ASTRON Netherlands Institute for Radio Astronomy

Spread Spectrum and Ultra-Wideband Technology

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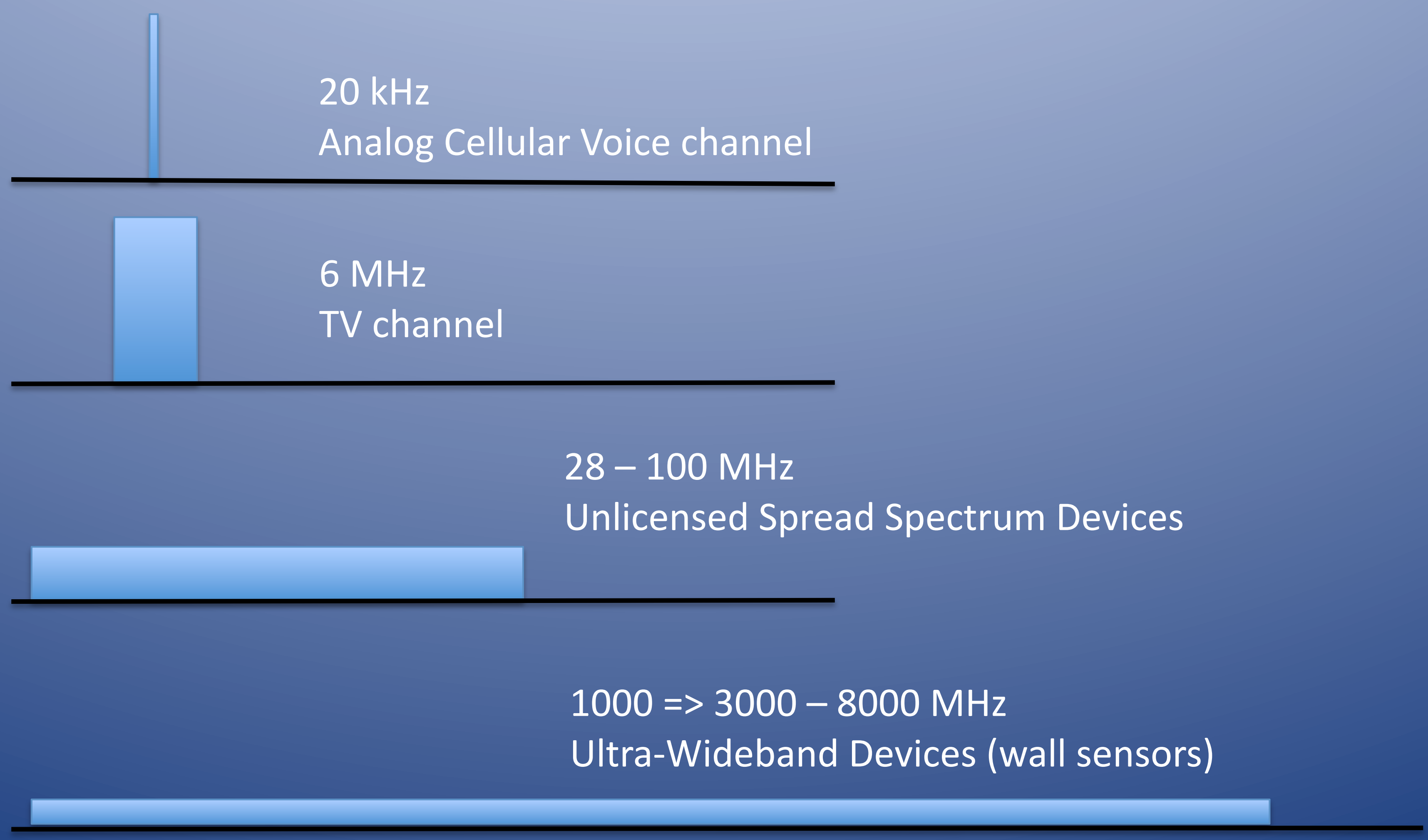
The Case for UWB

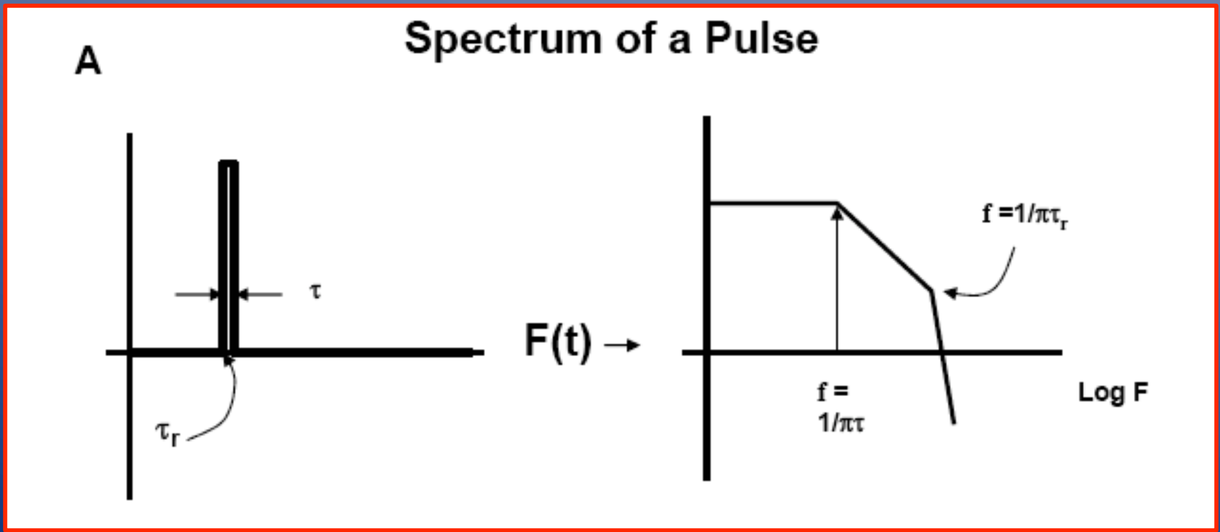
- "encourage the deployment on a reasonable and timely basis of advanced telecommunications capability" (FCC 1996)
- Broaden the deployment of broadband technologies
- Broadband includes any platform capable of transmitting high-bandwidth intensive services
- Harmonized regulatory treatment of competing bb services
- Encourage and facilitate an environment that stimulates investment and innovation in broadband technologies and services

- Low Cost - Utilizes baseband radio architecture implemented in CMOS
- Low Power Consumption - Low transmit duty cycles
- High Capacity - Large occupied bandwidth
  - Shannon-Hartley theorem
- Multipath Robust - Frequency diversity


20 kHz
Analog Cellular Voice channel
6 MHz
TV channel
28 – 100 MHz
Unlicensed Spread Spectrum Devices
1000 => 3000 – 8000 MHz
Ultra-Wideband Devices (wall sensors)

What is UWB ?

- Wireless communication or remote sensing using non-sinusoidal or limited cycle sinusoidal carriers
- UWB signals are typically produced by applying an impulse, mono-cycle, or step signal to a resonant antenna
- In the frequency domain, a very (ultra) wide spectrum signature is created
- Pulsed UWB a subset, OFDM & many other modulation schemes
- Pulsed UWB is cheapest and least controllable (most dangerous)

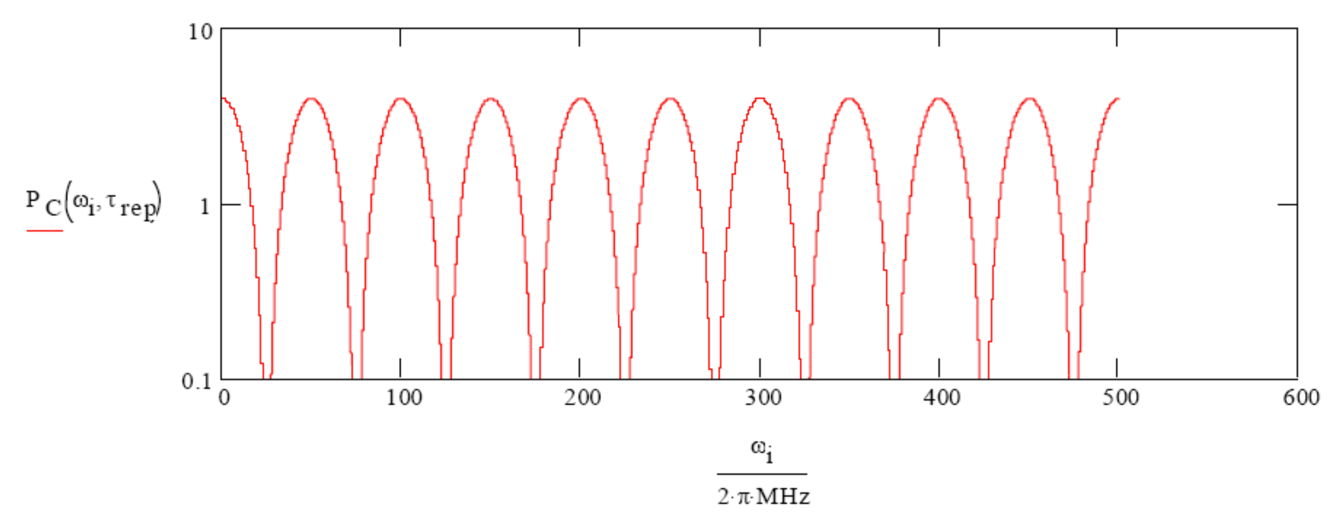


Early UWB history dates to birth of radio

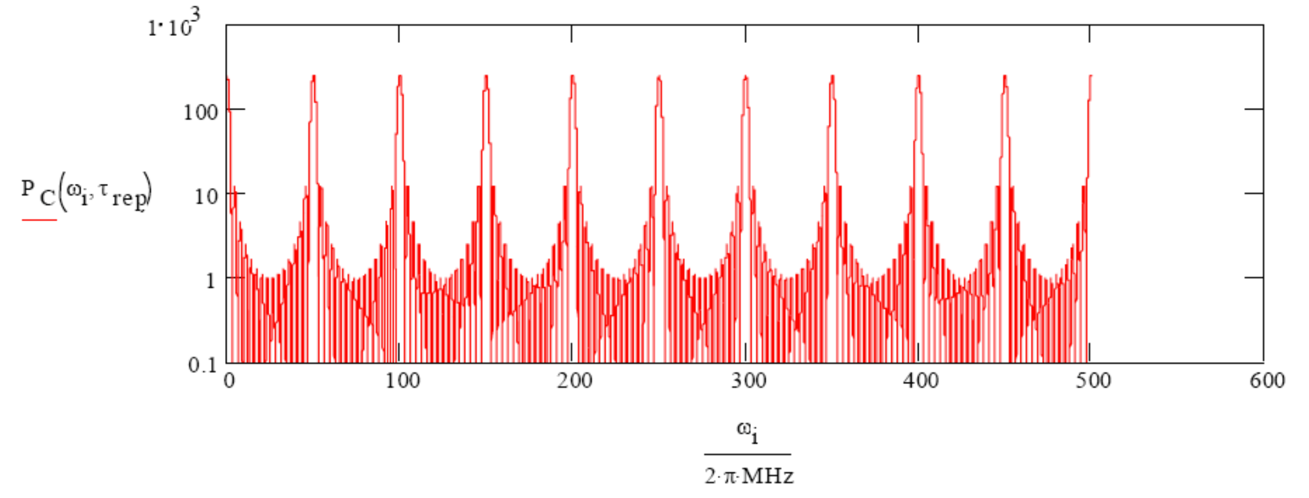
Marconi spark gap transmitters generated impulse excitation of an antenna, producing an UWB-like spectrum

