



The Evolution of Modern UWB Technology: *A Spectrum Management Perspective*

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Initiation of UWB Regulatory Framework

- Need for UWB rules recognized in 1998:
 - four manufacturers petitioned FCC for waivers to operate UWB devices under Part 15 (unlicensed) rules
 - FCC made aware of ongoing unregulated GPR operations
- FCC issued Notice of Inquiry (NOI) in September, 1998
- NOI requested information w.r.t. potential UWB characteristics and operations be submitted to public record



Response to UWB NOI

- Public record filings primarily described direct-pulse (DP) UWB waveforms generated by the edge of very fast rise-time, short-duration pulse (an impulse)
- Resulting impulse used to “shock excite” a resonant antenna
 - Properly designed antenna functions as band-pass filter, shaping resultant spectra
- Extremely (ultra) wideband spectrum signature created in the frequency domain
- Prospect of direct sequence encoding of impulse stream introduced (DS-UWB)

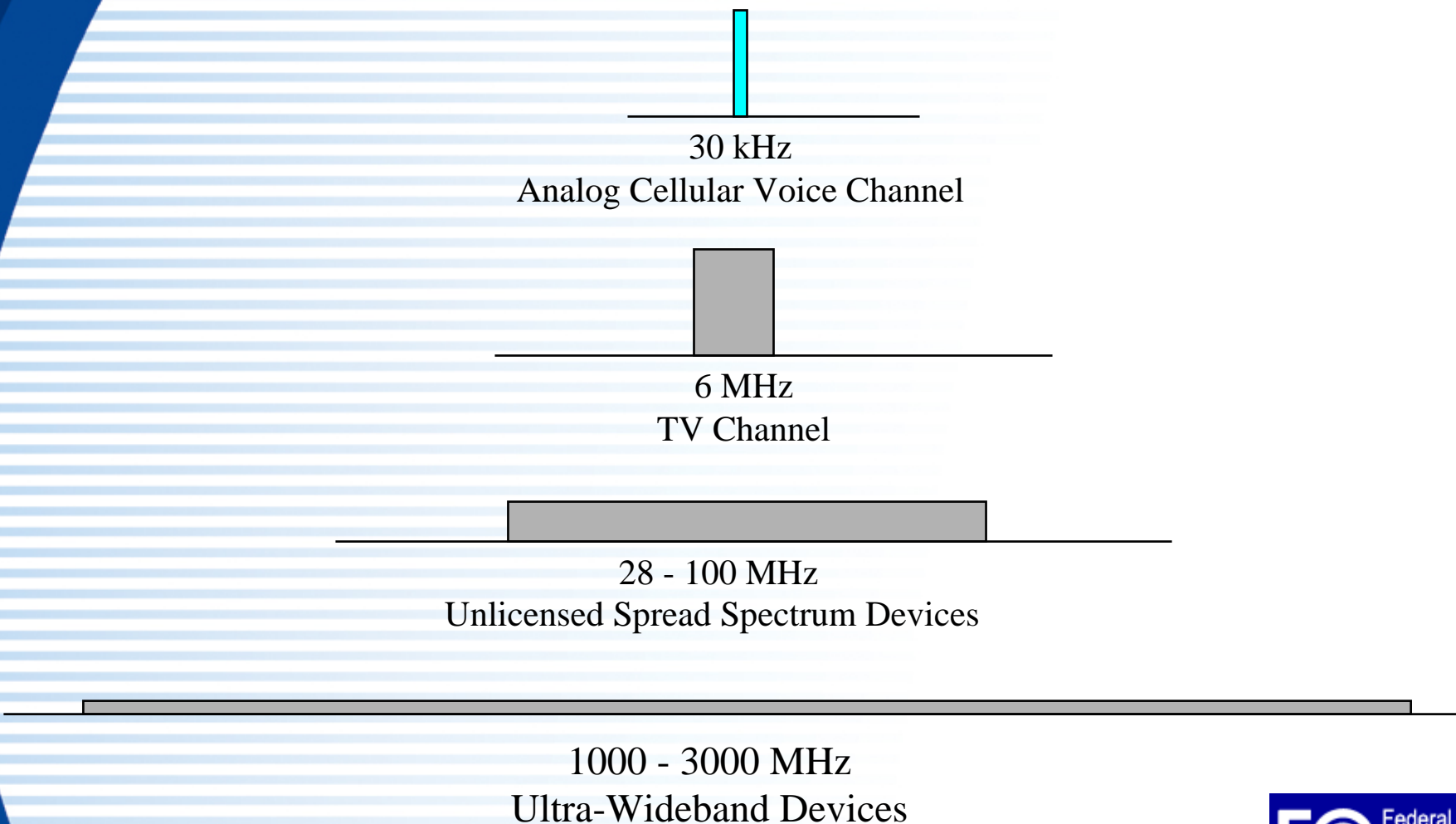


Impact of NOI

- Made clear the need to implement wireless UWB as an underlay technology
- Initiated extensive investigations into potential interference to incumbent services and systems
- Identified likely applications for and benefits associated with UWB technology



