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

Submission Title: [**Ultra-Wideband Tutorial**]
Date Submitted: [**March 11, 2002**]
Source: [Matt Welborn] Company [**XtremeSpectrum**]
Address [8133 Leesburg Pike, Suite 700, Vienna, VA 22182]
Voice:[(703) 269-3052], FAX: [(703) 269-3092], E-Mail:[mwelborn@xtremespectrum.com]
Source: [Kai Siwiak] Company [**Time Domain**]
Address:[7057 Old Madison Pike, Huntsville, Al. 35806]
Voice:[(256) 990-9062], FAX: [(256) 922-0387], E-Mail:[kai.siwiak@timedomain.com]

Re: [N/A]

Abstract: [This document is a Tutorial that describes the FCC's first Report and Order on Ultra-Wideband Technology. Preliminary details of the R&O are presented as well as background information on UWB technology.]

Purpose: [This Tutorial is intended to inform the membership on the UWB R&O and UWB in general.]

Ultra-Wideband Tutorial

Editors: Matthew Welborn and Kai Siwiak

Reviewers: Bob Huang, Jeff Foerster, John McCorkle, and Michael Dydyk

Sponsors: Sony, Intel, Siemens, Sharp Labs, TI, Motorola, IBM, Time Domain and XtremeSpectrum

Ultra-Wideband Tutorial

- Goal: To provide the 802 standards committee with information about new developments in ultra-wideband technology
- Roadmap
  - New rules for UWB devices
  - History of UWB
  - Short introduction to UWB technology
  - Relevance to IEEE 802

FCC's UWB Proceedings

- Notice of Inquiry: September 1998
- Notice of Proposed Rulemaking: May 2000
  - Over 900 documents on record
    - Government, academic and commercial groups
    - Empirical and analytical studies
    - Characterized interaction mechanisms and measured thresholds for impact of UWB signals on government and commercial systems
- First UWB Report & Order: Adopted February 2002
    - Full text of the R&O is not yet released [as of 3/11/2002]
    - FCC has issued preliminary emission guidelines
    - NTIA has issued a summary analysis with emission and usage recommendations

Summary of the FCC Rules

- Significant protection for sensitive systems
  - GPS, Federal aviation systems, etc.
- Lowest Limits Ever by FCC
- Incorporates NTIA recommendations
- Allows UWB technology to coexist with existing radio services without causing interference

The R&O rules are “designed to ensure that existing and planned radio services, particularly safety services, are protected.”

FCC UWB Device Classifications

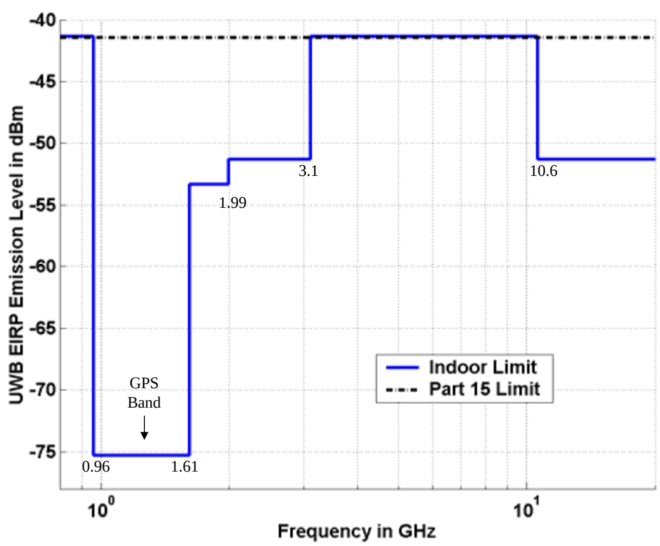
- R&O authorizes 5 classes of devices – Different limits for each:
  - Imaging Systems
    1. Ground penetrating radars, wall imaging, medical imaging
    2. Thru-wall Imaging & Surveillance Systems
  - Communication and Measurement Systems
    3. Indoor Systems
    4. Outdoor Hand-held Systems
  - Vehicular Radar Systems
    5. collision avoidance, improved airbag activation, suspension systems, etc.