UWB Signal Generation

- Waveforms generated by edge of very fast rise-time pulse
- Impulse obtained from first derivative of step rise-time
- Monocycle obtained from first derivative of the impulse (or second derivative of step rise-time)
- Resulting narrow pulse used to “shock excite” a resonant antenna
- Properly designed antenna can function as bandpass filter, limiting the resultant spectra

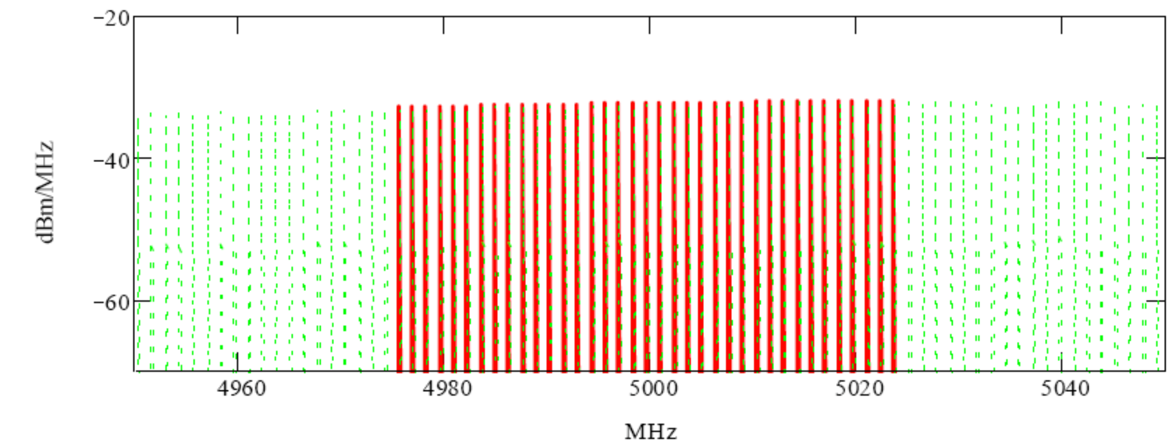


2 pulses



16 pulses

100 pulses



Modulation Schemes

- **Pulse Position Modulation (PPM)**
  Position of pulse (in time) determines binary state (0 or 1)
- **Bi-phase modulation (BPM)**
  Pulse shape and its negative used to represent zero and one
- **Pulse Amplitude Modulation (PAM)**
  Pulse amplitude level determines binary state
- **On-Off Keying (OOK)**
  Binary state determined by presence or absence of a pulse
- **Direct sequence & DS code-division multiple access (DS-CDMA)**
  High duty-cycle polarity coded sequences of pulses (up to GHz)
- **Binary Phase Shift Keying (BPSK)**
  State is represented by change in signal phase
- **Orthogonal frequency division multiplexing (OFDM)**
  several sub-carriers phase & amplitude modulated – high OOB base
- **Multi-band modulation & multi-user techniques**
  Freq-hopping (FH), Time-division multiple access (TDMA)

UWB Applications

- High-speed mobile local area networks (LANs)
- Wireless personal area networks (WPANs)
- Imaging systems (ground penetrating and through-wall radar, medical imaging)
- Electronic surveillance and detection
- Secure communications
- Personnel and asset tracking
- Automotive radar (anti-collision) and sensors

- Imaging Systems < 960 MHz
- Communications and Field Disturbance Sensors 3.1-10.6 GHz
- Short Range Vehicular Radar 22-29 GHz
- 960-3100 MHz range protected - including GPS L1, L2, and L5 bands

Operational Characteristics ITU-R SM.1754

UWB application	Operational characteristics
1 Radar imaging	– Mostly occasional use by professionals in limited numbers – Use is limited to specific locations or geographic areas
Ground penetrating radar	– Occasional use by professionals at infrequent intervals and specific sites – A specific application may have a limited number of devices that operate in mobile continuous use on roadways – Transmission is directed towards the ground
In-wall radar imaging	– Occasional use at infrequent intervals – Professional users: typically engineers, designers, and professional of the construction industry – Transmission is directed toward a wall – Devices are operated typically in direct contact with the wall to maximize measurement resolution and sensitivity
Through–wall radar imaging	– Device is transportable – Used by trained personal: normally police, emergency teams, security and military – Occasional use at infrequent intervals – Deployed in limited numbers – Transmission is directed towards a wall – Devices may operate at some distance from the wall to maximize operation safety in case of hostile action

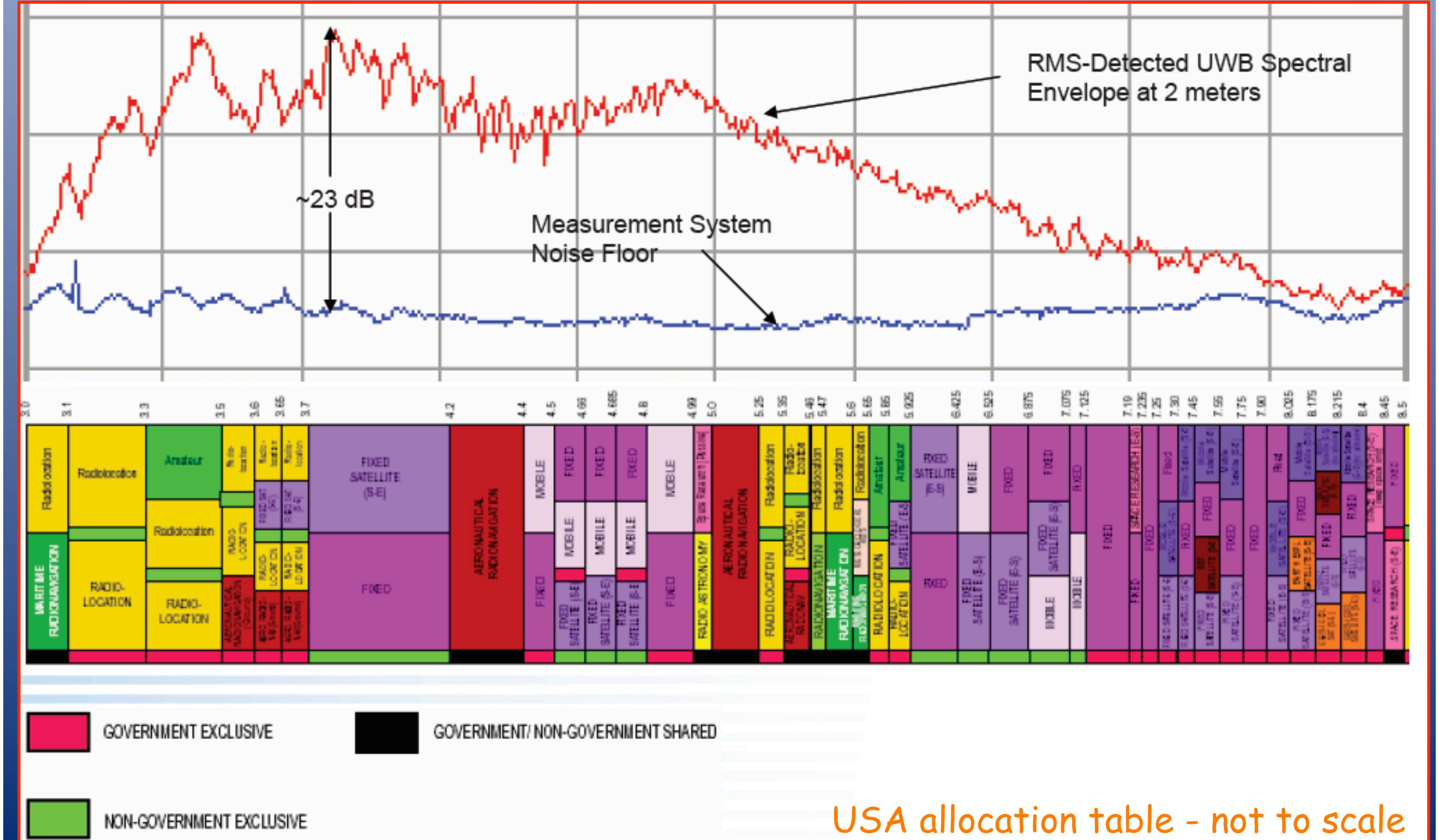
ITU-R SM.1754

UWB application	Operational characteristics
Medical imaging	– May be used for a variety of health applications for imaging inside the body of a person or an animal – Indoor stationary occasional use by trained personnel – Transmission is directed towards a body
2 Surveillance	– Operate as "security fences" by establishing a stationary RF perimeter field and detecting the intrusion of persons or objects in that field – Continuous outdoor and indoor use in a stationary manner
3 Vehicular radar	– Mobile usage – High-density use may occur on highways and major roads – Terrestrial transportation use only – Transmission is generally in a horizontal direction
4 Measurement	– Stationary indoor/outdoor use
5 Location sensing and tracking	– Typically fixed infrastructure; mostly stationary use – Transmitters always under positive control
6 Communication	– High-density use may occur in certain indoor environments such as office buildings – Some applications have occasional use such as an UWB wireless mouse; others will operate at a higher percentage of time, such as a video link – Outdoor use may also occur

Spectrum Issues (ITU-R SM.1756)