Comparison of UWB Bandwidth





Conventional Spectrum Management

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM

FREQ. BANDS COLOR KEY

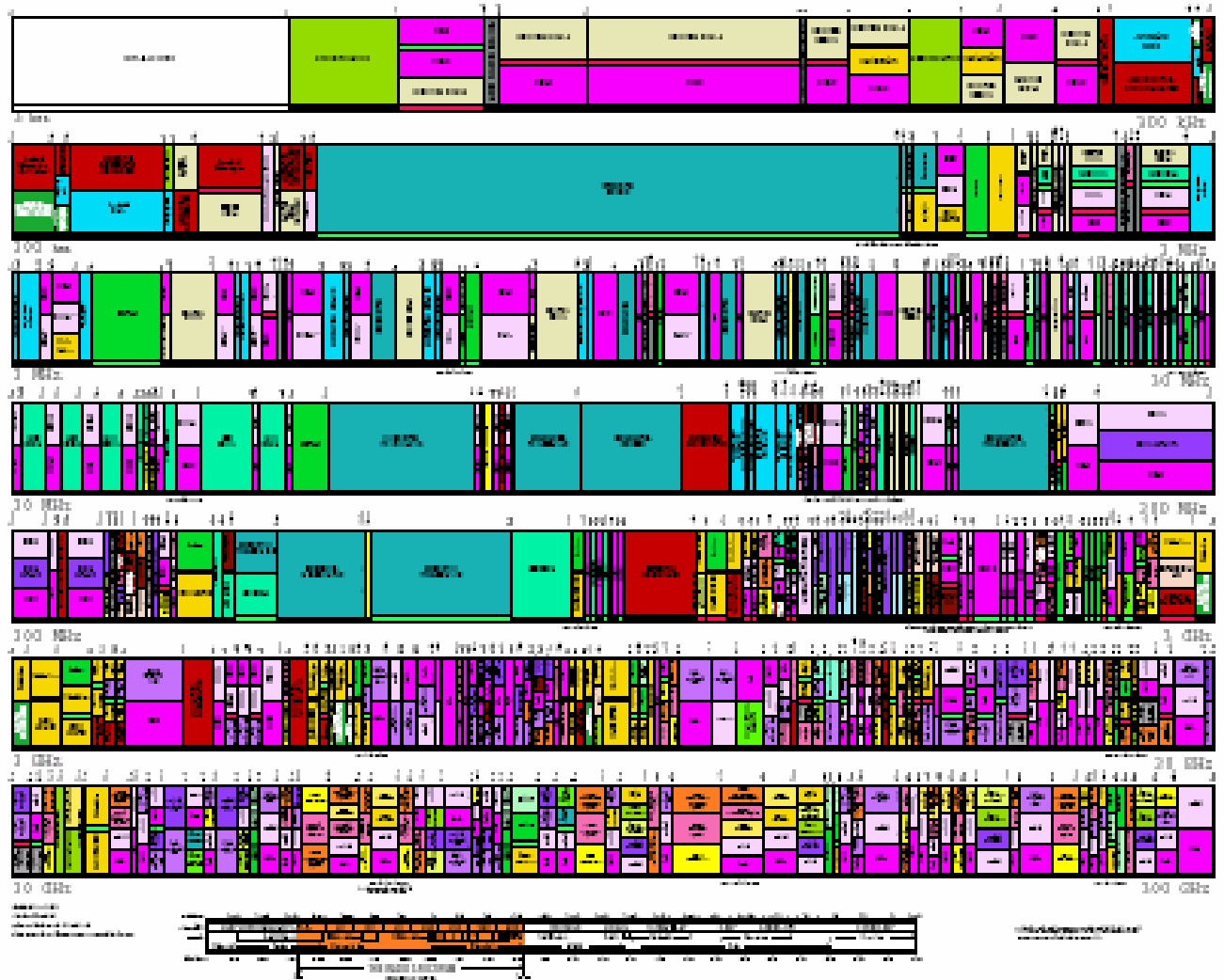
30 MHz	60 MHz	110 MHz
120 MHz	180 MHz	230 MHz
300 MHz	380 MHz	430 MHz
500 MHz	630 MHz	690 MHz
700 MHz	800 MHz	870 MHz
930 MHz	1030 MHz	1130 MHz
1230 MHz	1330 MHz	1430 MHz
1530 MHz	1630 MHz	1730 MHz
1830 MHz	1930 MHz	2030 MHz
2130 MHz	2230 MHz	2330 MHz
2430 MHz	2530 MHz	2630 MHz
2730 MHz	2830 MHz	2930 MHz
3030 MHz	3130 MHz	3230 MHz
3330 MHz	3430 MHz	3530 MHz
3630 MHz	3730 MHz	3830 MHz
3930 MHz	4030 MHz	4130 MHz
4230 MHz	4330 MHz	4430 MHz
4530 MHz	4630 MHz	4730 MHz
4830 MHz	4930 MHz	5030 MHz
5130 MHz	5230 MHz	5330 MHz
5430 MHz	5530 MHz	5630 MHz
5730 MHz	5830 MHz	5930 MHz
6030 MHz	6130 MHz	6230 MHz
6330 MHz	6430 MHz	6530 MHz
6630 MHz	6730 MHz	6830 MHz
6930 MHz	7030 MHz	7130 MHz
7230 MHz	7330 MHz	7430 MHz
7530 MHz	7630 MHz	7730 MHz
7830 MHz	7930 MHz	8030 MHz
8130 MHz	8230 MHz	8330 MHz
8430 MHz	8530 MHz	8630 MHz
8730 MHz	8830 MHz	8930 MHz
9030 MHz	9130 MHz	9230 MHz
