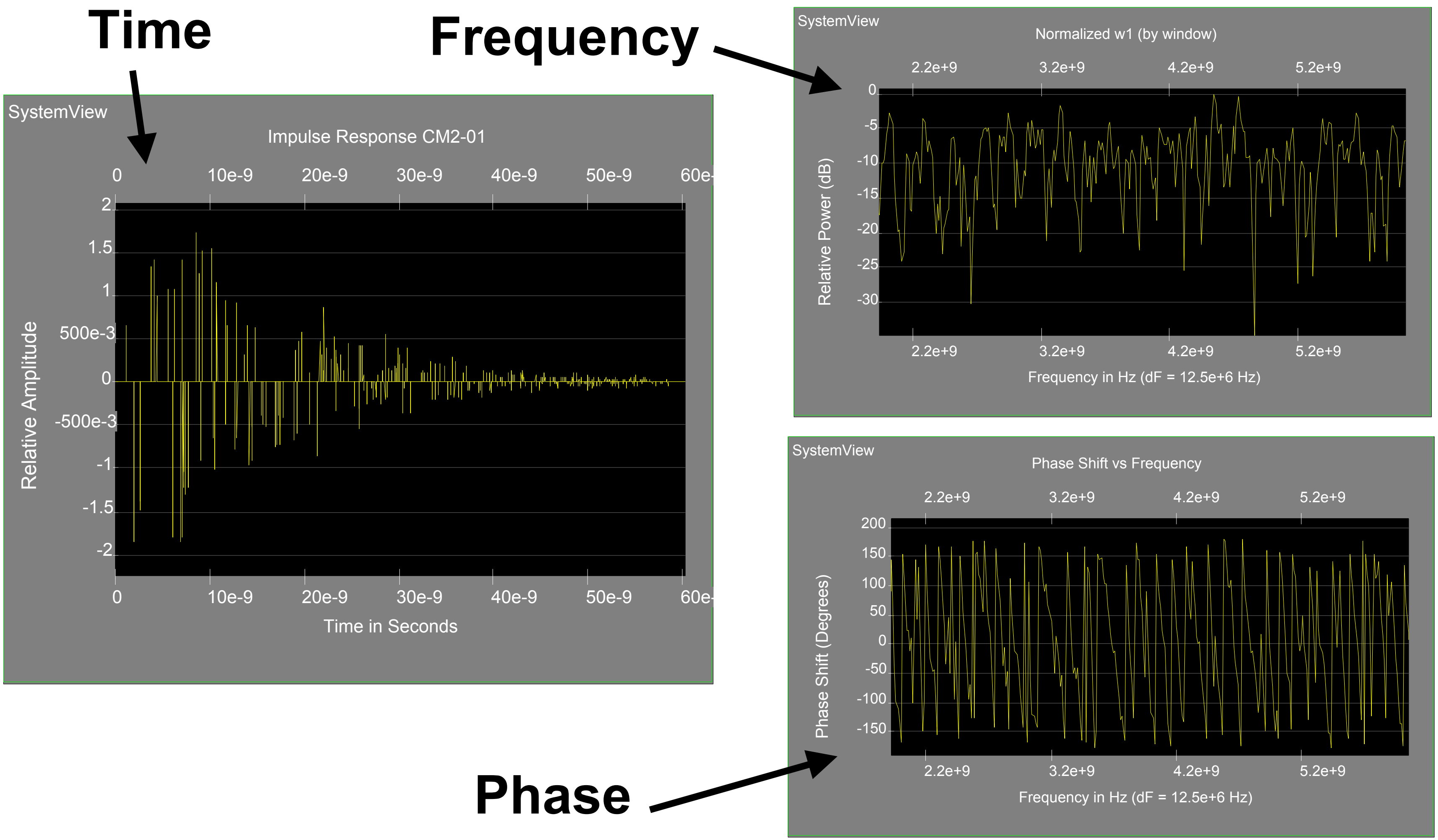
- OFDM has excellent robustness to multipath.
- FEC and DCM* compensate for faded tones.