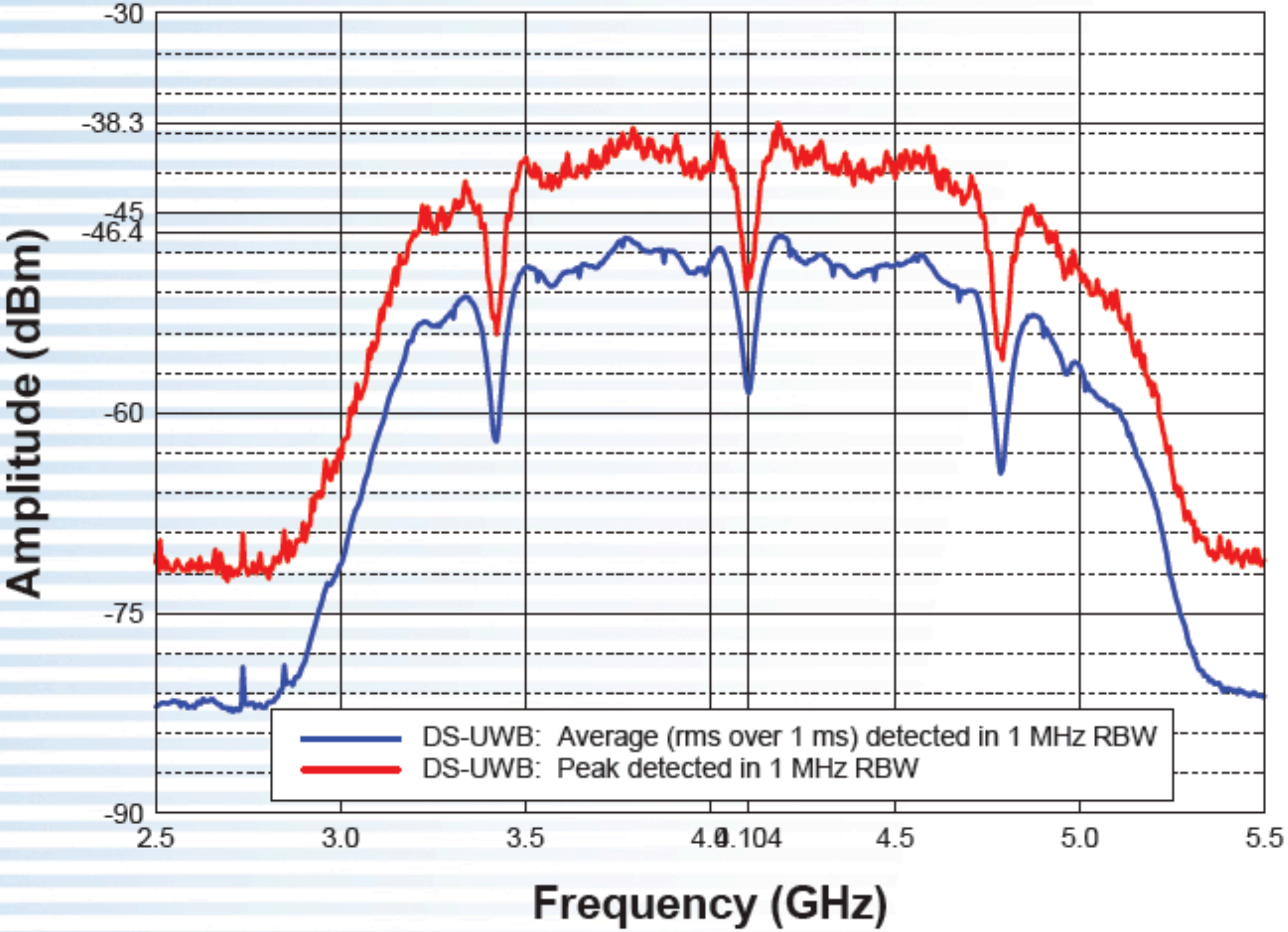
- UWB communications require access to large swaths of radio spectrum
- UWB emissions incompatible with existing spectrum management protocol
- Spectrum identified for UWB operation will necessitate access to "restricted bands"
  - Restricted bands typically reserved for Safety-of-Life, national security and/or scientific research operations
- Requires operation in spectrum long used by incumbent licensees, often on a sole basis
- RAS, EESS (passive) and SRS (passive) - low levels of interference received may have a degrading effect on passive service band usage.
- RR No. 5.340 enables the passive services to deploy and operate their systems
- Special attention should be given to the protection requirements of the passive services

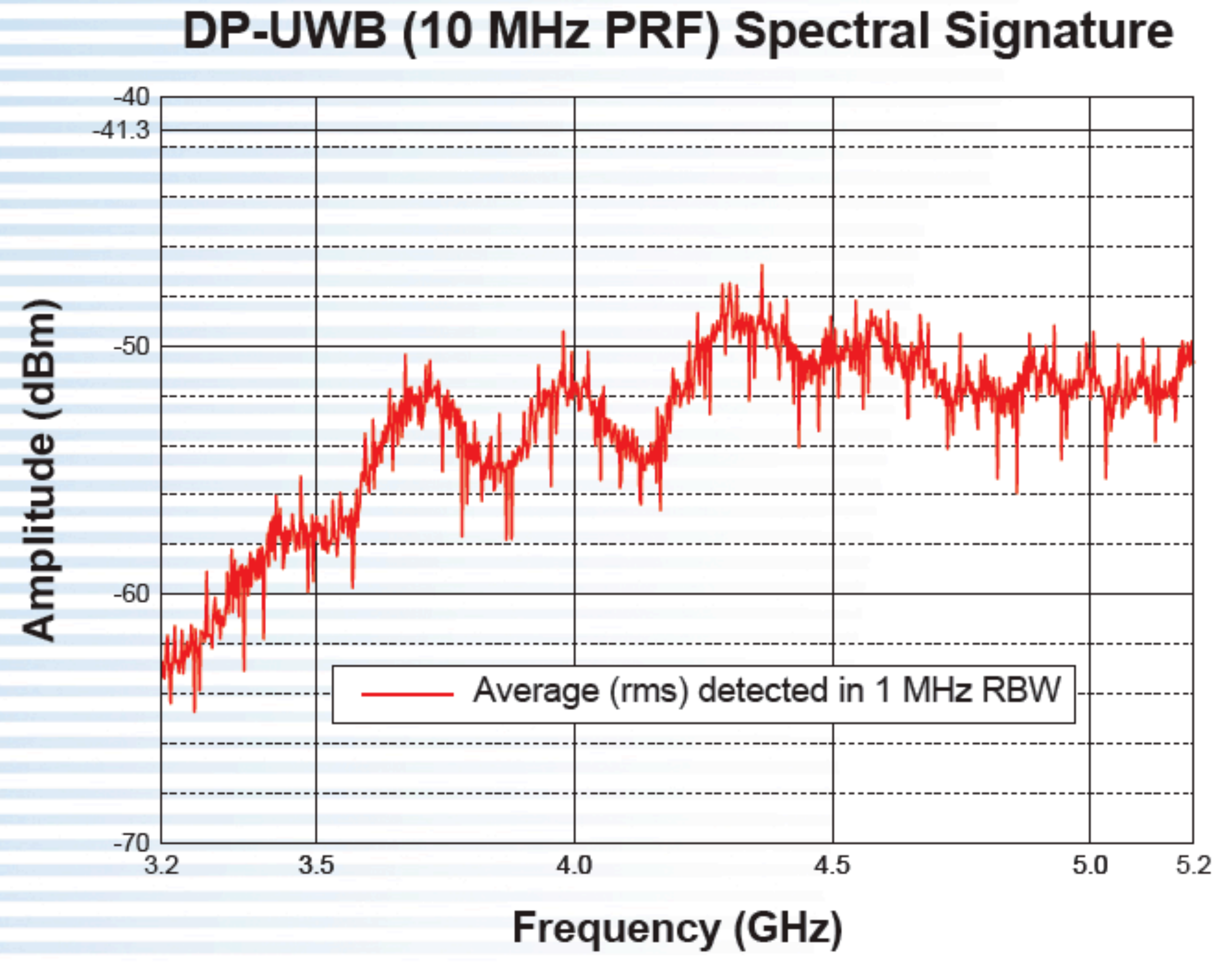
UWB spectral envelope - the problem



USA allocation table - not to scale

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

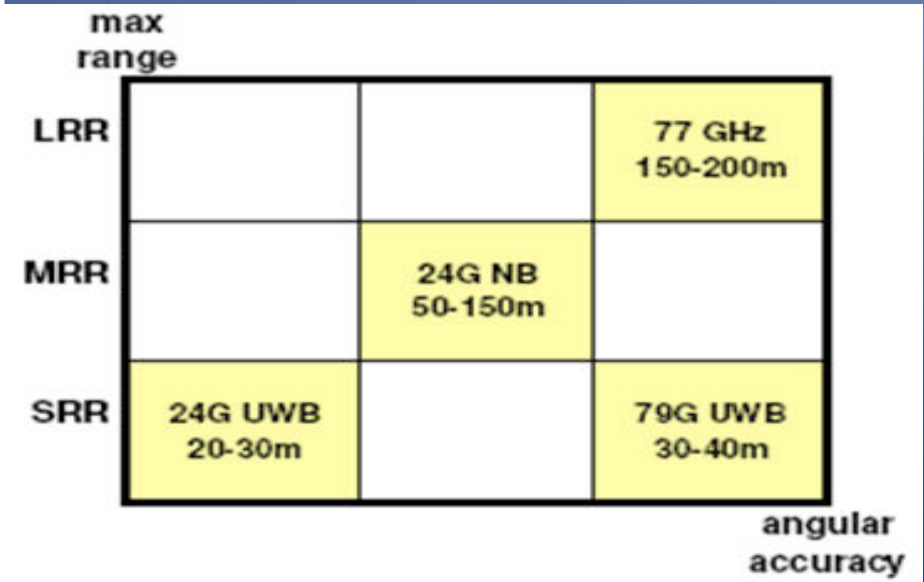



DP-UWB (10 MHz PRF) Spectral Signature
-40
-41.3
-50
-60
-70
Amplitude (dBm)
3.2
3.5
4.0
4.5
5.0
5.2
Frequency (GHz)
Average (rms) detected in 1 MHz RBW

Short Range Radars (SRR) - automotive

- 2004 – two bands – until 2013 (CEPT ECC & other admins)
  - 24 GHz temporary (21.65 – 26.65 GHz)
  - 79 GHz permanent (77 – 81 GHz)
- Transition to 79 GHz 'difficult' because system integration and validation (or cost aspect)
- 79 GHz needed for measurement range and angular accuracy
- ECC Decision to be made: remain at 24 GHz, or another extension at 26 GHz, or only move to 79 GHz