9330 MHz	9430 MHz	9530 MHz
9630 MHz	9730 MHz	9830 MHz
9930 MHz	10030 MHz	10130 MHz
10230 MHz	10330 MHz	10430 MHz
10530 MHz	10630 MHz	10730 MHz
10830 MHz	10930 MHz	11030 MHz
11130 MHz	11230 MHz	11330 MHz
11430 MHz	11530 MHz	11630 MHz
11730 MHz	11830 MHz	11930 MHz
12030 MHz	12130 MHz	12230 MHz
12330 MHz	12430 MHz	12530 MHz
12630 MHz	12730 MHz	12830 MHz
12930 MHz	13030 MHz	13130 MHz
13230 MHz	13330 MHz	13430 MHz
13530 MHz	13630 MHz	13730 MHz
13830 MHz	13930 MHz	14030 MHz
14130 MHz	14230 MHz	14330 MHz
14430 MHz	14530 MHz	14630 MHz
14730 MHz	14830 MHz	14930 MHz
15030 MHz	15130 MHz	15230 MHz
15330 MHz	15430 MHz	15530 MHz
15630 MHz	15730 MHz	15830 MHz
15930 MHz	16030 MHz	16130 MHz
16230 MHz	16330 MHz	16430 MHz
16530 MHz	16630 MHz	16730 MHz
16830 MHz	16930 MHz	17030 MHz
17130 MHz	17230 MHz	17330 MHz
17430 MHz	17530 MHz	17630 MHz
17730 MHz	17830 MHz	17930 MHz
18030 MHz	18130 MHz	18230 MHz
18330 MHz	18430 MHz	18530 MHz
18630 MHz	18730 MHz	18830 MHz
18930 MHz	19030 MHz	19130 MHz
19230 MHz	19330 MHz	19430 MHz
19530 MHz	19630 MHz	19730 MHz
19830 MHz	19930 MHz	20030 MHz