* Dual-Carrier Modulation (new)

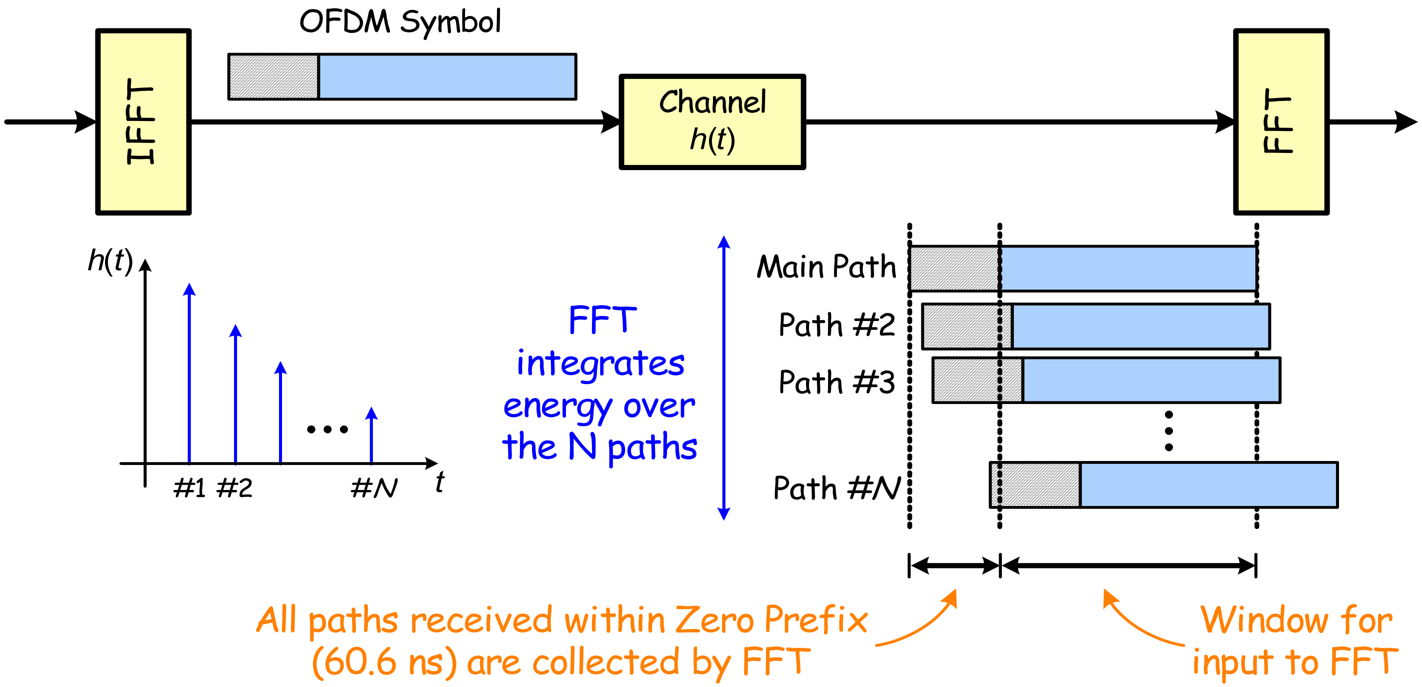
Multipath – The Engineer's Nightmare & Opportunity

Typical UWB Channel Impulse Response



Why OFDM is Preferred (3)

- Typical channels have hundreds of paths
- MB-OFDM captures energy from virtually all of them.



Previous Submissions (1 of 2)

1. **MB-OFDM Specification**, Anuj Batra (Texas Instruments), et al., doc. 15-04-493
2. **MB-OFDM Proposal Update**, David Leeper (Intel) doc 15-05-0397
3. **DAA for Multi-band OFDM UWB**, Jim Lansford (Alereon), doc. 15-05-0575
4. **Market Needs for a High-Speed WPAN Specification,** Robert Huang (Sony) and Mark Fidler (Hewlett Packard), doc. 15-04-0410
5. **MB-OFDM for Mobile Handhelds,** Pekka A. Ranta (Nokia), doc. 15-04-432
6. **In-band Interference Properties of MB-OFDM,** Charles Razzell (Philips), doc. 15-04-0412

Previous Submissions (2 of 2)

7. **Spectral Sculpting and Future-Ready UWB,** David Leeper (Intel), Hirohisa Yamaguchi (TI), et al., doc. 15-04-0425
8. **CCA Algorithm Proposal for MB-OFDM,** Charles Razzell, doc. 15-04-0413
9. **What is Fundamental?**, Anuj Batra, et al., doc. 15-04-430
10. **Time to market for MB-OFDM**, Roberto Aiello (Staccato) Eric Broockman (Alereon) and David Yaish (Wisair) doc. 15-04-432
11. **MB-OFDM Update**, Matt Shoemake (WiQuest), doc. 15-04-518
12. **MB-OFDM Update**, Charles Razzell (Philips), doc 15-04-273

Selected References

15-03-0343, **MultiBand OFDM September 2003 presentation**, Anuj Batra

15-03-0449, **MultiBand OFDM Physical Layer Presentation**, Roberto Aiello and Anand Dabak