  – ECC 'consensus' => do not prolong SRR at 24GHz



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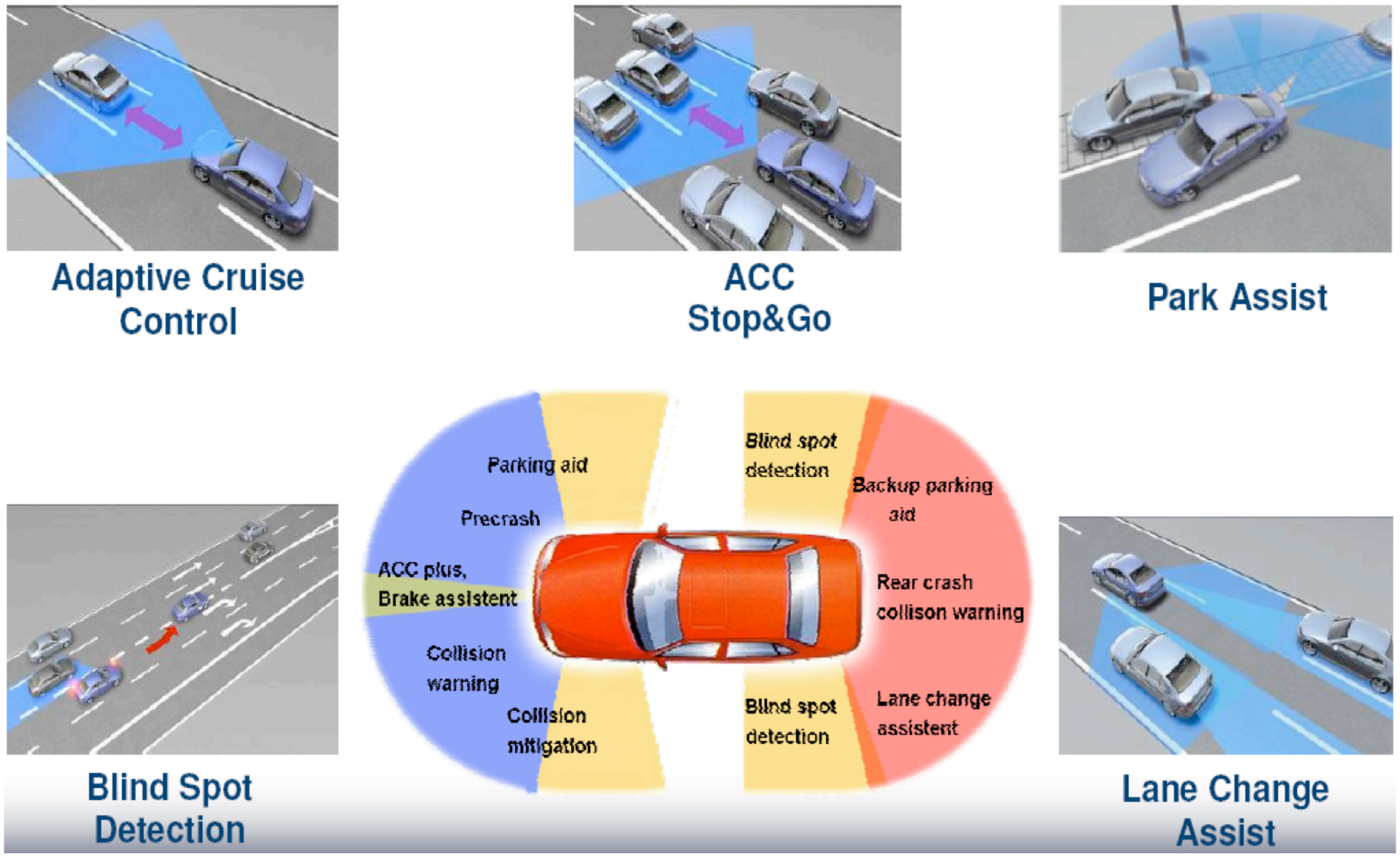
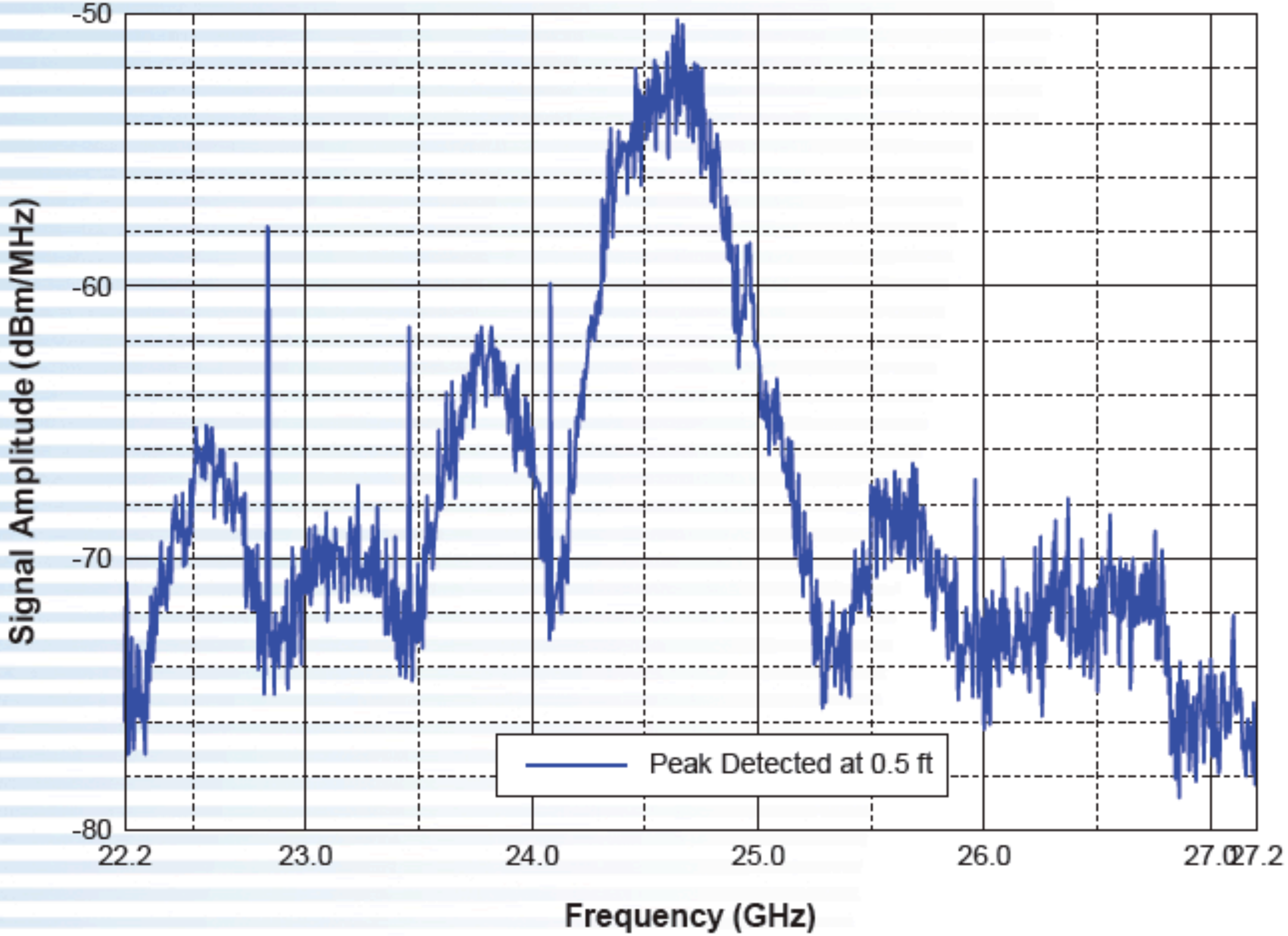


UWB Automotive Radar Emissions



Simulations of Interference Potential

ITU-R SM.2057 (808p)

FIGURE 208

FWA central square scenario (plane projection)

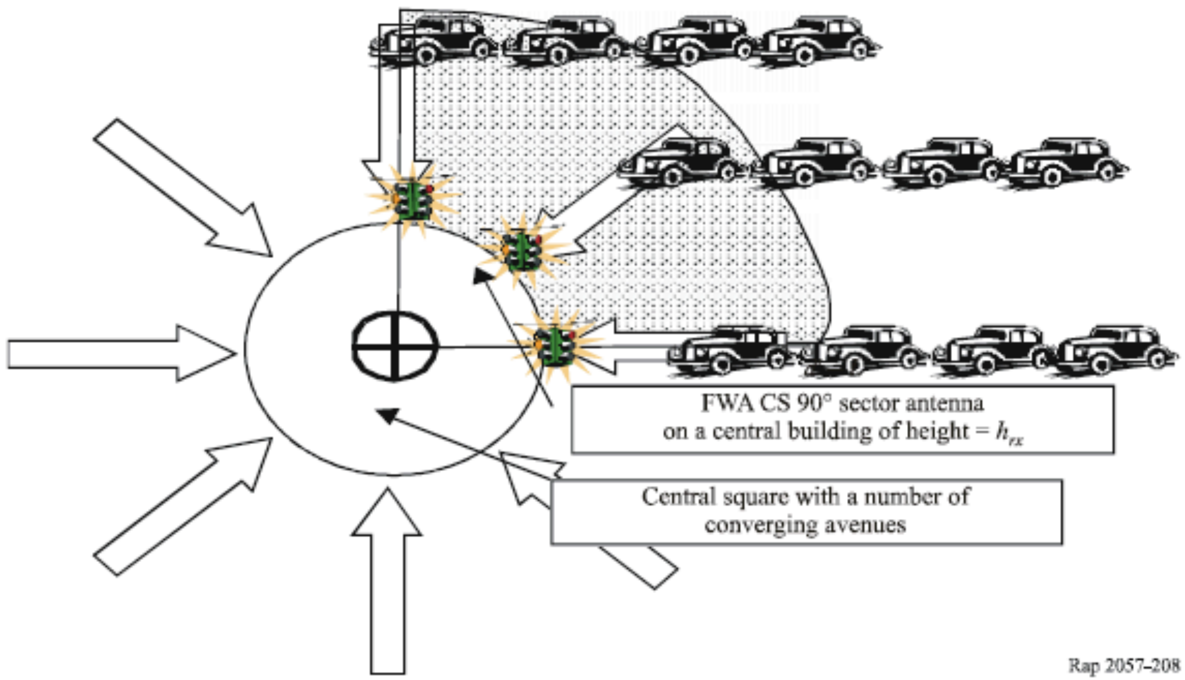
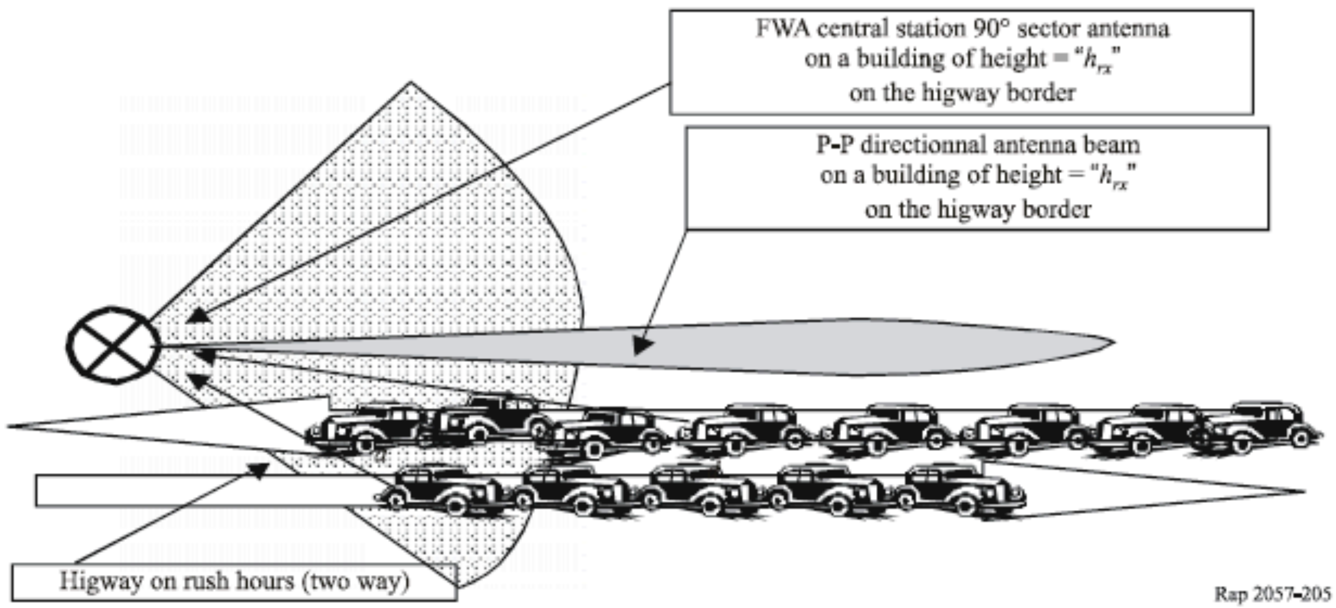


FIGURE 205

The road or highway scenario (plan projection)