SERVICE CODES

0	1	2	3	4	5	6	7	8	9
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

SELECTED BAND CHARACTERS

0	1	2	3	4	5	6	7	8	9
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0





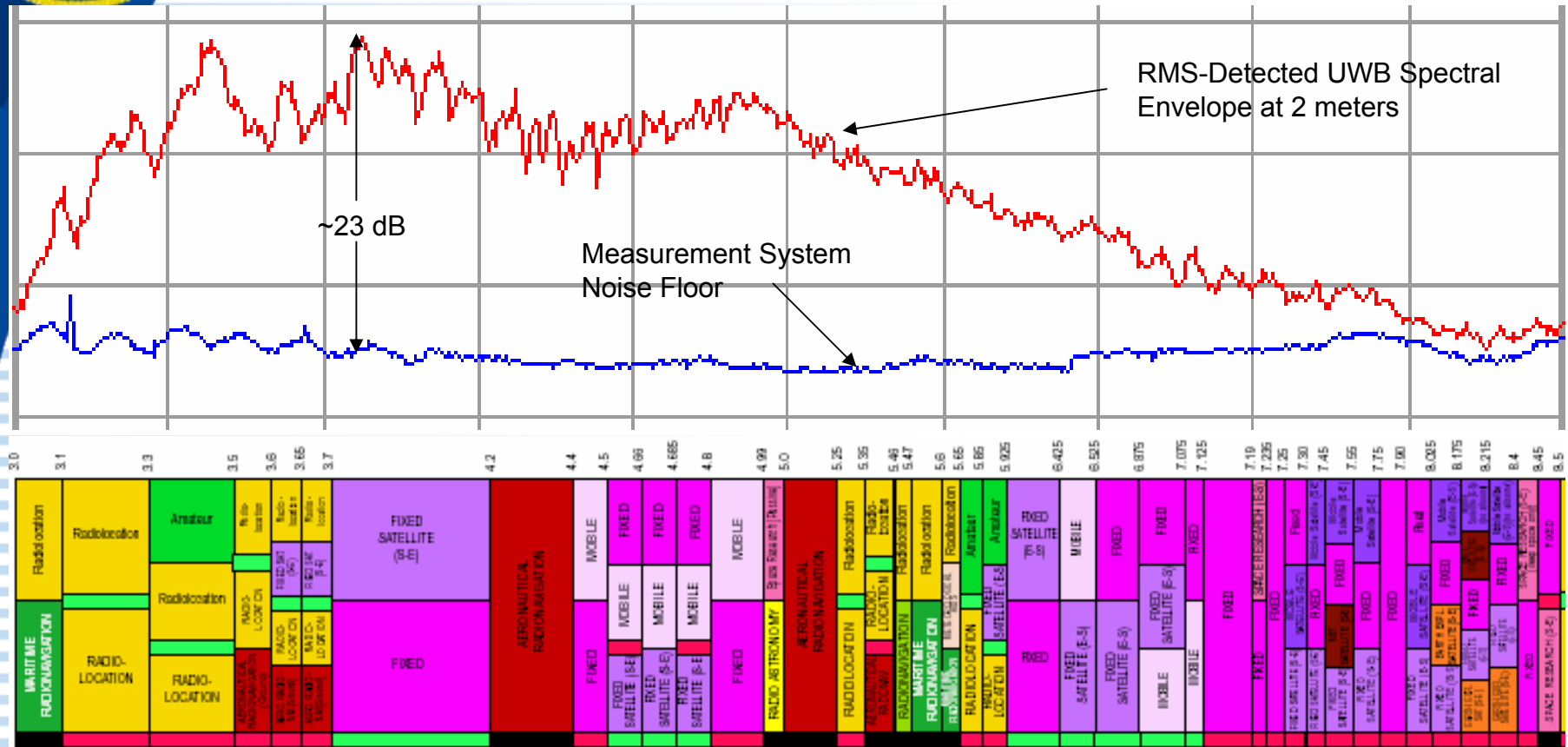
Primary Spectrum Issues

- UWB waveforms require access to large swaths of radio spectrum
- UWB emissions incompatible with existing spectrum management protocol
- Spectrum identified for UWB operation will necessitate access to “restricted bands”
 - Restricted bands typically reserved for Safety-of-Life, National Security and/or Scientific Research operations
- Requires operation in spectrum long used by incumbent licensees, often on a sole basis (i.e., entrenched)



UWB Spectral Envelope

Not to Scale – For Illustration Only



GOVERNMENT EXCLUSIVE
 GOVERNMENT/ NON-GOVERNMENT SHARED

NON-GOVERNMENT EXCLUSIVE



Potential Benefits of UWB Technology

- Low Cost
 - Utilizes base-band radio architecture implemented in CMOS
- Low Power Consumption
 - Low transmit duty cycles
- High Capacity
 - via wide occupied bandwidth
 - Shannon-Hartley theorem
- Multi-path Robustness



Notice of Proposed Rulemaking

- Released in May 2000
- Used information from public record to develop proposed regulations
- Acknowledged and encouraged ongoing EMC tests and analyses
- Requested public comment on rules proposals



UWB EMC Tests and Analyses

● NTIA/ITS

- Measured UWB characteristics
- Measured interference potential to GPS and other Government systems
- Assessed UWB compatibility w.r.t. incumbent Government systems

● DOT/SU/Rockwell Collins

- Measured interference potential to GPS
- Assessed UWB compatibility w.r.t. aviation applications of GPS



UWB EMC Tests and Analyses (continued)

● TDC/UT/APL

- Measured interference potential to GPS
- Assessed UWB EMC w.r.t. GPS and other systems

● FAA/RTCA

- Analyzed potential interference to GPS

● AARL

- Analyzed EMC w.r.t. Amateur stations



UWB EMC Tests and Analyses (continued)

- Motorola/Sprint/Qualcomm/Telcordia/TDC
 - Analyzed EMC w.r.t. PCS
- Cisco Systems, Inc
 - Analyzed EMC w.r.t. MMDS systems
- XM Satellite Radio
 - Analyzed EMC w.r.t. DARS systems
- DARPA NETEX
 - Measured and analyzed UWB potential interference to selected legacy military systems



