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

Submission Title: Interference Comparison: UWB-OFDM Versus UWB-DS-CDMA

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Abstract: Regulatory bodies around the world are interested in enabling the benefits of UWB technology, but have a duty to write the regulations so as to obtain those benefits with a low potential for interference. Similarly, the IEEE also represents a wide mixture of industries and has a duty, as a technical body, to lead the UWB industry to the safest approach. This talk analyzes the interference of the MBOA-OFDM and XSI/ParthusCeva/Motorola DS-CDMA proposed systems on victim receivers with 10 MHz to 20 MHz bandwidth as seen at the video detector. The UWB-OFDM system is found to cause significantly more interference than DS-CDMA. While the standardization decision might be difficult if the weight placed on interference had to be so large as to essentially ignore other performance factors, In this case, the decision is made easier because not only is the DS-CDMA approach safer from an interference point of view, it has better performance-- based on fundamental principles (see 0344r0). In fact, the MBOA-OFDM system derives no fundamental benefit from UWB, other than to enable higher power under some interpretations of the FCC rules. If regulations are interpreted so as to equalize the interference between the two systems, then the MBOA-OFDM performance will be even more degraded relative to DS-CDMA.

Purpose: Informational: This talk is submitted to help the TG3A voters understand the fundamental differences between interference effects of UWB DS-CDMA and UWB OFDM systems.

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UWB – A New and Unique Opportunity

- ❖ Because of fundamental physics, UWB is a market opportunity that changes the fundamental tradeoffs of performance vs. cost/power consumption
 - ❑ Bluetooth price, but speed and QoS beyond 802.11a,g
 - ❑ An intersection of PC and CE products (including mobile telephony)
 - ❑ (Plus a host of uses other than high speed communications)

 - ❖ Due to its uniqueness, Regulators granted a fundamental change in the allocation of spectrum
 - ❑ Wide low-power versus \leftrightarrow narrow high-power
 - ❑ Intentional versus unintentional
 - “UWB” previously only allowed as unintentional byproduct
-
- Submission
- Slide 2
- John McCorkle, XtremeSpectrum
- o Digital noise, Hair dryers etc., city noise, industrial noise

UWB - Anti-Interference Driven

- ❖ **Regulators** are driven by mission to produce win-win for all users of spectrum
 - ❑ Pluses - desire to enable people to enjoy UWB's fundamental benefits
 - High data rates, ranging and imaging in multipath and through lossy media (walls, earth)
 - ❑ Minuses – Being careful to limit the potential to cause harmful interference
 - ❑ Constituents –entire mix of government, industry, & personal uses of RF
 - Regulators must pick a worst-case victim receiver types and not interfere with any of them.

- ❖ **IEEE** is a technical body that as a whole, has identical interests
 - ❑ Fundamental performance/complexity superiority—especially important as “UWB” matures
 - ❑ Minimizing interference to everyone else who uses the spectrum
 - ❑ As a whole, IEEE represents the same broad base of constituents.

- ❖ Potential for interference is a serious issue and must be weighted very heavily
 - ❑ Impact on its success and on its future is at stake.
 - ❑ Required in order to be consistent with the goals of IEEE.

- ❖ **The IEEE 802.15.3a committee should not choose an implementation that produces more interference and expect regulators, or the broader industry to accept it.**

FCC's Certification Procedures

- ❖ Certification is a specific term meaning that the device is approved by the FCC and can be mass produced and sold.
- ❖ **After Maturity** Compliance Testing and Certification Procedures
 - ❑ Independent testing labs perform test and issue certification
 - Independent testing labs are given authority by FCC to independently certify devices
- ❖ The case for UWB today is the **Before Maturity** case
- ❖ **Before Maturity** Compliance Testing Certification Procedures
 - ❑ Role of independent testing labs is:
 - Do initial compliance tests on devices
 - Submit to FCC a test report specifying procedures and results
 - o Letter of Conformance
 - ❑ Role of FCC is:
 - Interpret rules
 - Review/repeat tests as it considers necessary
 - Issue FCC Certification
 - Authorize independent labs when it is satisfied everyone is testing properly

Status of Certification of UWB devices

- ❖ Devices have already been FCC certified – GPR, thru wall imaging, etc.
 - ❑ None had rules-interpretation questions
 - ❑ All were specifically anticipated by the rules

- ❖ DS-CDMA is similar
 - ❑ Has no rules-interpretation question - was anticipated by the rules
 - ❑ DS-CDMA has Letter of Conformance by independent lab based on a clear understanding of the rules
 - ❑ Devices have a clear path to certification - Compliance with FCC rules is assured

- ❖ MBOA-OFDM compliance is still in question – rules-interpretation question
 - ❑ **MBOA Devices have NOT been FCC certified**
 - Press reports to the contrary are false
 - Only the FCC can do this and the FCC has not
 - ❑ The path to certification is not clear (different interpretations of rules)
 - Certification could require a significant power reduction
 - ❑ Rather than being anticipated, frequency hopping and gated waveforms were NOT anticipated to be applicable under the rules

Status of Request for Declaratory Ruling

- ❖ People are confused over how to interpret the FCC's "hopping must be turned off" and "Gating must be turned off" rule
- ❖ FCC was asked to clarify the interpretation
 - ❑ Under one interpretation - "A"
 - Gated/FH systems do not comply with the current FCC measurement rules unless the power of the hopped/gated bursts is reduced
 - ❑ Under the other interpretation - "B"
 - Bursts from the Gated/FH emissions are not reduced and can cause more interference than DS emissions.
- ❖ Interpretation of rules for MBOA-OFDM testing ***is still an issue***
 - ❑ The FCC said it was an issue but declined to affirm any interpretation
 - ❑ The FCC suggested that the IEEE study the interference effects and do the right thing:

IEEE should choose the approach that produces the highest performance for the least interference

What Is Status of Certification of DS-CDMA?

- ❖ DS-CDMA devices have been tested at an independent lab
 - ❑ The devices tested were found to be compliant

BUT REMEMBER

- ❖ Only end user products can be type-certified for sale
- ❖ CE manufacturers will be working with Si suppliers and the FCC on certification prior to introducing and demonstrating products at CES 2004.

Modulation Choice Has Three Keys

❑ Interference to others

- Minimization of potential to interfere with others
- Certainty in meeting regulations already in effect
- Flexible to meet potentially different world-wide reg's

❑ Hardware Complexity & Scalability

- Scales to diverse application needs (cost/performance flexibility, xmit only, slow-far vs fast-short, wall-plug vs battery, ranging, imaging)
 - High ratio of incremental performance to incremental complexity/power in the context of scaling to different applications
- Supports different MAC's for different app's (e.g. CSMA, TDMA)
- Clear path for performance to approach theoretical bounds over time

❑ Radio Performance

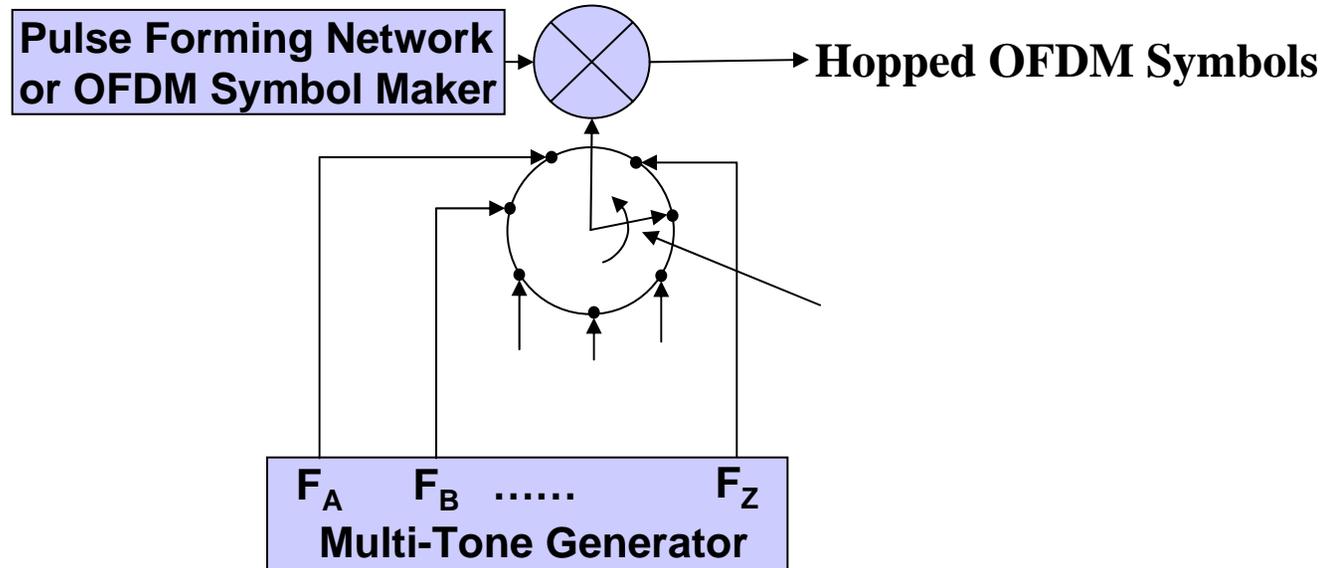
- Range & Data Rate
 - Constellation with greatest distance between points
 - Ability to take advantage of multipath energy
 - Energy capture alone is not sufficient, must be able to take advantage of it
- Multi-User Performance -- Maximum coding of energy
 - Consumer usage means pervasive horizontal deployment
 - Each user will want maximum rate supported and high QOS in multipath
- Robustness to incoming RFI as well as multi-user interference (MUI)