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FWA central square scenario (plane projection)

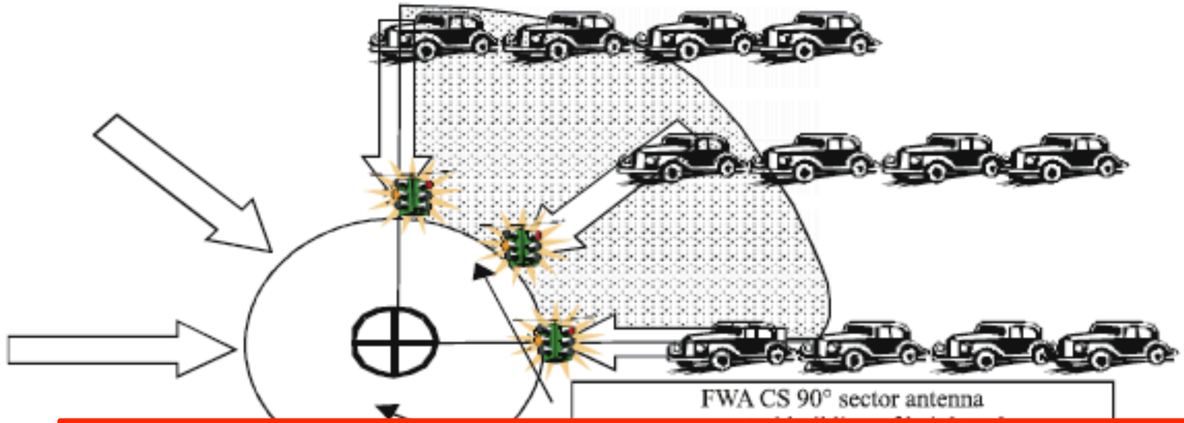
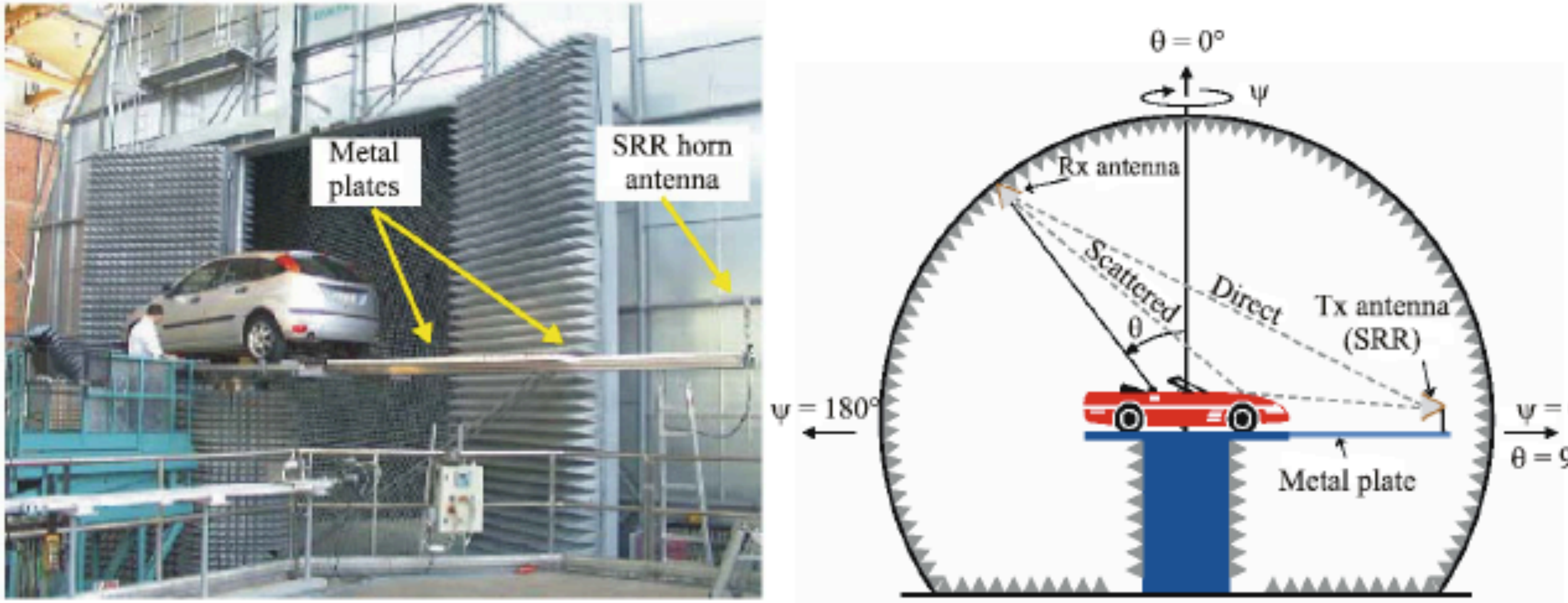


FIGURE 232

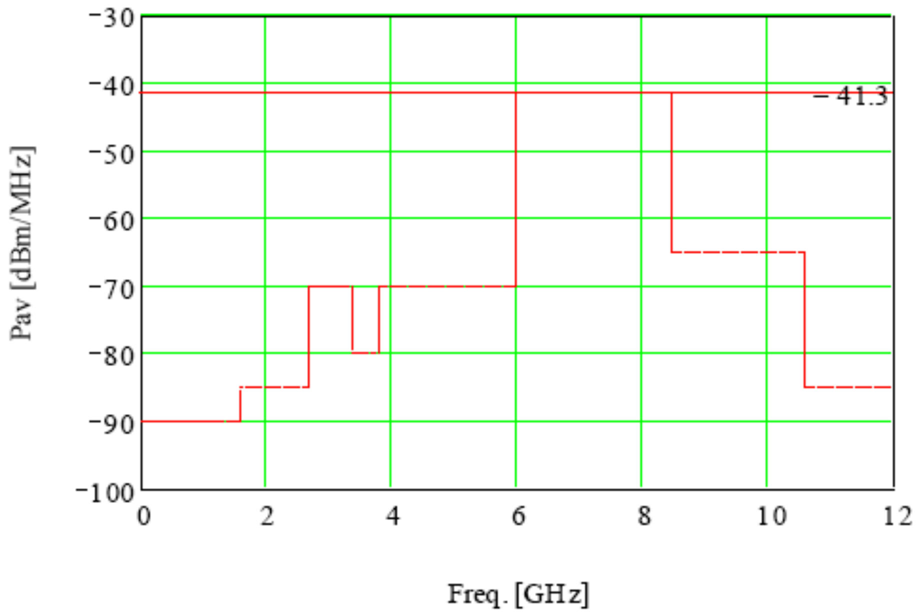
Coupling parameter measurements for a passenger car, conducted at the Joint Research Centre ISPRA, Italy



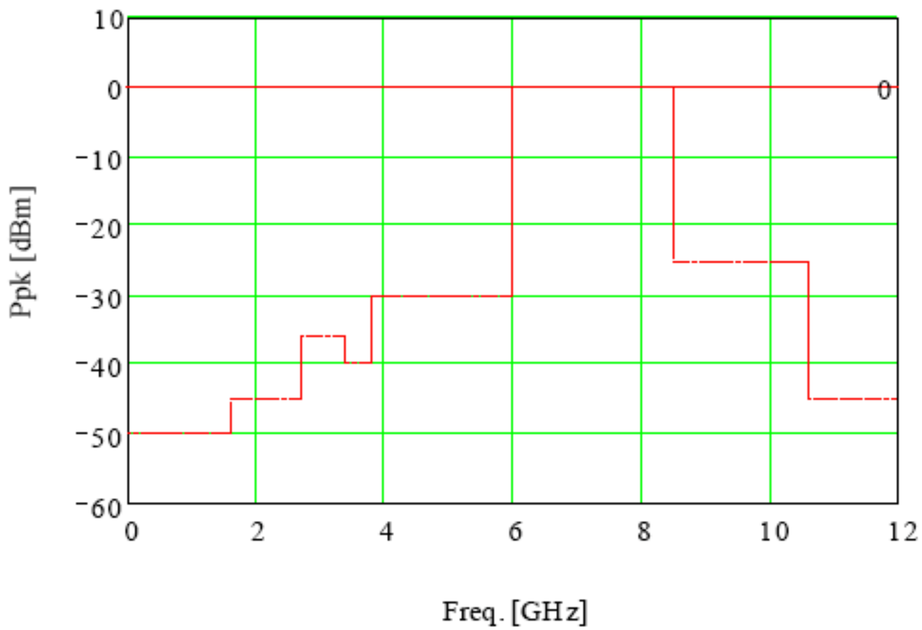
Rap 2057-232

ECC Decisions 06(04) & 07(01) & 06(12)(amended)

- License exempt operation of UWB devices in freq range 1 – 10 GHz with constraints in emitted and average power levels
- Separate Decisions on fixed and mobile Material Sensing and Material Analysis (BMA) devices
- Pulse Repetition Frequency (PRF) > 5 MHz
- “Listen before talk” & “Detect and Avoid” devices

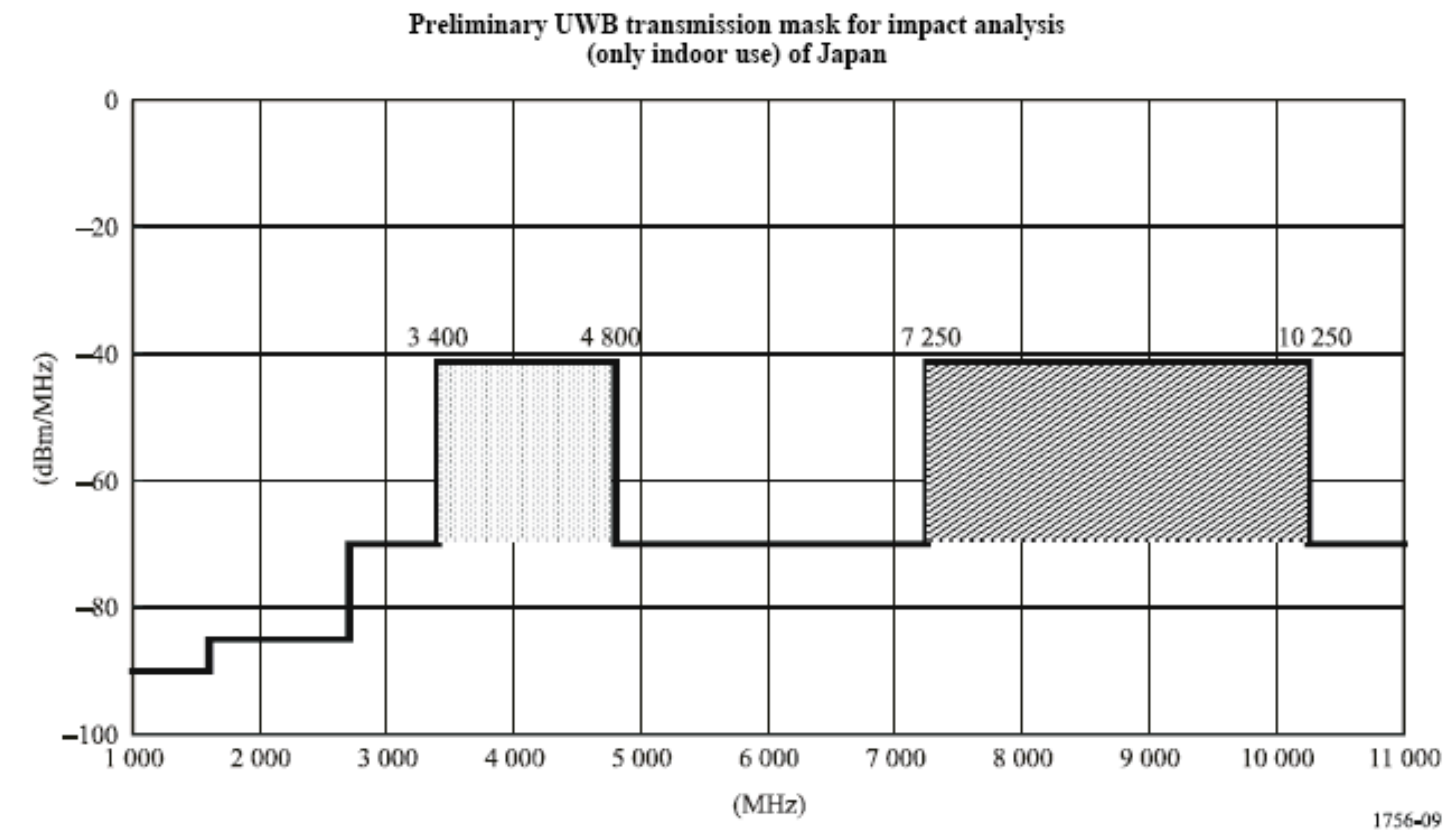


Mean EIRP [dBm/MHz]