Measurement Results

- Measured interference levels relatively consistent among various test efforts
- Interference levels w.r.t. GPS validate thresholds previously defined by RTCA/FAA and documented within ITU
- UWB interference found to appear as either “noise-like” or “CW-like” within an incumbent receiver’s passband
 - Traditional interference analysis techniques are applicable



Interference Analysis Results

- Very little consistency among competing factions
- Incumbents utilized extremely conservative assumptions in analyses
 - often ignored realistic UWB operational constraints and application proliferation probabilities – NIMBY syndrome
- UWB proponents favored more liberal assumptions in analyses



First UWB Report and Order (R&O)

- Issued in February, 2002
- Incorporated information obtained from measurement and analysis efforts and from other comments submitted to the public record
- Coordinated closely with Government agencies via NTIA and IRAC
- Established a regulatory framework to facilitate the introduction of UWB for use in limited applications



First UWB Report and Order (R&O) (continued)

- Defined a UWB waveform
 - 500 MHz minimum bandwidth @ -10 dB points, or
 - fractional bandwidth ≥ 0.20
 - upper, lower, center frequencies and frequency of maximum emission
- Identified permissible UWB applications
 - Imaging
 - Surveillance
 - Communications (Indoor and Outdoor)



First UWB Report and Order (R&O) (continued)

- Established application-based emissions masks for:
 - Imaging (GPRs, surface and medical imaging)
 - Surveillance (proximity detection)
 - Communications (digital file transfers)
 - Vehicular radar
- Specified additional requirements to further protect incumbents
 - trained operators for GPRs
 - no outdoor infrastructure for communications
 - off-axis attenuation of vehicular radars



Memorandum of Opinion and Order

- MO&O and Further NPRM released in Feb, 2003
- Through-Wall Imaging recognized as permissible UWB application
 - established applicable emissions limits
- Modified band requirements for GPRs
- Responded to petitions for reconsideration of the initial R&O



MBOA Waiver Petition

- Filed in August, 2004
- Proposed a multi-band (MB) orthogonal frequency division multiplexed (OFDM) implementation of UWB
- Requested clarification and waiver from requirement to stop band sequencing when performing compliance testing of emission levels



MBOA Waiver Petition

(continued)

- Waiver request approved by FCC in March, 2005
- Approval of waiver constituted no change to existing UWB rules or emissions masks
- Only change affected was in the way radiated emissions are measured
 - Requirement to suspend band sequencing (hopping) when measuring for compliance to the emissions mask was removed
 - Now permissible to perform the measurement with the device radiating in normal operating mode



UWB Measurement Procedures

- Procedures consistent with ANSI C63.4 with some technology-specific variations
- Detailed information can be obtained from developing ITU TG1/8 contribution
 - Available at: http://www.fcc.gov/oet/ITU_tsk_grp/int-documents/Chair_report_9_18_Jun_04/Annex_4_PDN_R_UWB_MEAS.doc
- FCC also maintains an FAQ regarding UWB compliance measurements
 - Available at:
<http://gullfoss2.fcc.gov/prod/oet/cf/kdb/forms/FTSSearchResultPage.cfm?id=20253&switch=P>
 - Currently undergoing update



UWB Measurement Procedures (continued)

- Verification of UWB emissions to limits must utilize radiated emissions measurements
- CISPR quasi-peak detector must be used below 960 MHz
- Average (rms) and peak detector must be used above 960 MHz
 - Average measurements integrated over 1 ms
 - Discourage use of a sample detector and post processing to determine rms average



UWB Application-Specific Measurement Issues

- Radiated emissions from UWB GPRs can be measured with the DUT placed on a sand bed.
- If this option is exercised, 4.7 dB must be added to the measured levels.
- Care must be taken to identify and address ambient signals within the measurement space



UWB Application-Specific Measurement Issues

- UWB Communications Devices
 - Detecting radiated emissions to levels specified by the emissions mask in the 960-1610 MHz band is challenging
 - Measurement system must be sensitized to the greatest possible extent by employing a very low noise preamplifier (less than 1 dB NF) and high gain antenna
 - Recommended measurement range of one meter



UWB Application-Specific Measurement Issues

- UWB Communications Devices (continued)
 - A spectral line test required within the GPS bands (1164-1240 MHz and 1559-1610 MHz)
 - For this test, the RBW can be narrowed to reveal spectral lines
 - Rules specify no less than 1 kHz RBW, but practical limit is more like 10 kHz
 - A peak detector must be used to measure peak emission level
 - Maximum hold feature should be employed
 - Measured level must then be expressed in a 50 MHz bandwidth by adding $20\log(50/\text{RBW})$