Summary of Preliminary R&O Limits

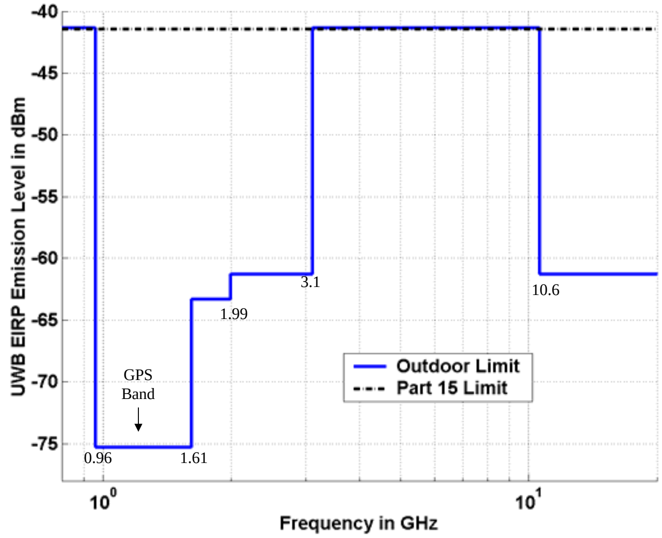
Application	*Frequency Band for Operation at Part 15 Limits*	*User Restrictions*
Imaging	3.1 to 10.6 GHz (GPR <960 MHz)	Yes
Through-wall and Surveillance	1.99 to 10.6 GHz	Yes
Communications (indoor & outdoor)*	3.1 to 10.6 GHz	No
Vehicular	24 to 29 GHz	No

*Indoor and outdoor communications devices have different out-of-band emission limits

UWB Emission Limit for Indoor Systems



UWB Emission Limit for Outdoor Hand-held Systems



R&O is Ultra-Conservative Says FCC

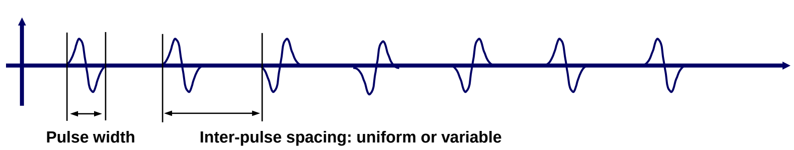
- R&O is described as a "*cautious first step*" by the Commission
- One commissioner describes the R&O limits as "*ultra-conservative*" and "*intentionally at the extreme end of what FCC engineers … believe necessary.*"

History of UWB Technology

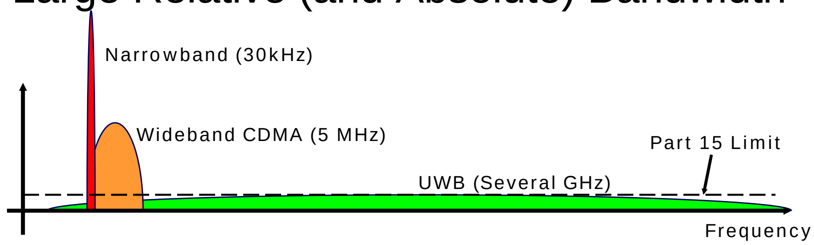
- Before 1900: Wireless Began as UWB
  - Large RF bandwidths, but did not take advantage of large spreading gain
- 1900-40s: Wireless goes ‘tuned’
  - Analog processing: filters, resonators
  - ‘Separation of services by wavelength’
  - Era of wireless telephony begins: AM / SSB / FM
  - Commercial broadcasting matures, radar and signal processing
- 1970-90s: Digital techniques applied to UWB
  - Wide band impulse radar
  - Allows for realization of the HUGE available spreading gain
- Now: UWB approved by FCC for commercialization

What is UWB?

- UWB signals are typically modulated pulse trains
  - Very short pulse duration (<1 ns)
  - Uniform or non-uniform inter-pulse spacing
- Pulse repetition frequency (PRF) can range from hundreds of thousands to billions of pulses/second
- Modulation techniques include pulse-position modulation, binary phase-shift keying and others



Large Relative (and Absolute) Bandwidth



- UWB is a form of extremely wide spread spectrum where RF energy is spread over gigahertz of spectrum
  - Wider than any narrowband system by orders of magnitude
  - Power seen by a narrowband system is a fraction of the total
  - UWB signals can be designed to look like imperceptible random noise to conventional radios

Very Low Power Spectral Density (PSD)

- FCC limits ensure that UWB emission levels are exceedingly small
  - At or below spurious emission limits for all radios
  - At or below unintentional emitter limits
  - Lowest limits ever applied by FCC to any system
- Part 15 limits equate to –41.25 dBm/MHz
  - For comparison, PSD limits for 2.4 GHz ISM and 5 GHz U-NII bands are 40+ dB higher per MHz
- Total emissions over several gigahertz of bandwidth are a small fraction of a milliwatt