15-04-0010, **MultiBand OFDM January 2004 Presentation**, Roberto Aiello, Gadi Shor and Naiel Askar

15-04-0013, **C-Band Satellite Interference Measurements TDK RF Test Range**, Evan Green, Gerald Rogerson and Bud Nation

15-04-0017, **Coexistence MultiBand OFDM and IEEE 802.11a Interference Measurements**, Dave Magee, Mike DiRenzo, Jaiganesh Balakrishnan, Anuj Batra

15-04-0018, **Video of MB-OFDM, DS-UWB and AWGN Interference Test**, Pat Carson and Evan Green

MB-OFDM Contributors (1)

Roberto Aiello	Staccato Communications
Anand Anandakumar	Jaalaa
Naiel Askar	General Atomics
Jaiganesh Balakrishnan	Texas Instruments
Anuj Batra	Texas Instruments
Nathan Belk	Texas Instruments
Roger Bertschmann	SiWorks
Dagnachew Birru	Philips
Leo Bogod	Nokia
Chuck Brabenac	Intel
Vern Brethour	Alereon
Stephan ten Brink	Realtek Semiconductors
Sujai Chari	Tzero
Jonathon Cheah	Femto Devices
Francois Chin	Institute for Infocomm Research
Anand Dabak	Texas Instruments
Joe Decuir	MCCI
Yossi Erlich	Infineon
Eran Fishler	Infineon
Jeff Foerster	Intel
Paul Fontaine	Texas Instruments

Vasanth Gaddam	Philips
Miki Genossar	Adimos
Ranjit Gharurey	University of Michigan
Manish Goel	Texas Instruments
Sorin Goldenberg	Wisair
Danielle Griffith	Texas Instruments
Assaf Gurevitz	Infineon
Jin-Meng Ho	Texas Instruments
Dale Hocevar	Texas Instrements
Eyal Hochdorf	Infineon
Srinath Hosur	Texas Instruments
Osamu Inagawa	NEC Electronics
Daryl Kaiser	Tzero
Joy Kelly	Alereon
HaeSik Kim	Samsung Advanced Institute of Technology
YongSuk Kim	Samsung Advanced Institute of Technology
Noam Kogos	Adimos
Rajeev Krishnamoorthy	Tzero
Nishant Kumar	Staccato Communications
Haim Kupershmidt	Wisair
Do-Hoon Kwon	Samsung Advanced Institute of Technology
Torbjorn Larsson	Staccato Communications

MB-OFDM Contributors (2)

Joe Lauer	Broadcom
Simon Lee	Texas Instruments
David Leeper	Intel
Jerry Lin	Texas Instruments
Susan Lin	General Atomics
Srinivas Lingam	Texas Instruments
Steve Lo	Tzero
Ian Macnamara	Nokia
David Magee	Texas Instruments
Ravishankar Mahadevappa	Realtek Semiconductors
Tom Matheney	Alereon
Dan Meacham	Staccato Communications
Suzuki Mitsuhiro	Sony
Shaomin Mo	Panasonic
Andreas F. Molisch	Mitsubishi Electric Research Laboratories
Lars Mucke	Staccato Communications
Yves-Paul Nakache	Mitsubishi Electric Research Laboratories
Hideo Ohba	NEC Electronics
Eric Ojard	Broadcom
Philip Orlik	Mitsubishi Electric Research Laboratories
SeungYoung Park	Samsung Advanced Institute of Technology
Shrenik Patel	Alereon
Xiaoming Peng	Institute for Infocomm Research
Sridhar Rajagopal	WiQuest
Pekka Ranta	Nokia
Yaron Rashi	Infineon
Charles Razzell	Philips
Jaeho Roh	Samsung Advanced Institute of Technology
Ebrahim Saberinia	University of Nevada, Las Vegas
Tomoki Saito	NEC Electronics
Yasufumi Sasaki	NEC Electronics
Assaf Sella	Wisair
Kevin Shelby	Alereon
Matthew Shoemake	WiQuest
Gadi Shor	Wisair
Srinivasa Somayazulu	Intel
Robert Sutton	TDK R&D
Kazuhisa Takamura	Sony
Nir Tal	Texas Instruments
Jun Tang	University of Minnesota
Larry Taylor	Staccato Communications
John Terry	WiQuest
Ahmed Tewfik	University of Minnesota
Takashi Usui	Sony
Hirohisa Yamaguchi	Texas Instruments
Jin Zhang	Mitsubishi Electric Research Laboratories
Anat Zilber	Adimos