UWB Application-Specific Measurement Issues

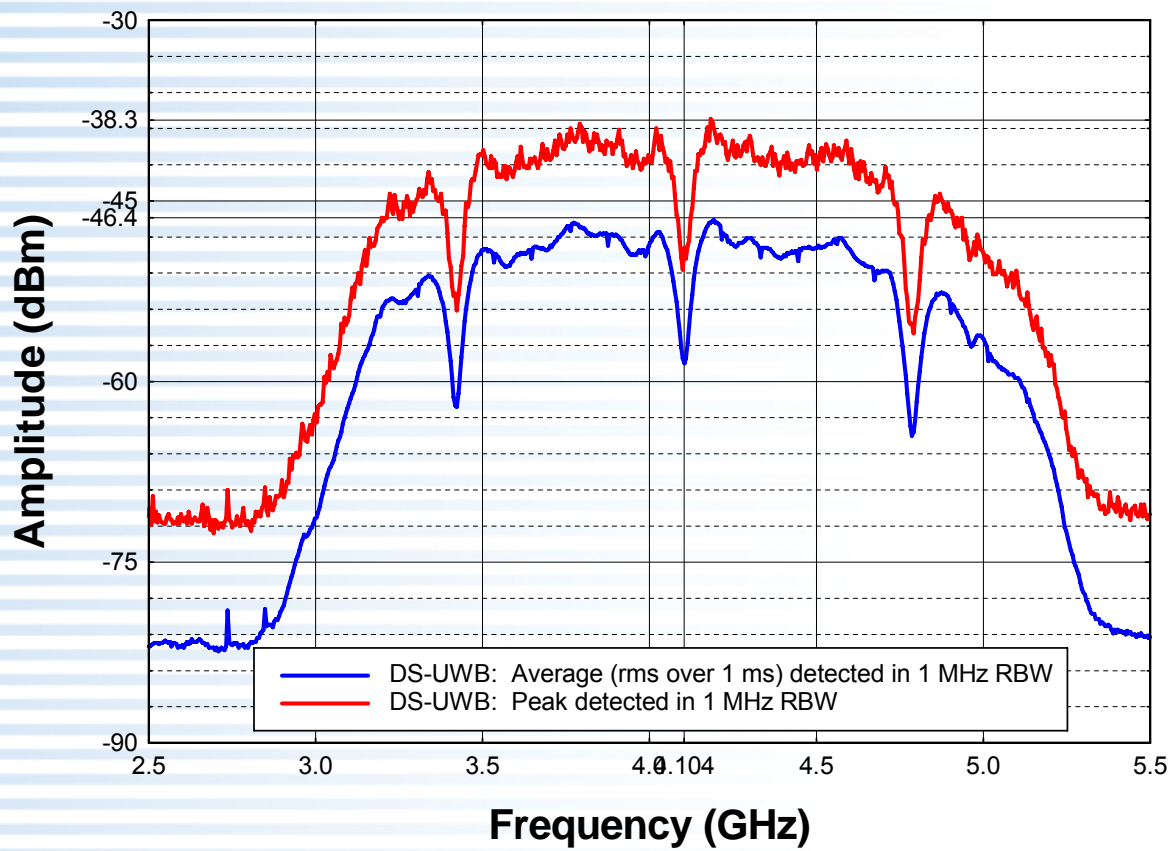
● Vehicular Radar

- Measurements must be made at very close range to overcome increased propagation path losses
- Problems identified with measuring off-mainbeam-axis emissions and harmonic emissions above 31 GHz to levels specified by emissions mask
 - Currently under review
 - Further guidance will be forthcoming



