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

- 30 kHz
  Analog Cellular Voice Channel

- 6 MHz
  TV Channel

- 28 - 100 MHz
  Unlicensed Spread Spectrum Devices

- 1000 - 3000 MHz
  Ultra-Wideband Devices
Conventional Spectrum Management
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

RMS-Detected UWB Spectral Envelope at 2 meters

~23 dB

Measurement System Noise Floor

~23 dB

Measurement System Noise Floor
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
Defined a UWB waveform

- 500 MHz minimum bandwidth @ -10 dB points, or
- fractional bandwidth \( \geq 0.20 \)
- upper, lower, center frequencies and frequency of maximum emission

Identified permissible UWB applications

- Imaging
- Surveillance
- Communications (Indoor and Outdoor)
- Vehicular Radar
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

- 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
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.
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 $20 \log(50/RBW)$
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

Frequency (GHz)

Amplitude (dBm)

-90
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40

DS-UWB: Average (rms over 1 ms) detected in 1 MHz RBW
DS-UWB: Peak detected in 1 MHz RBW
Example Spectrum Signatures
DS-UWB

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

Amplitude (dBm)

Frequency (GHz)

DS UWB (SC): Peak detected in 1-MHz RBW
DS UWB (SC): Avg (rms) detected in 1-MHz RBW
Example Spectrum Signatures
MBOA-UWB

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

Amplitude (dBm)
Frequency (GHz)

MB-OFDM UWB (HS1): Average (rms) detected in 1-MHz RBW
MB-OFDM UWB (HS1): Peak detected in 1-MHz RBW
Example Spectrum Signatures

DP-UWB

DP-UWB (10 MHz PRF) Spectral Signature

Average (rms) detected in 1 MHz RBW
Example Spectrum Signatures
Vehicular Radar

UWB Automotive Radar Emissions

Signal Amplitude (dBm/MHz)

Frequency (GHz)

Peak Detected at 0.5 ft