Choice of DS-CDMA Is Advantageous

- ❖ This talk illustrates both DS-CDMA and MBOA-OFDM interference in a 10 and 20 MHz victim receiver.
- ❖ The results demonstrate that MBOA-OFDM generates more interference.
- ❖ **DS-CDMA has higher performance and less interference**
 - ❑ DS-CDMA meets all three criteria best
 - Interference to others
 - Complexity and Scaleability
 - Performance

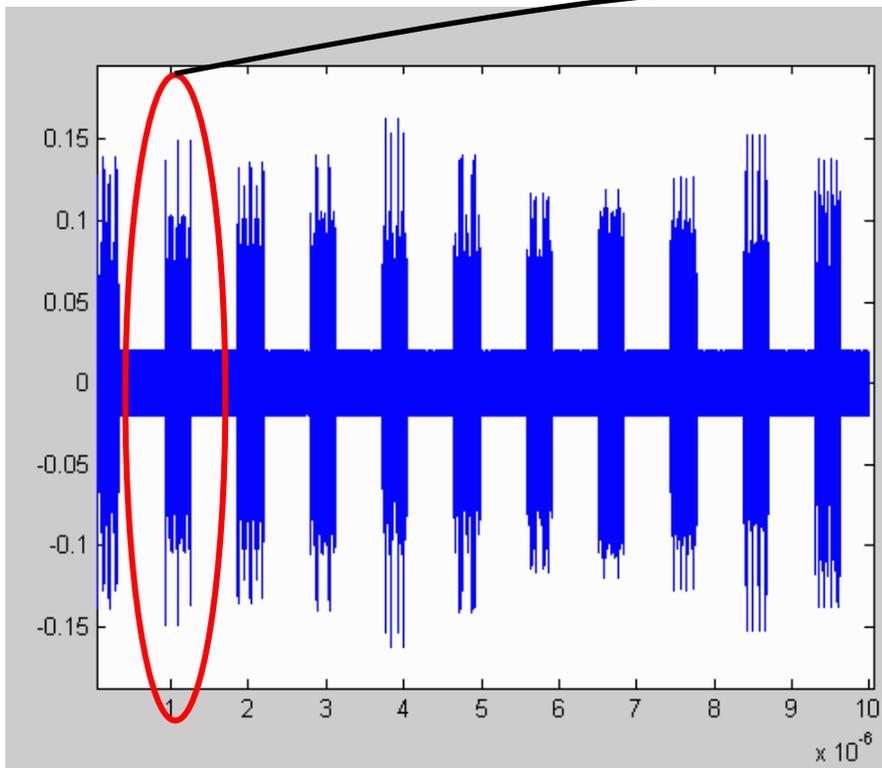
Illustration of MBOA FH-OFDM Transmitter

- ❖ Symbol is gated on for a 312 ns burst
- ❖ Each hop band has 312 ns burst followed by 624 ns quiet gap.
- ❖ The question regarding the FCC rule interpretation boils down to:
How big can the bursts get? -- But
- ❖ **Ultimately, the issue is what difference does it make to victims?**

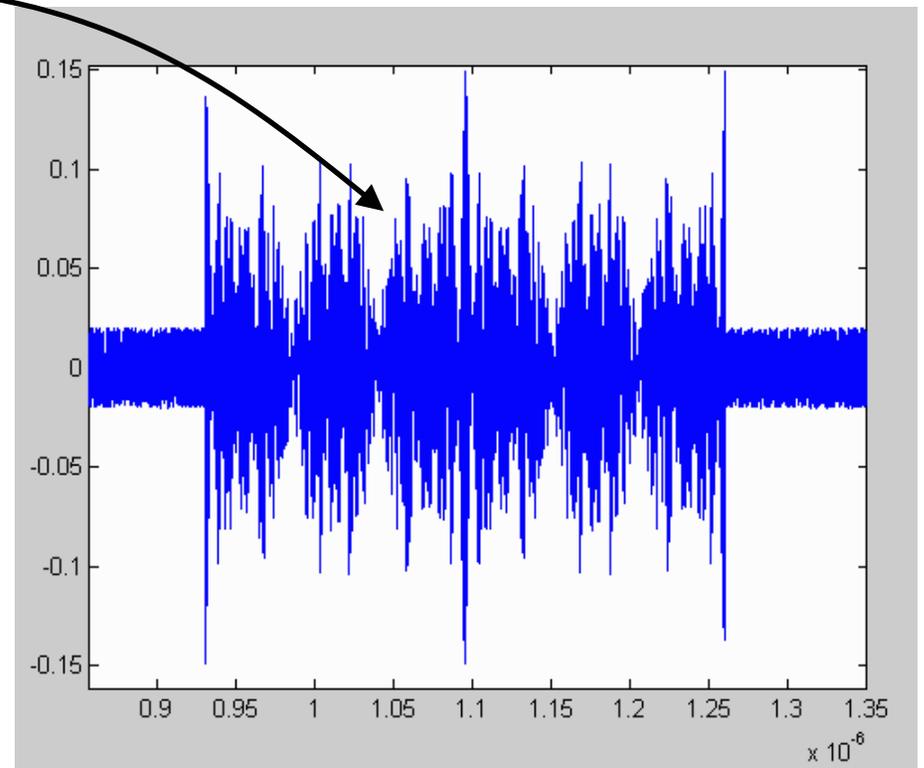


Frequency Hopping Waveform Is Gated On and Off

- ❖ Problem is that wider bandwidth receivers can see individual Bursts
 - ❑ They do no “averaging” to destroy peaks
- ❖ Burst Can Have Large Peaks within it – 9db Limit Applied In TI Implementation
 - ❑ Victim sensitivity to these is also a function of the victim bandwidth