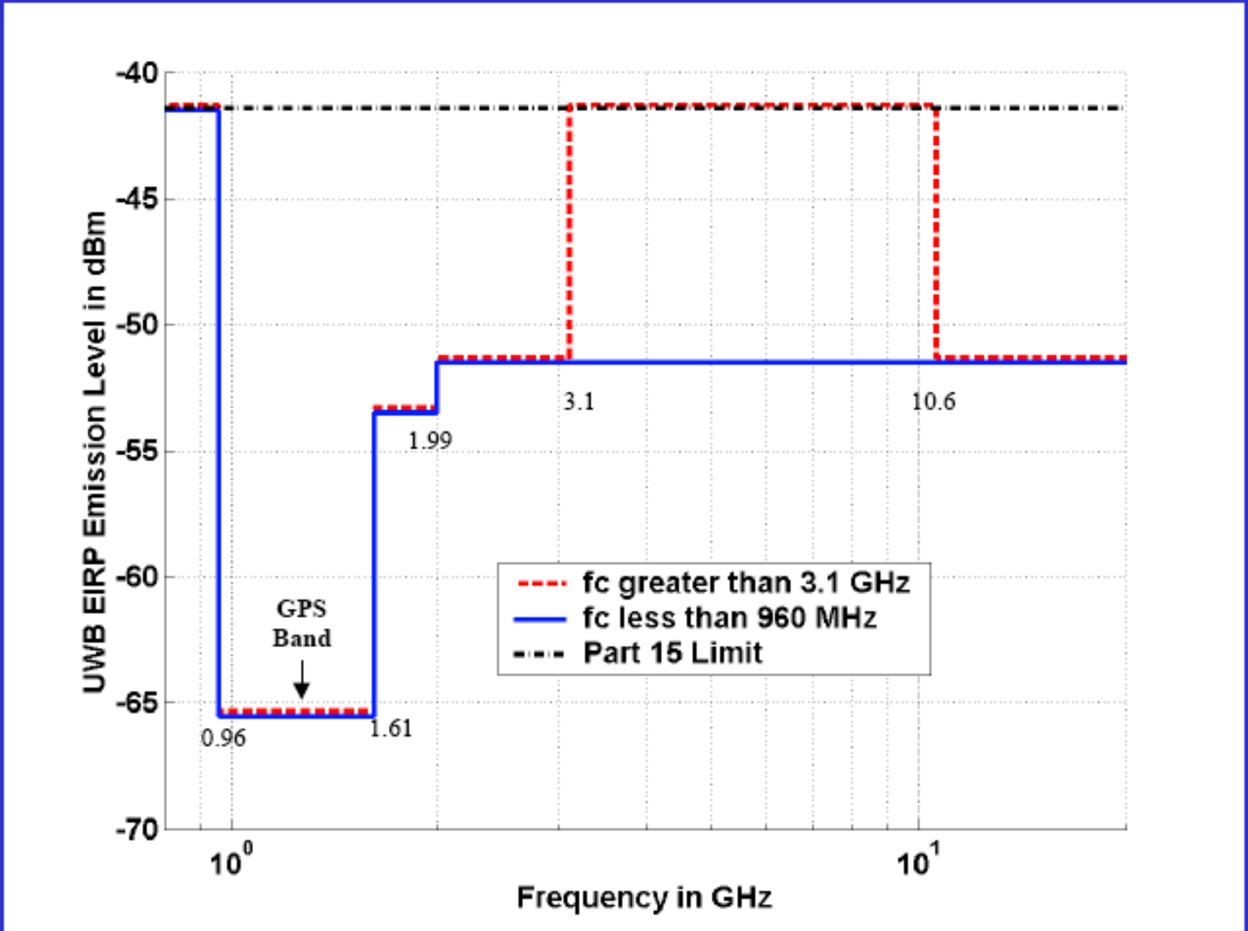
Peak EIRP [dBm]

Japan UWB

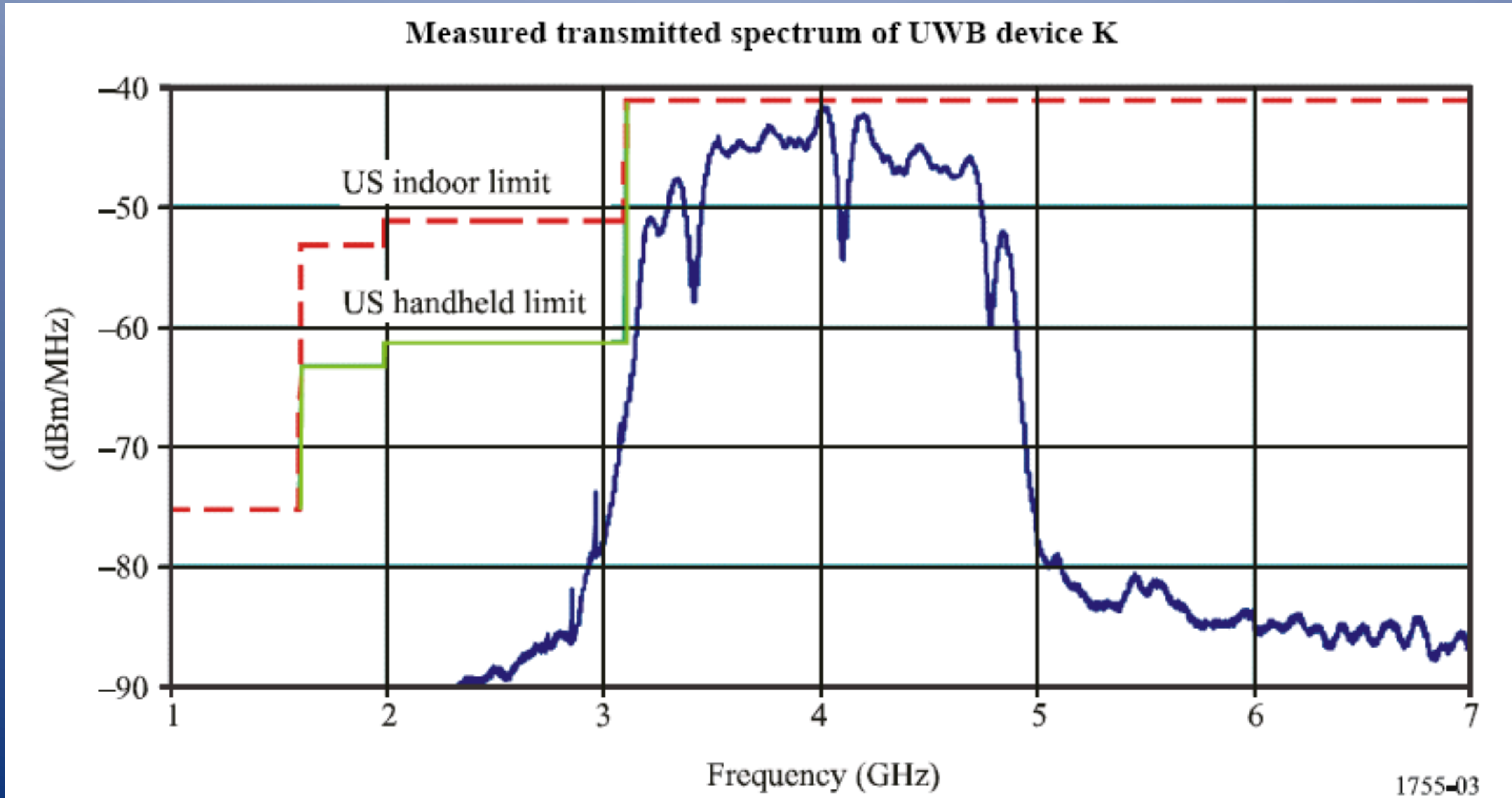

Preliminary UWB transmission mask for impact analysis
(only indoor use) of Japan
0
–20
–40
–60
–80
–100
(dBm/MHz)
3 400
4 800
7 250
10 250
1 000
2 000
3 000
4 000
5 000
6 000
7 000
8 000
9 000
10 000
11 000
(MHz)
1756-09