Example Spectrum Signatures DS-UWB

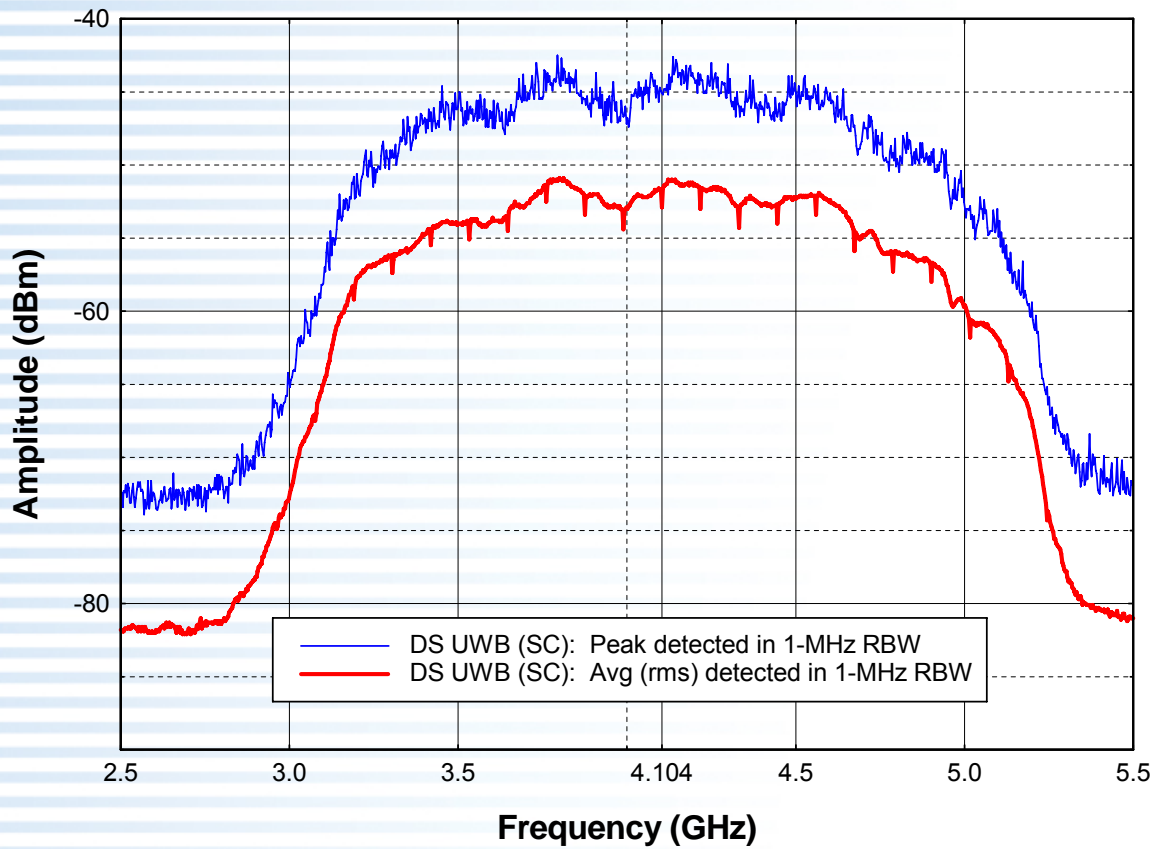
DS-UWB (full code) Peak and Average Spectral Envelopes