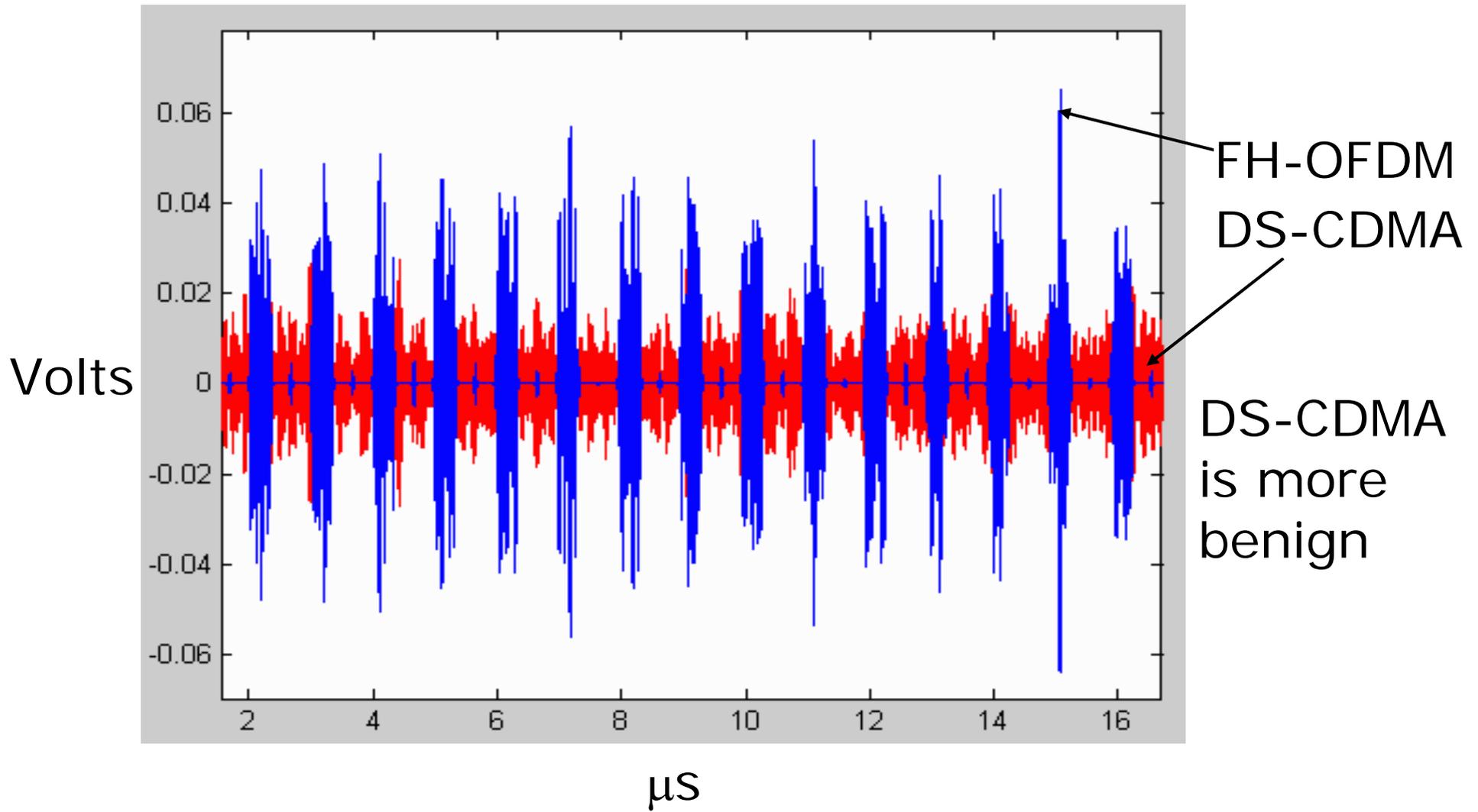


Pulse stream



Single “pulse”

FH/Gated versus DS-CDMA in a 40 MHz BW Victim Receiver – Pre Detection



Amplitude Probability Distributions (APD)

- ❖ Used by NIST Boulder to evaluate interference on wide variety of systems
- ❖ OFDM is NOT Gaussian!

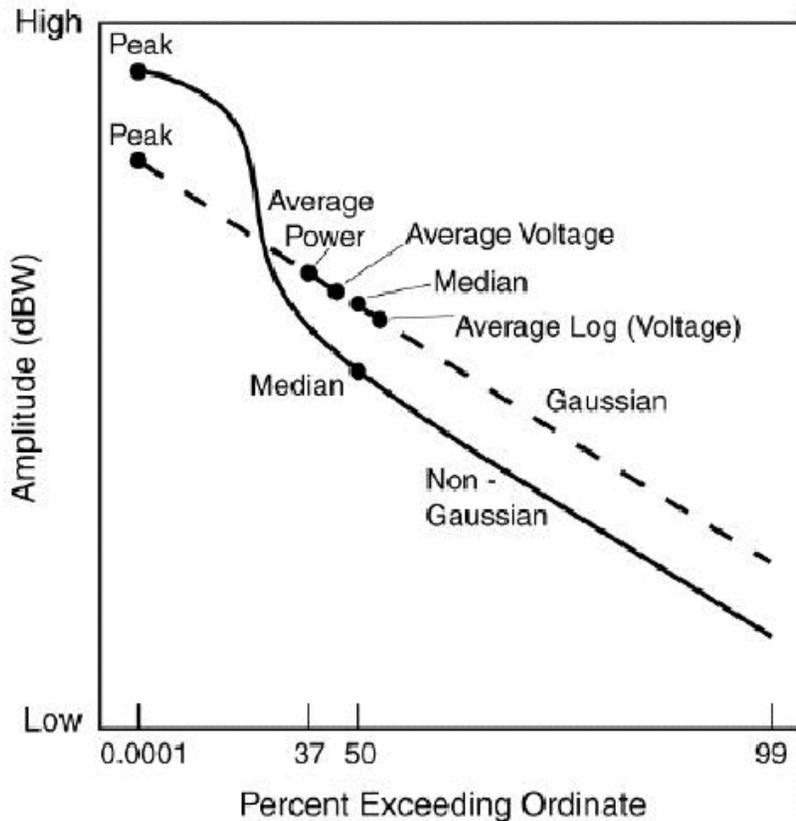
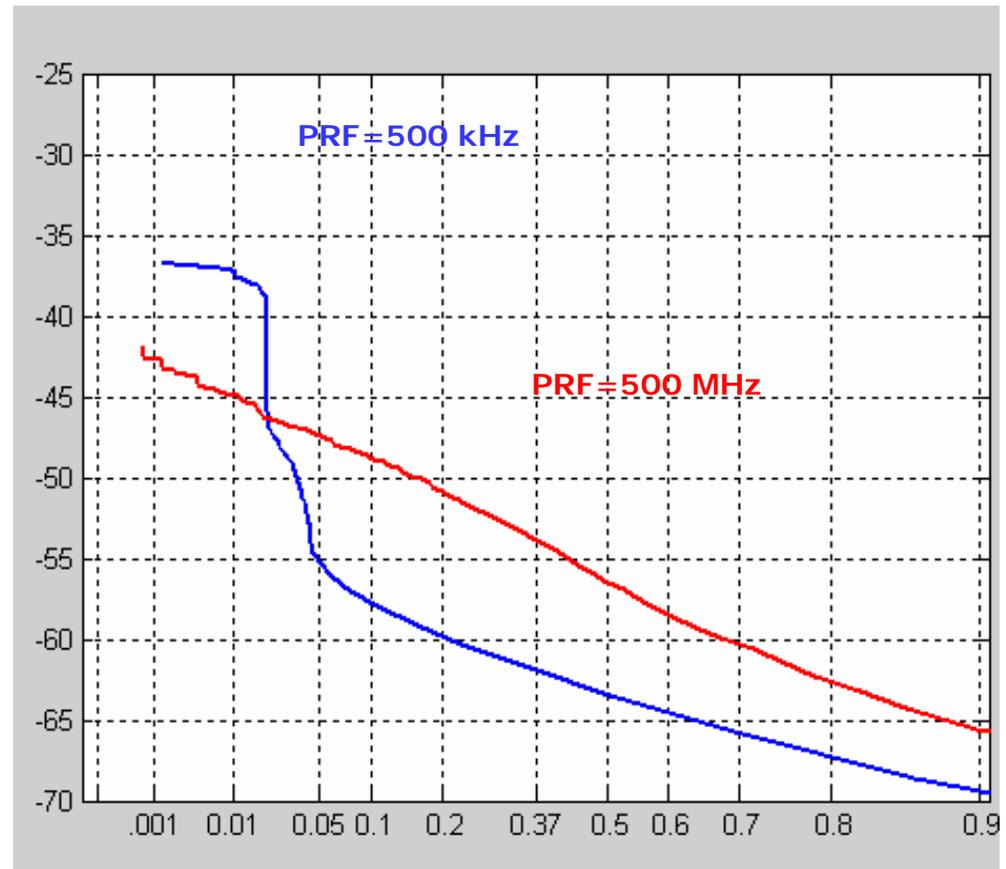


Figure A.4. Gaussian noise and non-Gaussian noise APDs plotted on a Rayleigh graph.