Preliminary

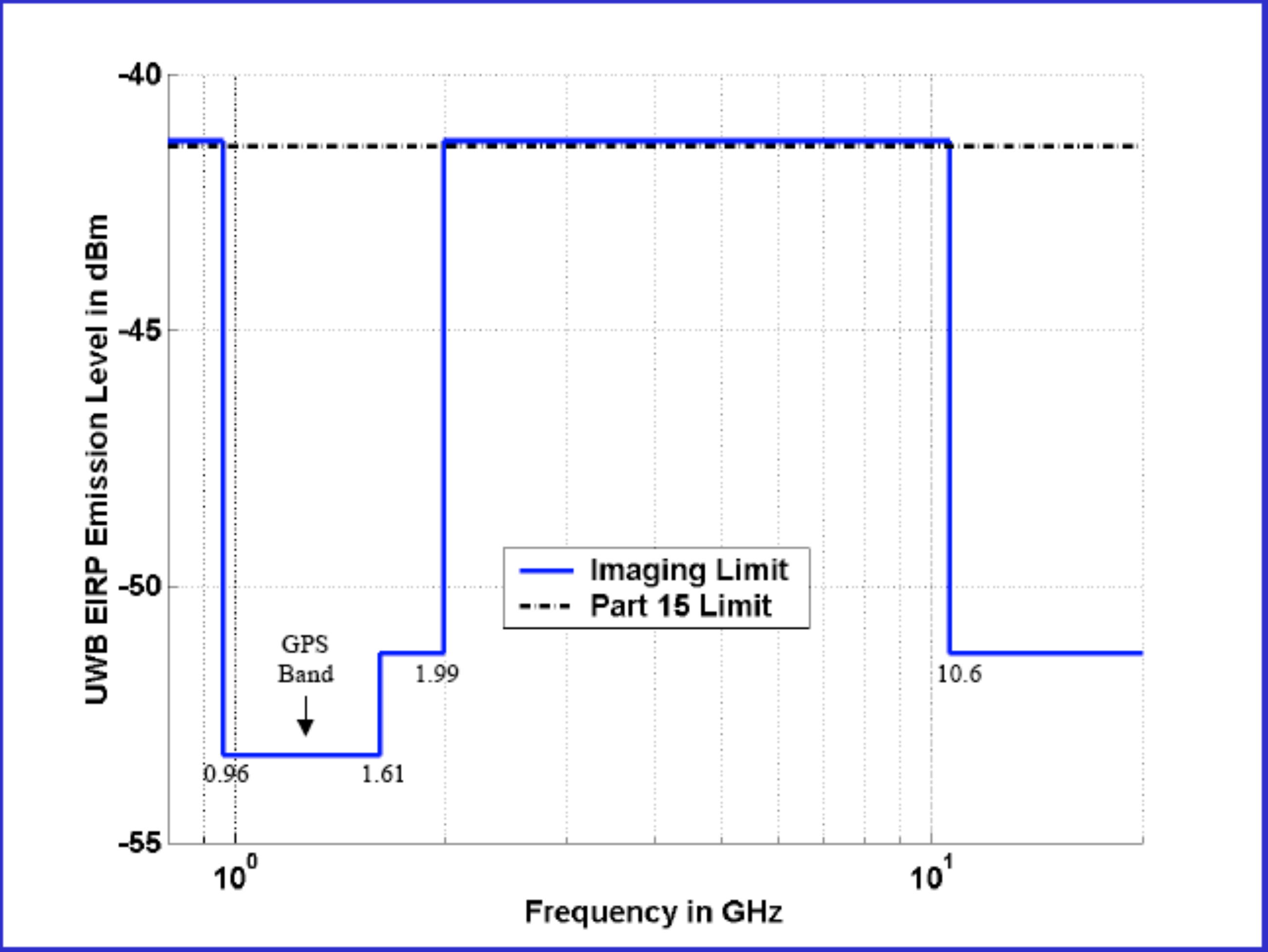
UWB Emission Limits for GPRs, Wall Imaging, & Medical Imaging Systems



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


Measured transmitted spectrum of UWB device K
–40
–50
–60
–70
–80
–90
(dBm/MHz)
US indoor limit
US handheld limit
1
2
3
4
5
6
7
Frequency (GHz)
1755-03

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.

Weakness Associated with UWB Technology

- **Compatibility of UWB receivers with “real world” electromagnetic environment remains unknown**
  - Since UWB authorized as an unlicensed service, interference protection not provided or considered
- **Limited studies of interference potential to UWB receivers**
  - Particularly from high power emitters (e.g., radar, PCS and cellular, paging, etc)
  - Mitigation possible through careful frequency band selection
- **Limited studies of interference potential from UWB to other services**

Mitigation techniques (SM.1755)

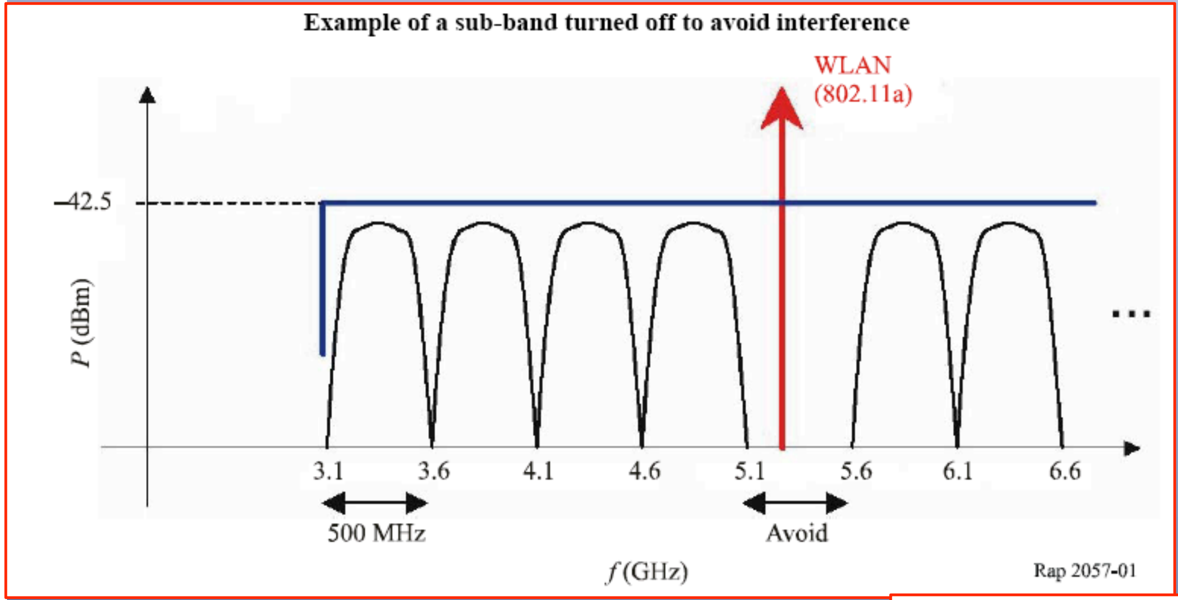
RAS

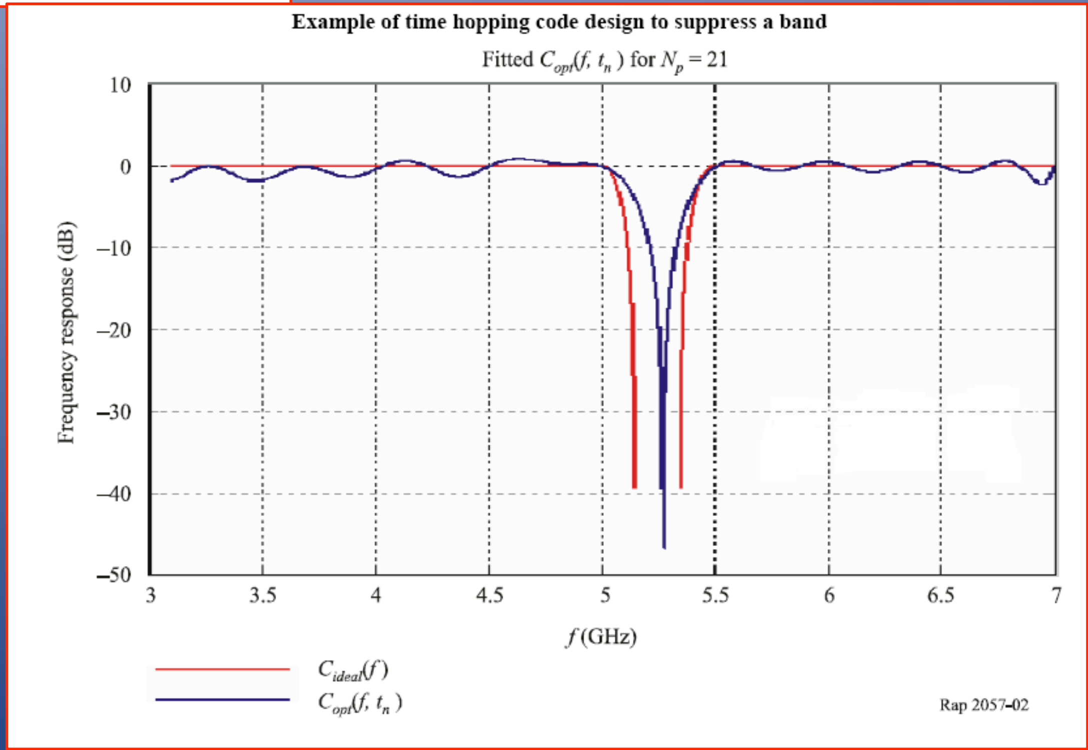
- it will be particularly difficult to filter out UWB signals
  - difficult even when keying is known – they are cheap devices
- reduce antenna side lobe performance
- blanking in time and/or frequency - not for UWB transmissions

UWB applications

- most effective – attenuation to the threshold level in RAS band
- use of terrain shielding – site & season dependent
- separation distances & exclusion zones
- set e.i.r.p. limit at 500 m range
- e.i.r.p. limit of –85 dBm/MHz offers full protection to RAS bands below 3 GHz and above 10.7 GHz

Impact on other services SM.1756





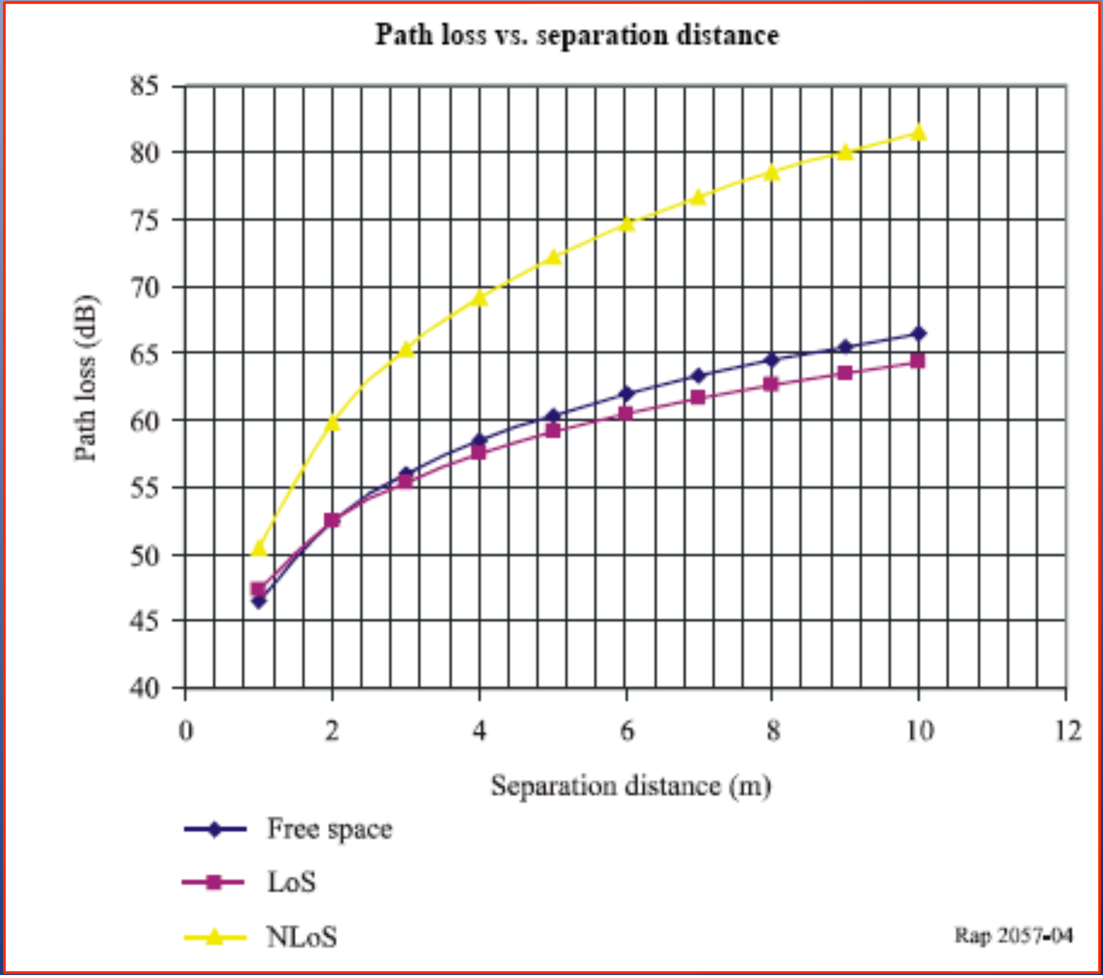
How to calculate things

Frequency	MHz	F
Data rate	Mbit/s	D_r
Distance d	m	D
Tx e.i.r.p. density	dBm/MHz	P_{tx}
Bandwidth	MHz	B
Average tx power	dBm	$P_{tx} + 10 \log (B) = A$
Path loss 1 m	dB	$20 \log (4 \pi F/c) = B$
Path at distance d	dB	$20 \log (d) = C$
Rx antenna gain	dBi	G_{rx}
Rx power	dBm	$A - B - C + G_{rx} = D$
Noise per bit	dBm	$-174 + 10 \log (D_r) = G$
Noise figure	dB	NF
Average noise	dBm	$G + NF = H$
Required E_b/N_0	dB	E
Implementation loss	dB	I
Link margin	dB	$D - H - E - I = M$