Large Fractional Bandwidth

- Original FCC UWB definition (NPRM) is 25% or more fractional bandwidth
  - Fractional Bandwidth is the ratio of signal bandwidth (10 dB) to center frequency: $B_f = B / F_C = 2(F_h - F_l) / (F_h + F_l)$
- Preliminary FCC rules enable in excess of 100% fractional bandwidths
  - 7.5 GHz maximum bandwidth at –10 dB points
- Large fractional bandwidth leads to
  - High processing gain
  - Multipath resolution and low signal fading

Scalable Technology with Low Power

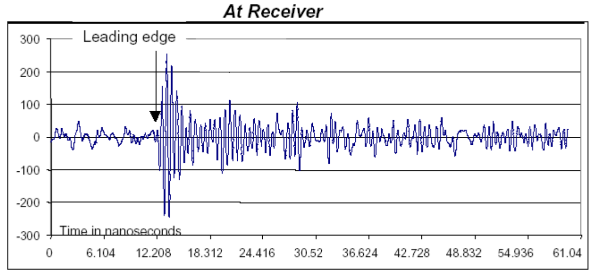
- UWB benefits from basic information theory results when: Signal Bandwidth >> Data Rate
- Power efficient low-order modulation can be used even for relatively high data rates
- Data rates can scale independent of PRF by integrating bit intervals over multiple pulse intervals

Multipath Performance

- Ultra-wide bandwidth provides robust performance in multipath environments
  - Less severe signal fading due to multipath propagation means fade margin of only a few dB
  - Extremely short pulses enable resolution and constructive use of multipath energy using RAKE receiver techniques

At Transmitter

At Receiver



Ranging and Imaging Capabilities

- Many early applications of modern UWB technology were in radar systems
- Sub-nanosecond time resolution leads to precision ranging and imaging capabilities
- Capabilities result from the large relative and coherent bandwidth

UWB in Wireless Applications

- Simple RF architectures
  - No power amplifiers required
  - No IF filtering
  - Minimal off-chip components/low BOM
- Low transmit power due to power-efficient modulation techniques
- Must handle strong narrowband interferers
- Rich multipath environment

Implications for Applications

- UWB characteristics:
  - Simultaneously low power, low cost high data-rate wireless communications
  - Attractive for high multipath environments
    - Enables the use of powerful RAKE receiver techniques
    - Low fading margin
  - Excellent range-rate scalability
    - Especially promising for high rates (>100 Mbps)
- Candidate Applications:
  - Wireless Video Projection, Image Transfer, High-speed Cable Replacement

Challenges for UWB

- Wide RF Bandwidth Implementation
- In-Band Interference
- Signal Processing Beyond Current DSP (today requires analog processing)
- Global Standardization
- Broadband Non-resonant Antennas

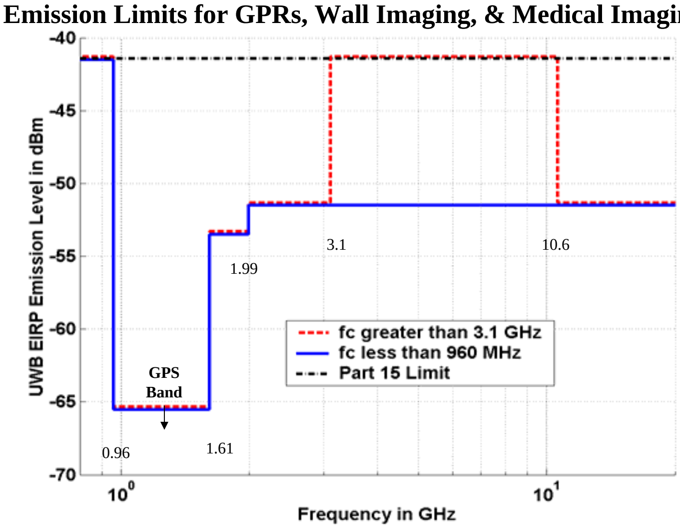
Relevance to IEEE 802

- UWB now has preliminary approval for unlicensed use in the United States
- UWB is complementary to other radio technologies in existing 802 standards
  - Potential to meet un-served application needs

Appendix

- Details of emission limits for UWB devices
- Detailed results of coexistence analyses