Results of MATLAB simulation of PN BPSK UWB in 50 MHz bandwidth

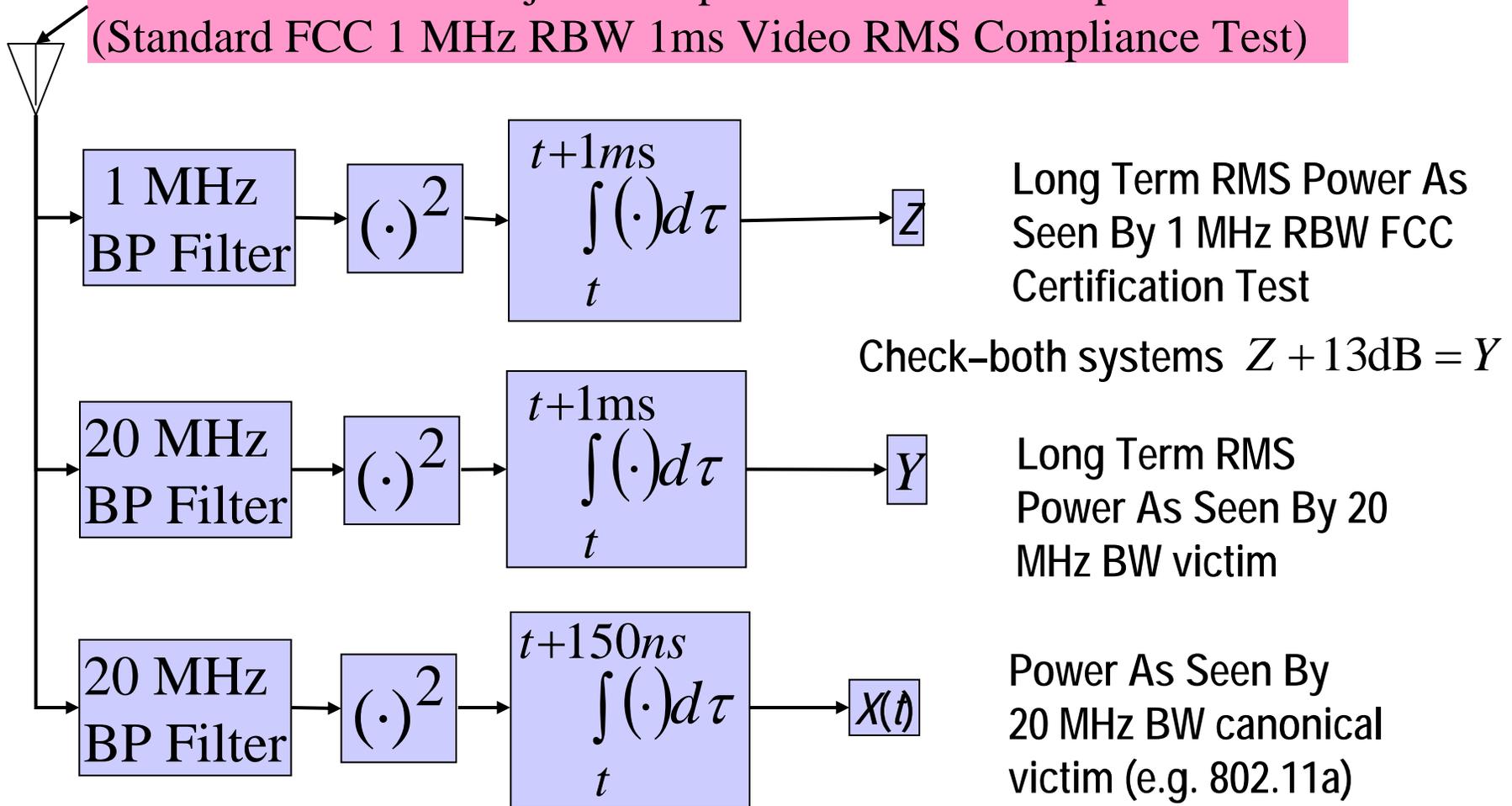
Quick Analysis

Address Canonical 20MHz BW System

- ❖ Slides Illustrate Increased Interference Potential of Gated/FH systems
- ❖ Representative of
 - Public Safety at 4.9 GHz
 - DSRC (Dedicated Short Range Communication) at 5.85 GHz
 - WLAN 802.11a (Unlicensed UNII at 5 GHz)
- ❖ Each has a bandwidth between 10 and 20 MHz
- ❖ Other systems with bandwidth greater than a few MHz are also at risk

Analysis Methodology

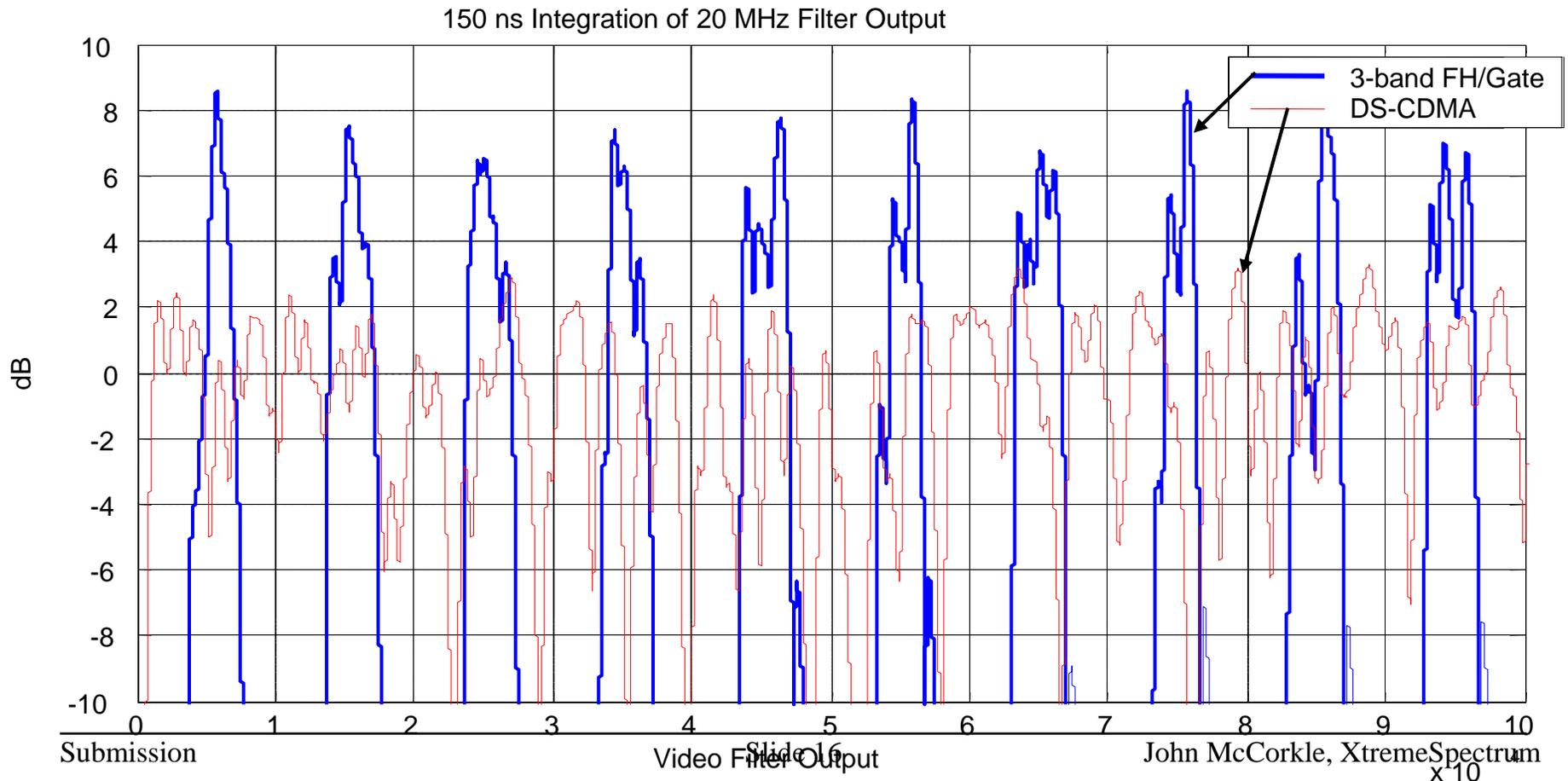
DS-CDMA and FH Adjusted to produce identical output "Z"
 (Standard FCC 1 MHz RBW 1ms Video RMS Compliance Test)



Normalize each system to its own bandwidth & amplitude at the BP frequency $dB(t) = 10 \log(X(t) / Y)$

Comparison of Interference To Canonical 20 MHz BW Victim with 3-hop FH/Gated

- ❖ Interference from DS-CDMA is nominally unchanged by integration time
- ❖ Interference from 3-band FH is about 5 dB higher than DS
- ❖ Interference from a 7-band FH is about 9 dB higher than DS



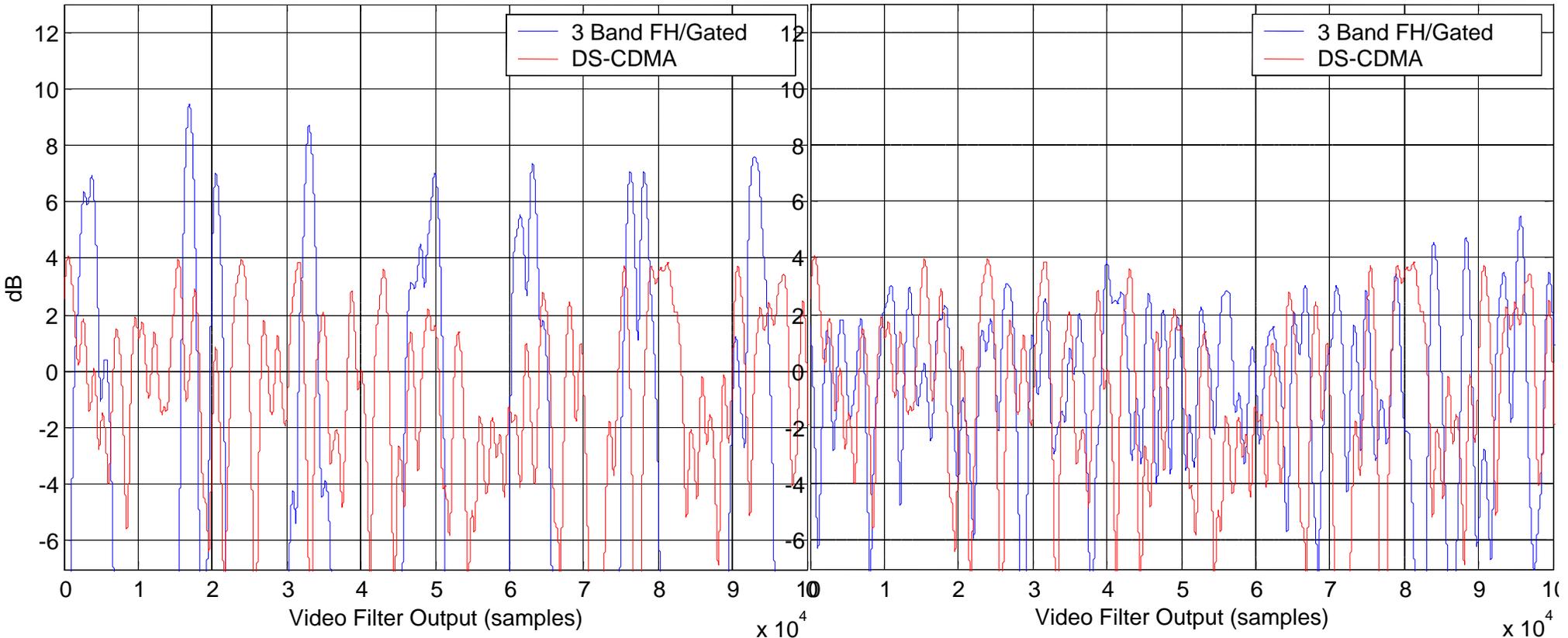
Result of Differing Interpretations Of Measurement With “Hopping Stopped” (3-hops, 10 MHz BW victim)