Examples – single device

- P_{tx} = 65 dBm/MHz @ 1.4 GHz at 100m => -230.3 dBW/m2/Hz
- RA.769 thresholds: Cont = -255 and SL = -239 dBW/m2/Hz
- Free space coordination distance 1800 m & 280 m

- Propagation modeling



Estimates of separation distances for a single device using UWB technology, for different spectrum masks (for continuum measurements)

RAS frequency bands (MHz)	Required MCL (dB) slope mask (outdoor)	Required MCL (dB) United States mask (outdoor)	Resulting separation distance (km) slope mask (outdoor)	Resulting separation distance (km) United States mask (outdoor)
608-614	58	138	–	–
1 400.0-1 427.0	98	114	1.37	9.6
1 660.0-1 670.0	102	124	1.86	27
2 690.0-2 700.0	120	126	10	21
4 990.0-5 000.0	144	145	86	96

TABLE 269

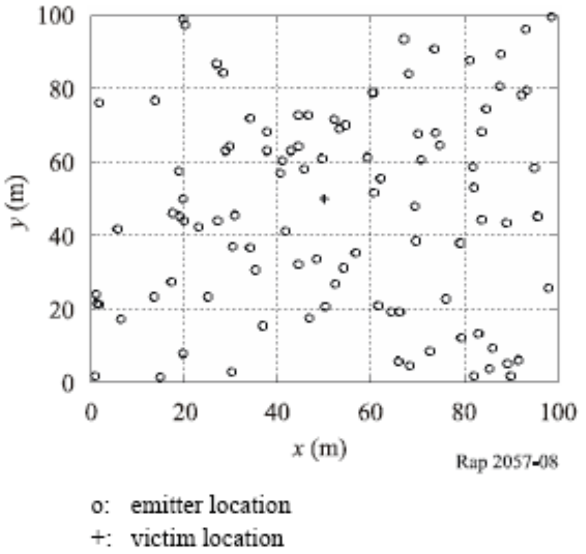
Estimates of separation distances for a single device using UWB technology, for different spectrum masks (for spectral-line measurements)

RAS frequency bands (MHz)	Required MCL (dB) slope mask (outdoor)	Required MCL (dB) United States mask (outdoor)	Resulting separation distance (km) slope mask (outdoor)	Resulting separation distance (km) United States mask (outdoor)
1 400.0-1 427.0	82	98	0.21	1.37
1 610.6-1 613.8	87	109	0.335	4.46
1 660.0-1 670.0	88	109	0.36	4.32
4 800.0-4 990.0	130	133	18.2	26.2

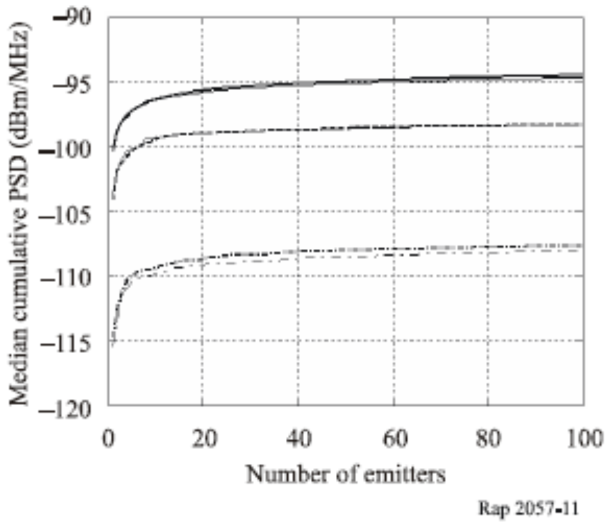
Distributions of UWB devices

- 100 identical UWB devices in 100 x 100 m or 1 km x 1 km zones (density $10^4/km^2$ or $10^2/km^2$)
- e.i.r.p = -41.3 dBm/MHz
- Conversion to RA.769 => -90 dB

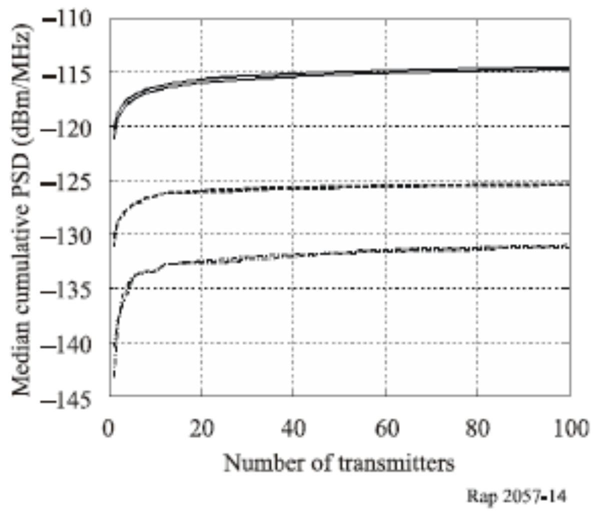
Typical 2-dimensional uniformly random distribution of 100 identical UWB transmitters within a 100 m × 100 m zone



Median cumulative PSD against number of distance-sorted transmitters in a 100 m × 100 m zone for free-space (solid lines), log-normal shadowing (dashed lines) and RPF (dash-dot lines) models for 50 (thin lines) and 200 (thick lines) random distributions



Median cumulative PSD against number of distance-sorted transmitters in a 1 000 m × 1 000 m zone for free space (solid lines), log-normal shadowing (dashed lines) and RPF (dash-dot lines) models for 50 (thin lines) and 200 (thick lines) random distributions



Conclusions

- Despite the masks UWB devices are potential interferors
- UWB applications will be widespread
- Because of the generic masks, each type application needs to be addressed separately

- Observatories need to address issue of required separation distances

- Automotive radars (SRR) need special care
  - 'drive-in' observatories and nearby roads

UWB Documentation

- ITU-R SM.1055 – Use of Spread Spectrum Techniques
- ITU-R SM.1754 - Measurement techniques of UWB transmissions
- ITU-R SM.1755 - Characteristics of ultra-wideband technology
- ITU-R SM.1756 - Framework for the introduction of devices using ultra-wideband technology
- ITU-R SM.1757 - **Impact of devices using ultra-wideband technology on systems operating within radiocommunication services**
- ITU-R SM.1794 - Wideband instantaneous bandwidth spectrum monitoring systems
- ITU-R SM.2057 - Studies related to the impact of devices using ultra-wideband technology on radiocommunication services

- CEPT – ECC & FCC & other Recommendations

- **Useful formulas**
- Antenna response pattern
- Sensitivity of radio astronomy systems (theoretical considerations)
- Estimates of sensitivity and detrimental interference levels
- Impact on the radio astronomy service of unwanted emissions
- Separation distances required for sharing
- Compatibility study between Mobile-Satellite Service in the 1610-1626.5 MHz band and Radio Astronomy Service in the 1610.6-1613.8 MHz band
- Conversion formula
- Calculations

CRAF Web-based Calculation Tools

- Conversion from pfd level (dB(W/m^2)) into field-strength (dB(microVolt/meter)) and e.i.r.p. (dBm)
- Conversion from pfd level (dB(W/m^2)) into e.i.r.p. (dBm)
- Conversion from erp (dBm) to e.i.r.p. (dBm)
- Conversion from e.i.r.p. (dBm) into pfd level (dB(W/m^2))
- Conversion from e.i.r.p.(dBm) into field-strength (dB(microVolt/meter)), pfd level (dB(W/m^2) and power level (dBW)
- Conversion from field-strength (dB(microVolt/meter)) into pfd level (dB(W/m^2))
- Conversion from power (dB(W)) to power flux density, pfd, (dB(W/m^2))
- Conversion from hour angle and declination to azimuth and elevation
- Estimates of sensitivity and detrimental interference levels for radio astronomy (Rec. ITU-R RA.769)
- Impact on the radio astronomy service of unwanted emissions in excess of the levels defined by Recommendation ITU-R RA.769. (Re: ITU-R 1-7/26 (2001) and ITU-R SM.1633)
- Estimate of visibility radius from a space station, aeronautical station or HAPS station to a radio astronomy station
- Estimate of acceptable e.i.r.p. of interfering transmitter using free space attenuation (Rec. ITU-R P.525)
- Estimate of acceptable e.i.r.p. of interfering transmitter (for frequencies above 0.7 GHz) (Rec. ITU-R P.452)
- Estimate of acceptable e.i.r.p. of interfering transmitter (for frequencies between 0.1 and 105 GHz) (Rec. ITU-R P.620)
- Calculation of pfd value at the surface of the Earth for FSS satellite
- Transmission loss for specified distance between transmitter and receiver (for frequencies above 0.7 GHz) (Rec. ITU-R P. 452)
- Path loss attenuation for specified distance between transmitter and receiver (Rec. ITU-R P.525)
- Transmission loss for diffraction scenario for specified distance between transmitter and receiver (Rec. ITU-R P.452 and P. 526)
- Rough separation distance estimate from e.i.r.p. and pfd for single interferer and simple free space propagation
- Separation distances required for sharing (Rec. ITU-R P.452)
- Separation distances for short range devices required to protect a radio astronomy station (Rec. ITU-R P.452)
- Separation distances for short range devices required to protect victim service (Rec. ITU-R P.1411 - using free space approach)
- Separation distances for terrestrial transmitting stations using free space attentuation (Rec. ITU-R P.525)
- Separation distances for land MESs at 1.6 GHz (*ERC Report 26*)
- Separation distances for terrestrial transmitting stations (*ERC Report 26* and for frequencies between 0.7 and 30 GHz)
- SEAMCAT

ありがとうございます

arigato gozaimasu