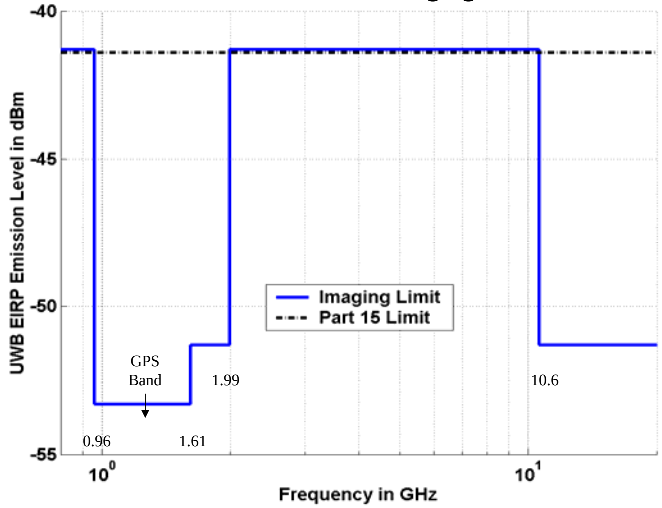
UWB Emission Limits for GPRs, Wall Imaging, & Medical Imaging Systems



Operation is limited to law enforcement, fire and rescue organizations, scientific research institutions, commercial mining companies, and construction companies.

March 2002 doc.: IEEE 802.15-02/133r1

UWB Emission Limits for Thru-wall Imaging & Surveillance Systems



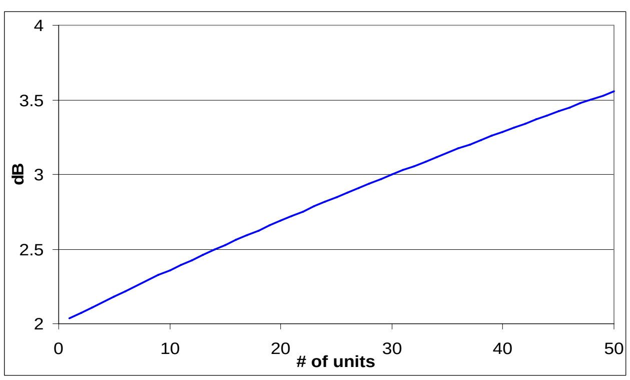
Operation is limited to law enforcement, fire and rescue organizations.
Surveillance systems may also be operated by public utilities and industrial entities.

Submission Slide 25 Matt Welborn (XtremeSpectrum) and Kai Siwiak (Time Domain)

March 2002 doc.: IEEE 802.15-02/133r1

Regulations Insure Exceedingly Safe

- **Example - Effective Noise Figure of a 2dB NF GPS**
  - **Assumes No Thermal Antenna Noise (antenna cannot see the earth)**
  - **Assumes all UWB devices transmitting simultaneously (but really TDMA)**
  - **All UWB devices 10m from GPS antenna**



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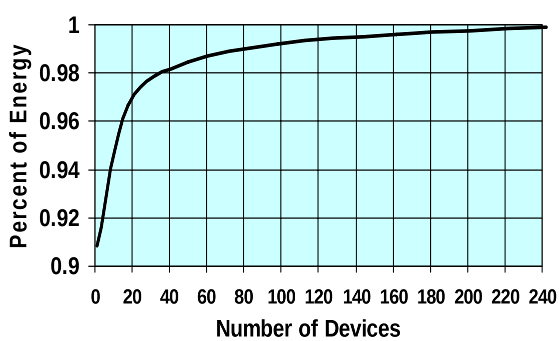
In-door Aggregation Is Insignificant

WPAN #	Range to Victim Receiver m	Power received by Victim Receiver picowatt/MHz	% of total energy received by victim receiver	Accumulated Power Received By Victim Receiver	Location of WPANs
1	3	0.029506	90.957	0.029506	Net in same room
2-18	7	0.001880	5.796	0.031386	17 Nets, 8 in adjacent rooms (left, right, above, below, left-above, right-above, left-below, right-below) PLUS 9 across the hall
19-50	11	0.000580	1.789	0.031966	32 Nets 16 in 2nd adjacent Rooms + 16 across hall
51-98	15	0.000252	0.776	0.032218	48 Nets, 24 in 3rd adjacet rooms + 24 across hall
99-162	19	0.000130	0.402	0.032348	64 Nets 32 in 4th adjacent rooms + 32 across hall
163-242	22	0.000091	0.280	0.032439	80 Nets 40 in 5th adjacent rooms + 40 across hall
Total Interference = .032439 picowatts/MHz = -104.9 dBm/MHz =1.099 times the power from the closest emitter					