Compliance Tests Done With “B”
Stopped = “one band operates”
(FH is allowed more interference)

Compliance Tests Done With “A”
Stopped = All hops operate in one band
(FH & DSSS have equal interference)

150 ns Video Integration of 10 MHz Filter Output

Hopping Stopped: 150 ns Video Integration of 10 MHz Filter Output

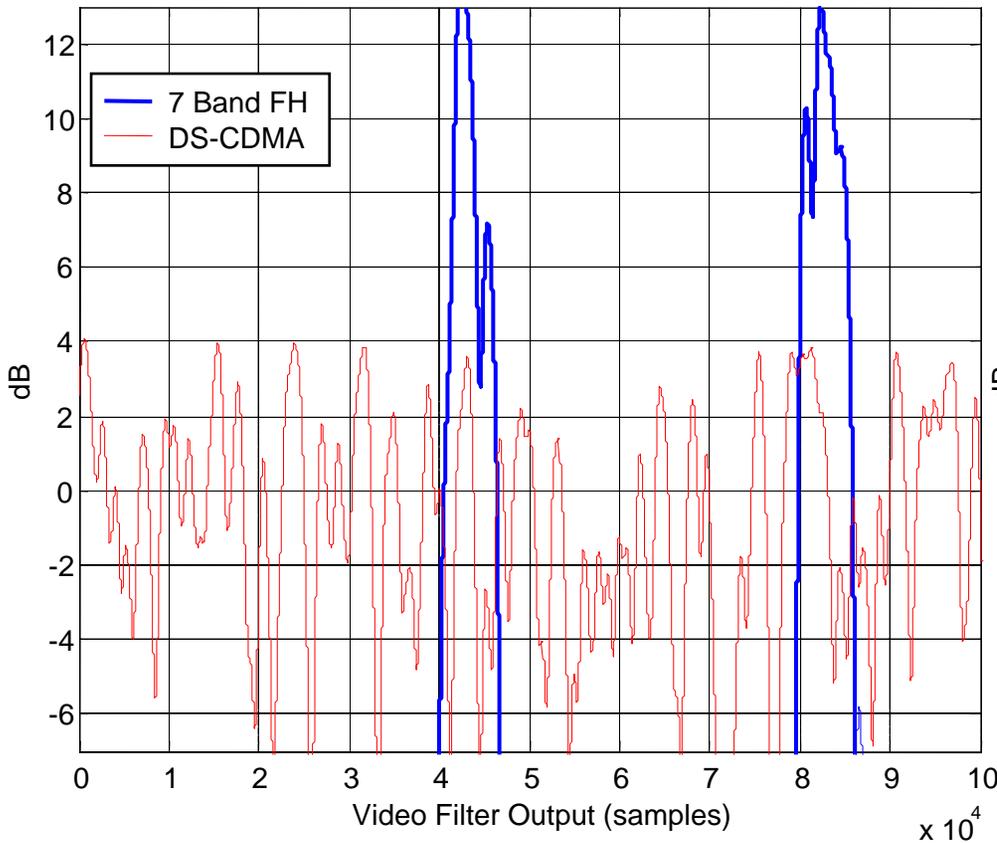


Differing Interpretations Of Measurement With “Hopping Stopped” (7-hops different hop code, 10 MHz victim)

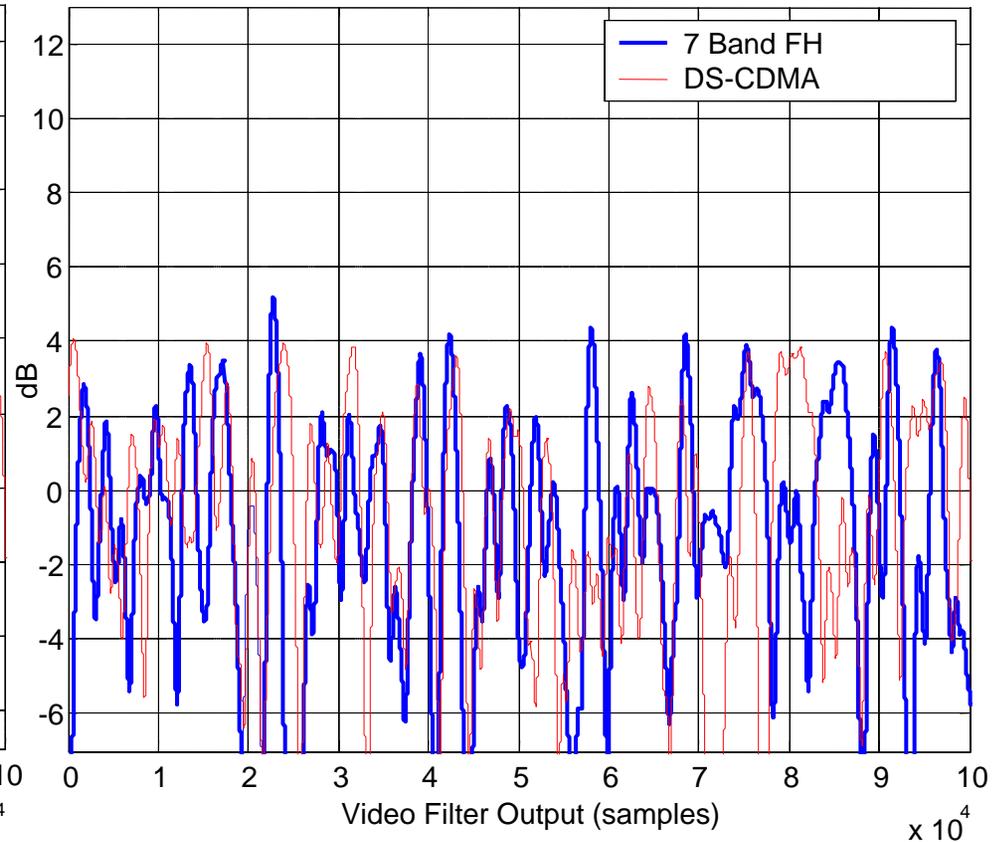
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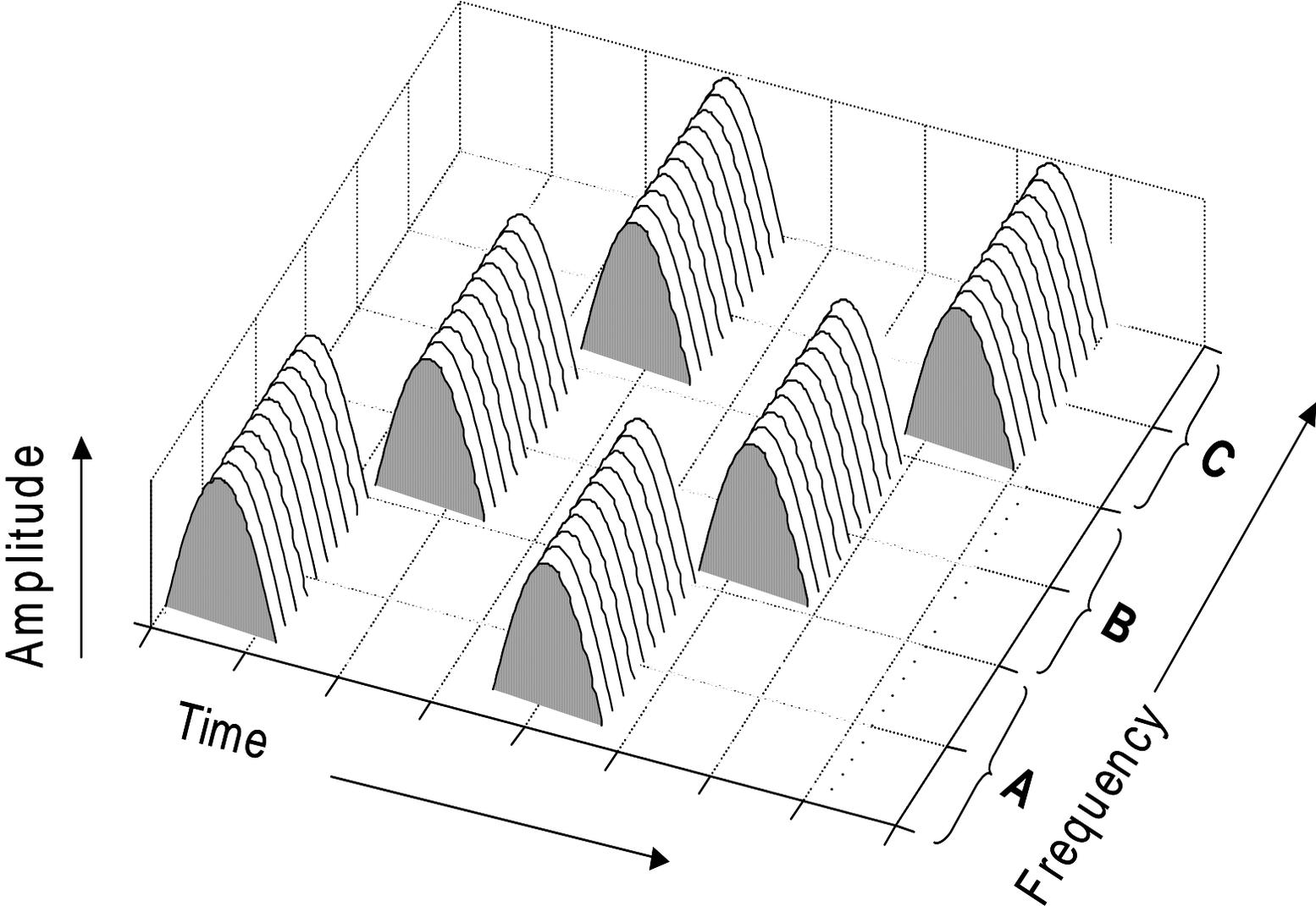
Hopping Stopped: 150 ns Video Integration of 10 MHz Filter Output