Example Spectrum Signatures DS-UWB

DS-UWB (sparse code) Peak and Average Spectral Envelopes

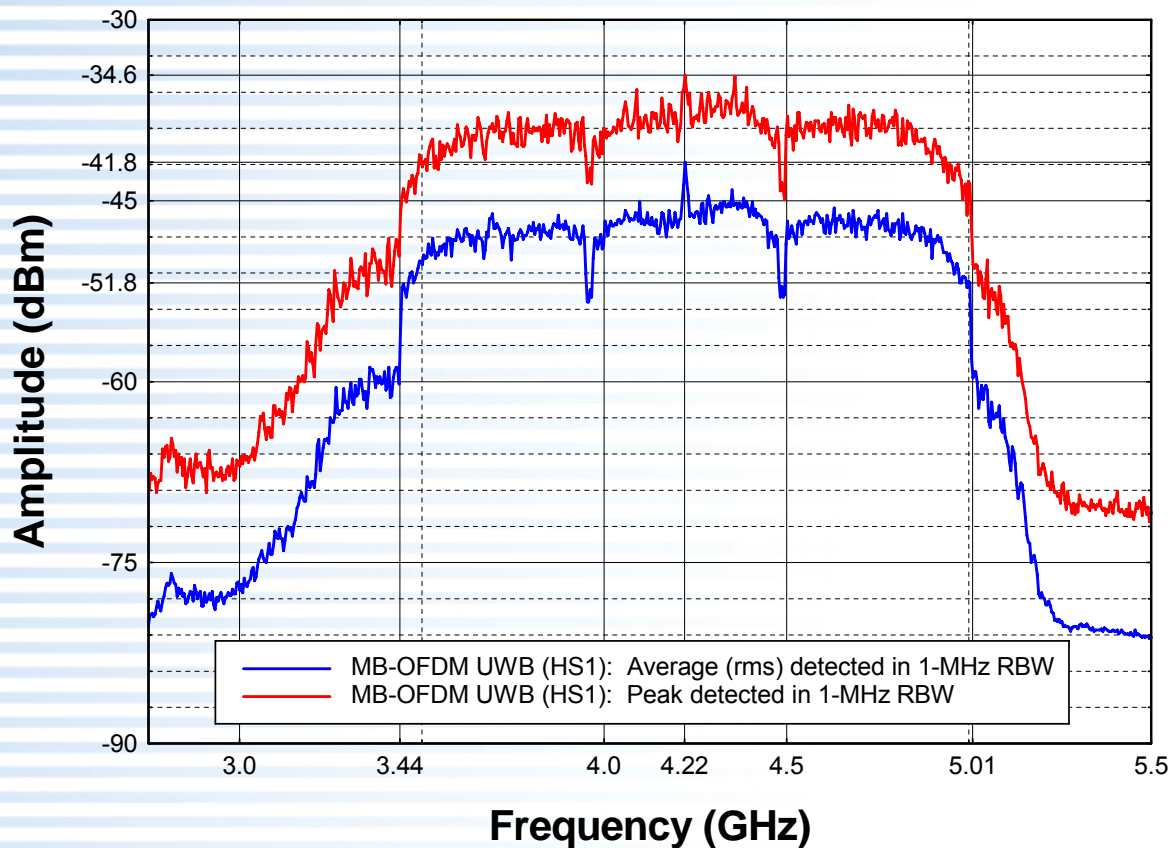




Example Spectrum Signatures

MBOA-UWB

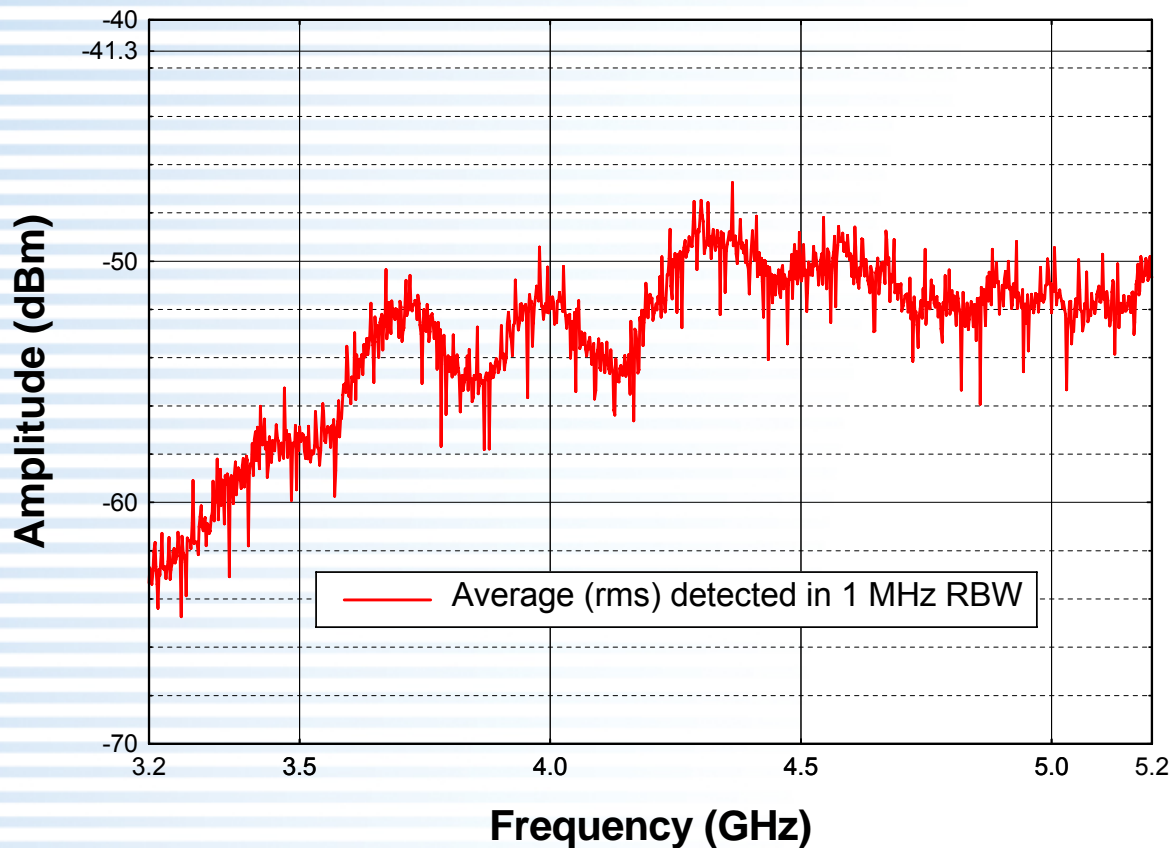
MB-OFDM UWB (HS1) Peak and Average Spectral Envelopes





Example Spectrum Signatures DP-UWB

DP-UWB (10 MHz PRF) Spectral Signature





Example Spectrum Signatures Vehicular Radar

UWB Automotive Radar Emissions