- By 4th ring, there are 64 simultaneous transmitters added at equal distance, yet together they produce less the 1/2 percent of the total interference power
- The tiny received noise does not increase without bound
- The more distant WPANs become insignificant
- <u>i.e. In-building aggregation is insignificant</u>

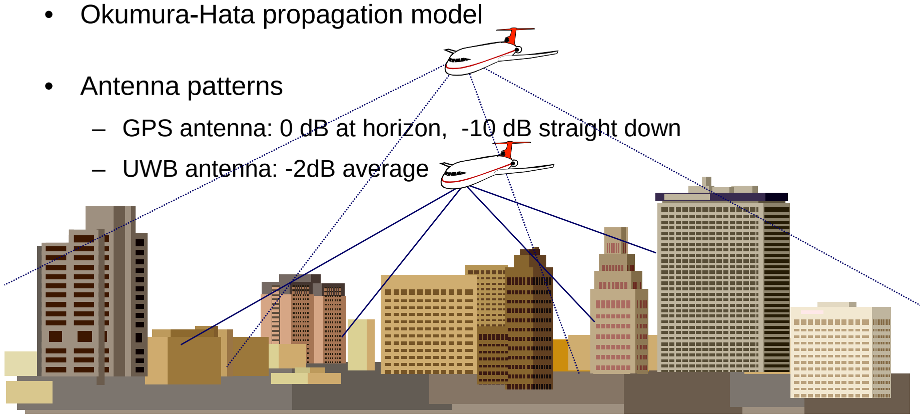
In-door Aggregation Is Insignificant

- Yes, Power adds Linearly
- But…as the number of devices grows, *<u>the energy added becomes insignificant</u>*
- i.e. Aggregation effect is immaterial

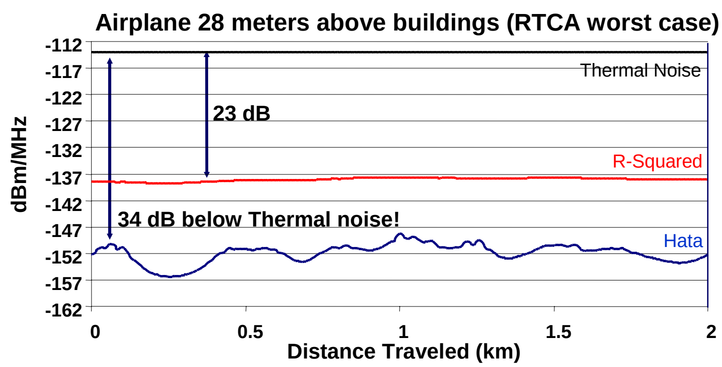


Outdoor Aggregation Is Insignificant

- As height goes down
  - Blockage by buildings tends to reduce the signal, but
  - The shorter path tends to increase the signal
- Okumura-Hata propagation model
- Antenna patterns
  - GPS antenna: 0 dB at horizon, -10 dB straight down
  - UWB antenna: -2dB average

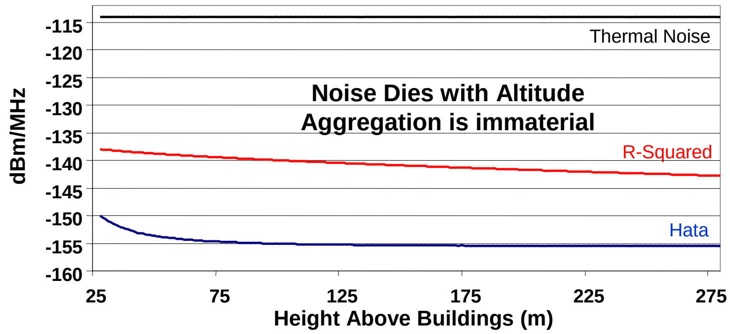


Low Altitude Airborne GPS Safety Criteria Satisfied



- City with 200 UWB devices per sq. km—aggregation is insignificant
  - Emitter density from NTIA report
  - All devices transmitting simultaneously
  - All devices outside, no building attenuation
  - Plane passes over highest elevation UWB
- Margin greater than 30dB

Higher Altitude Airborne GPS Safety Criteria Satisfied



- City with 200 UWB devices per sq. km —aggregation is insignificant
  - Emitter density from NTIA report
  - All devices transmitting simultaneously
  - All devices outside, no building attenuation
  - Plane directly over highest elevation UWB
- Margin greater than 30 dB and increases with altitude