Interpretations

- ❖ Following slides will illustrate the two suggested interpretations
- ❖ Under one interpretation - “A”
 - ❑ Gated/FH systems do not comply with the current FCC measurement rules unless the power of the hopped/gated bursts is reduced
 - ❑ guarantees that FH systems can be marketed that will operate as safely as DS-CDMA systems.
- ❖ Under the other interpretation - “B”
 - ❑ Bursts from the Gated/FH emissions are not reduced and can cause more interference than DS emissions.
- ❖ As shown on the previous slides, Interpretation “A” equalizes the interference potential for a broad class of receivers.

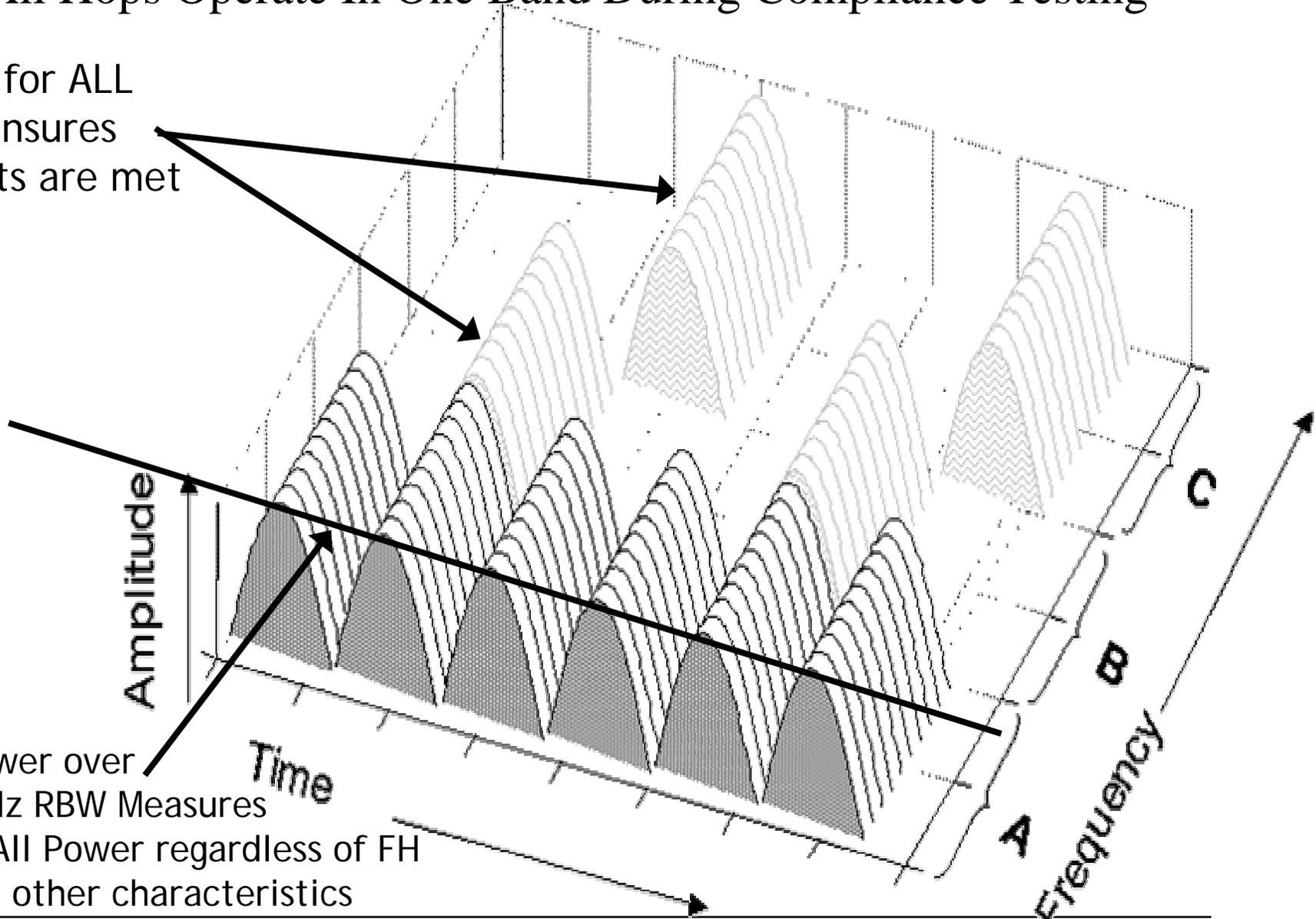
Normal FH Operation



“Hopping Off” Interpretation “A”

--All Hops Operate In One Band During Compliance Testing

Accounts for ALL Energy - Insures that Limits are met



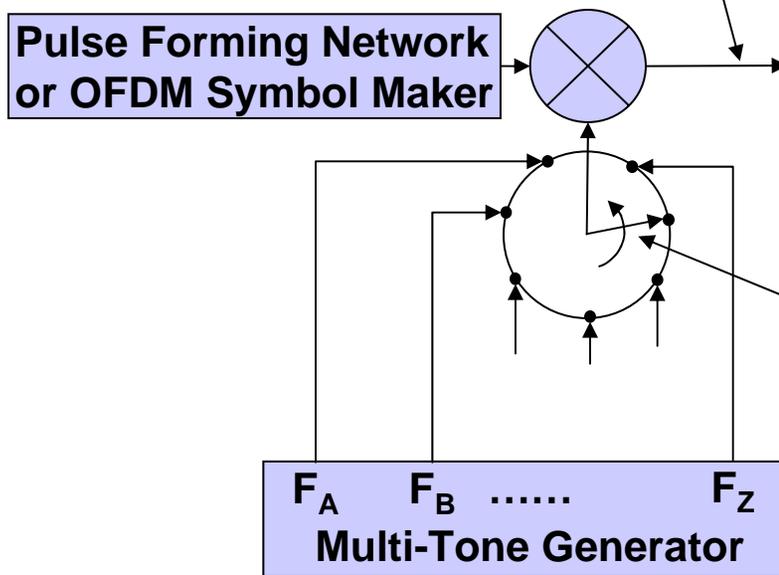
Average Power over 1ms in 1 MHz RBW Measures Bursts and All Power regardless of FH overlap and other characteristics

Device Illustration of testing using interpretation "A" All Hops Operate In One Band During Compliance Testing

With Hopping turned OFF:

1. Bandwidth here must meet FCC UWB definition of > 500 MHz bandwidth; AND
2. W/MHz emissions must be within all emission limits defined in the rules

- With or without hopping stopped
 - Pulses/Symbols always come out at same rate
 - The total average power is the same
- With hopping stopped all power is concentrated in one band instead of N bands
- Switch is synchronized to the PFN/symbol maker
- Switch rotates to hop the >500 MHz bandwidth pulse (or symbol) to a different center frequency
- Switch stops rotating to stop hopping

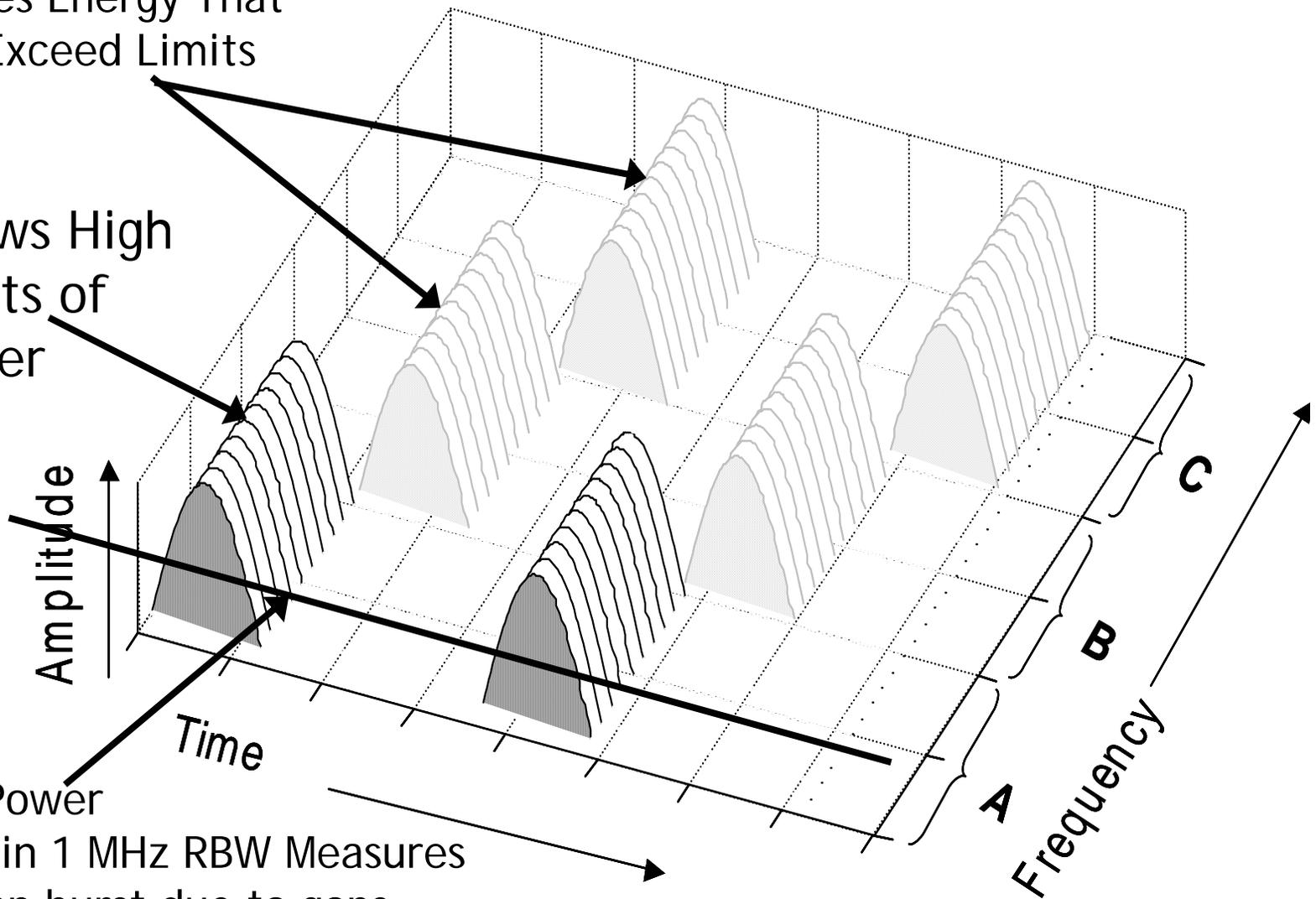


**To meet the emission limits with hopping turned off (under "A")
A compliant Gated/FH system has only 1/N th the power of a non-gated/FH system
But both gated/hopped and non-gated/hopped systems have equal burst emissions**

“Hopping Off” Interpretation “B” One Band Operates During Compliance Testing

Ignores Energy That
May Exceed Limits

Allows High
Bursts of
Power



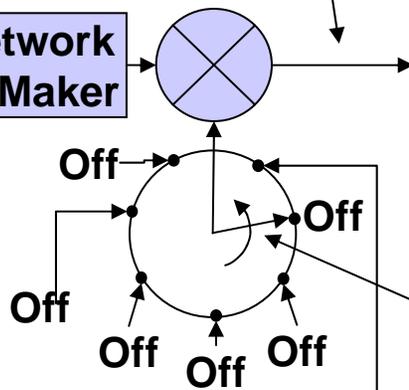
Average Power
over 1ms in 1 MHz RBW Measures
Lower than burst due to gaps

Device Illustration of testing using interpretation “B” One Band Operates During Compliance Testing

With Hopping turned OFF:

1. Bandwidth here must meet FCC UWB definition of > 500 MHz bandwidth; AND
2. W/MHz emissions must be within all emission limits defined in the rules

Pulse Forming Network
or OFDM Symbol Maker



- With hopping stopped
 - Pulses/Symbols come out at 1/N th rate
 - The total average power is 1/N
 - Power in other bands is ignored

- Switch is synchronized to the PFN/symbol maker
- Switch rotates to hop the >500 MHz bandwidth pulse (or symbol) to a different center frequency

F_A F_B F_Z
Multi-Tone Generator

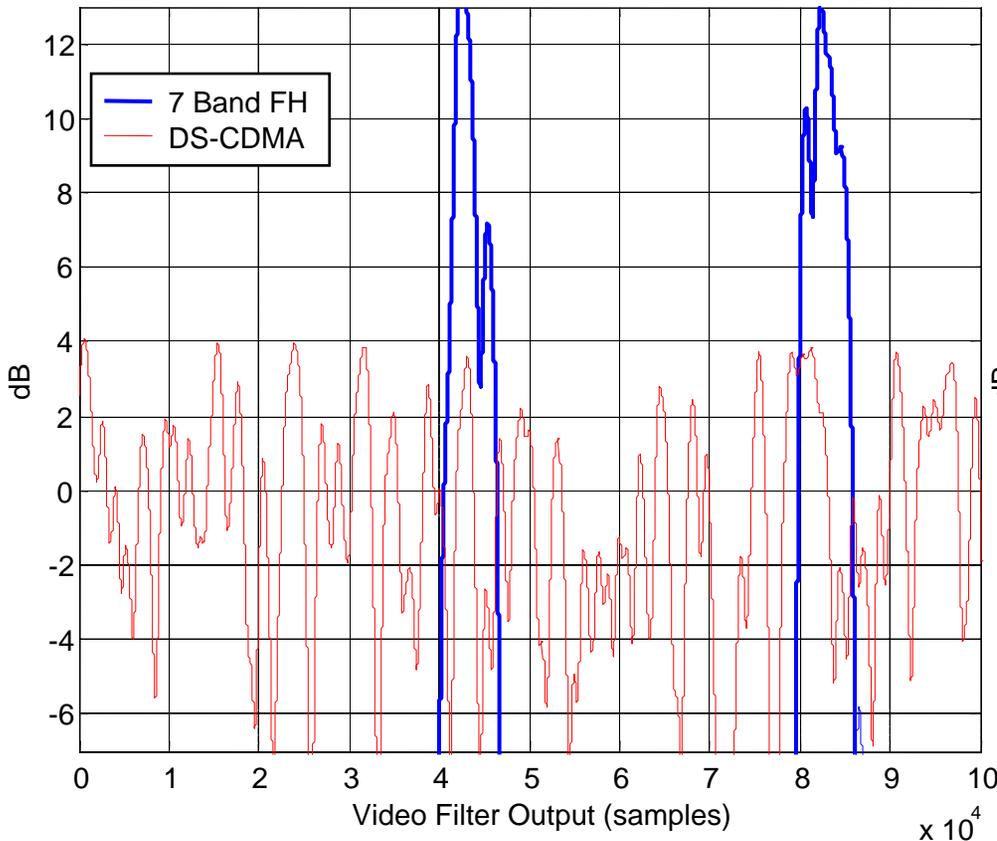
**Meeting the emission limits with hopping turned off (under “B”)
Allows large (N-times over standard -41.3 dBm limit) bursts for Gated/FH systems**

Differing Interpretations Of Measurement With “Hopping Stopped” (7-hops different hop code, 10 MHz victim)

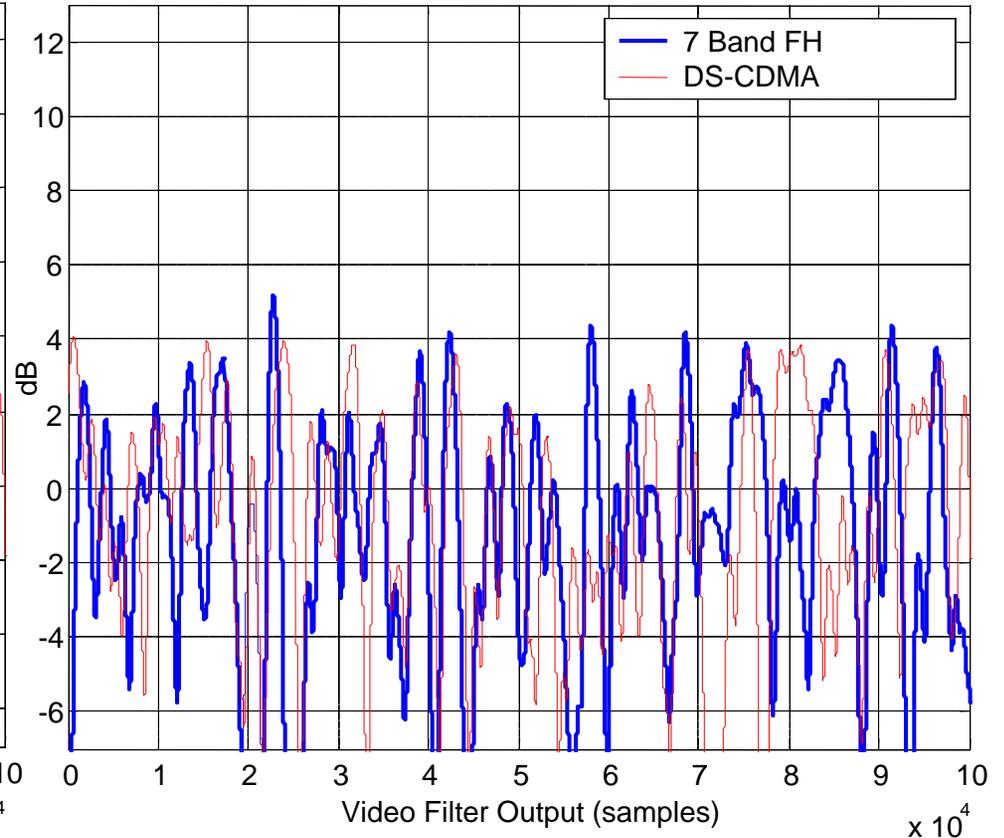
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Hopping Stopped: 150 ns Video Integration of 10 MHz Filter Output



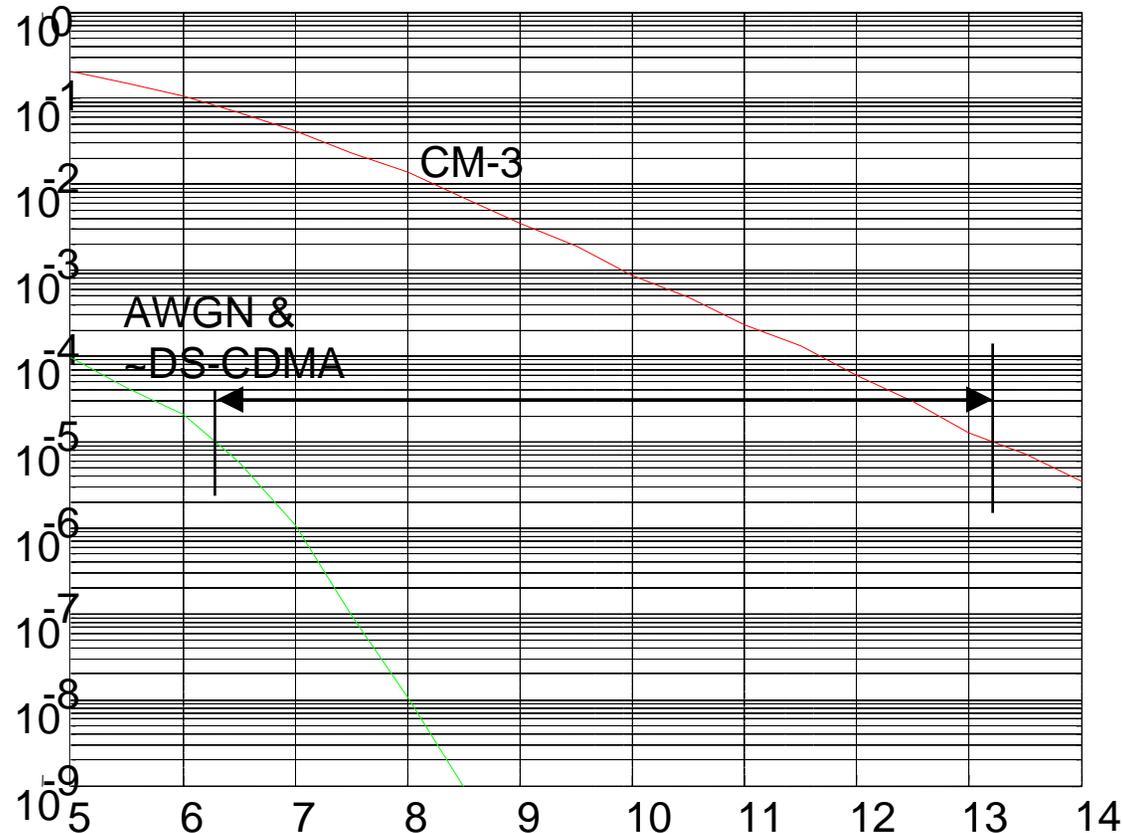
Interpretation “A” Makes More Sense

- ❖ Effective means that industry has broad latitude in choosing how to build devices, but that the test guarantees that emissions are limited such that no matter how the system is built, the interference is limited
- ❖ Effective Test: “A” Hopping stopped = all hops operate in one band
 - ❑ Equalizes the interference effects across differing systems
 - ❑ Accommodates the myriad of variations FH can take
 - Handles random hopping - which could put too much energy in a particular band.
 - Handles hopping where the hop-bands overlap – which could put too much energy into an overlap region
 - Accounts for sidelobe energy of neighboring hops could put too much energy into a band.
 - ❑ Accommodates all victim types – wide bandwidth video – to digital
- ❖ Test “A” Insures Gated/FH devices operate as safely as DS-CDMA
- ❖ Ineffective Test: “B” Hopping stopped = one band operates
 - ❑ Allows increased interference due to bursts
 - ❑ Could allow a “compliant” unit to exceed the limits when hopping was turned back on (i.e. ineffective)

Recall From Doc-0344 That OFDM Needs 1.3 To 6.9 dB (Depending on Mode) Higher Average Transmit Power For Equal Range & Data-rate

- ❖ **This means for equal range & data-rate, OFDM generates all the more interference**
- the sum of 6.9 dB + 4.7dB for 480Mbps and 3-hop mode**
- 11.6dB More Interference!**

4 MHz BW in CM3 Fading vs AWGN for R = 1/3 Punctured to R = 3/4, K=7



Choice of DS-CDMA Modulation Minimizes Interference

- ❖ DS-CDMA built from the ground up to minimize interfere
 - ❑ DS signal looks like white noise in essentially ALL victim bandwidths – White in Joint-Time-Frequency sense.
 - ❑ DS has very low peak-to-average
 - It does not burst - no gating or hopping bursts
 - ❑ The results shown here bear out the lower interference
- ❖ High chipping rate does not allow resolution of pulses until the victim bandwidth exceeds 1.4 GHz
- ❖ There are no known systems (other than UWB) that operate in these bands with that much bandwidth

CONCLUSIONS

- ❖ The issues raised are not merely quibbles over testing procedures.
 - ❑ They go to the heart of matters shaping the entire UWB industry
 - ❑ Increased interference from Gated/FH is real and a significant concern
 - ❑ Consequences for RF environment is shared by all spectrum users
 - Government, industry and private
- ❖ IEEE as well as regulatory agencies have a duty to maximize the ratio of performance to interference-potential
 - ❑ Effectively minimizing interference to all spectrum users
- ❖ The IEEE 802.15.3a committee should not choose an implementation that produces more interference and expect regulators, or the broader industry to accept it.
- ❖ The results demonstrate that MBOA-OFDM generates more interference.
- ❖ **Not only does DS-CDMA have lower interference, at the same time it has higher performance**
 - **Exactly the traits sought after in a solution.**