A Brief on UWB Technology

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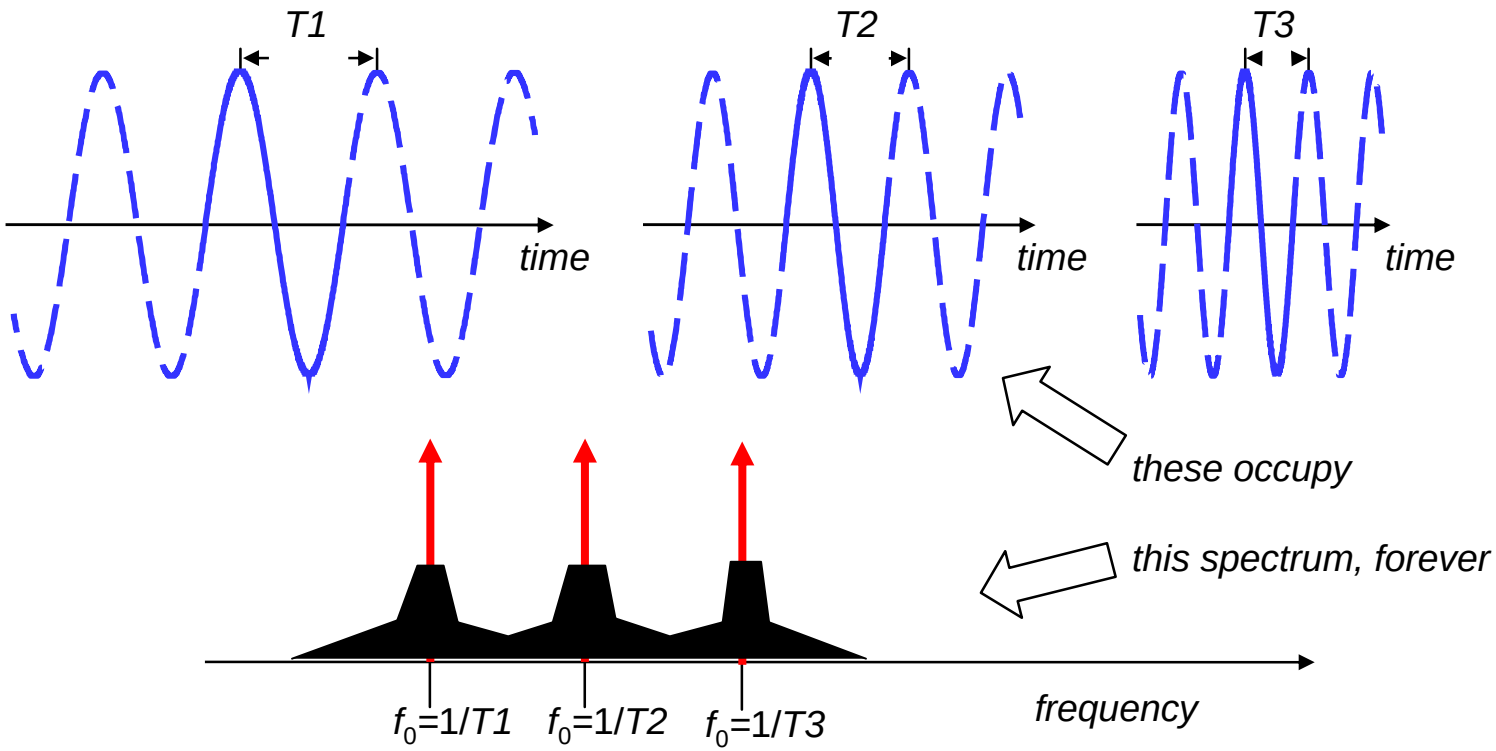
17-19 August 2004

San Diego, CA

UWB vs. Narrow Band

- Narrow band systems use the transmission medium in the frequency domain
- UWB impulse system use the medium in the time domain
- Actual systems use a mix of time and frequency
- Will appear in the IEEE802.15.3a and 4a standards

Narrow Band: Separation by Frequency



Coexistence is a matter of coordination and control of out-of-band emissions

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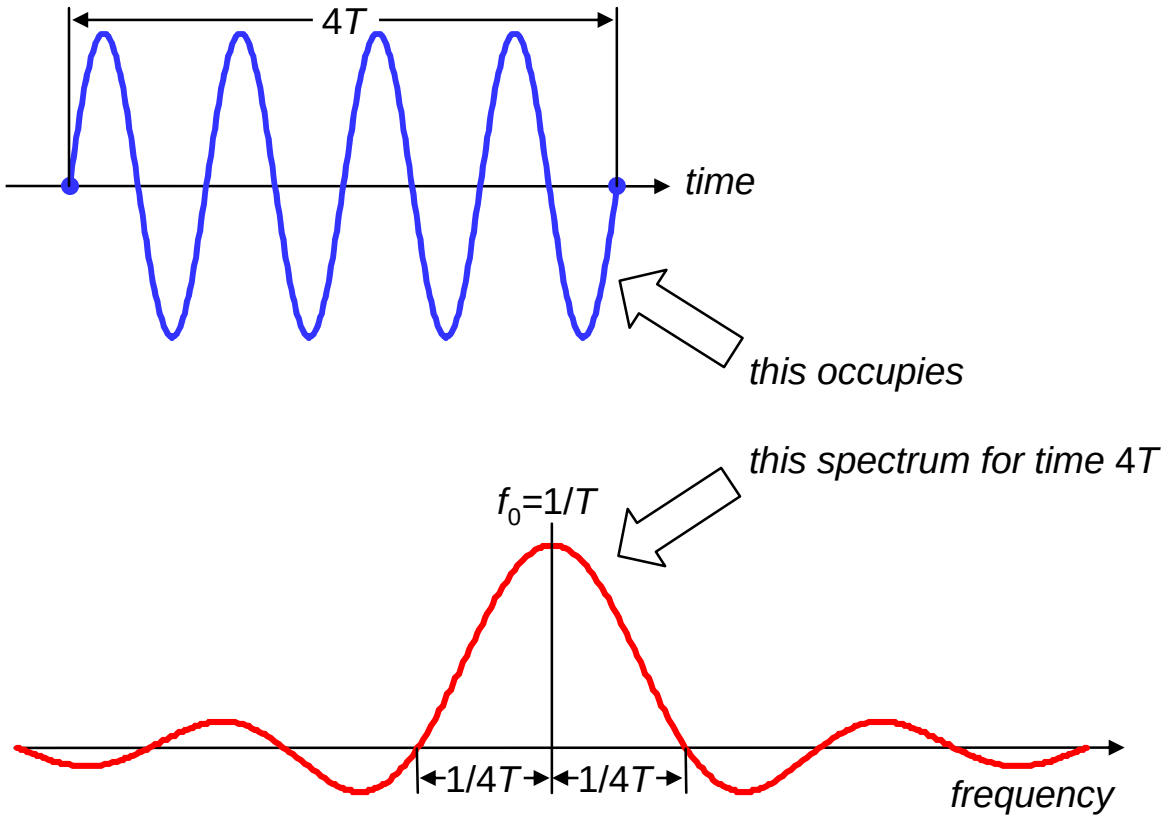
A finite length signal in time, occupies a definite spectrum width in frequency, for ***that finite time***



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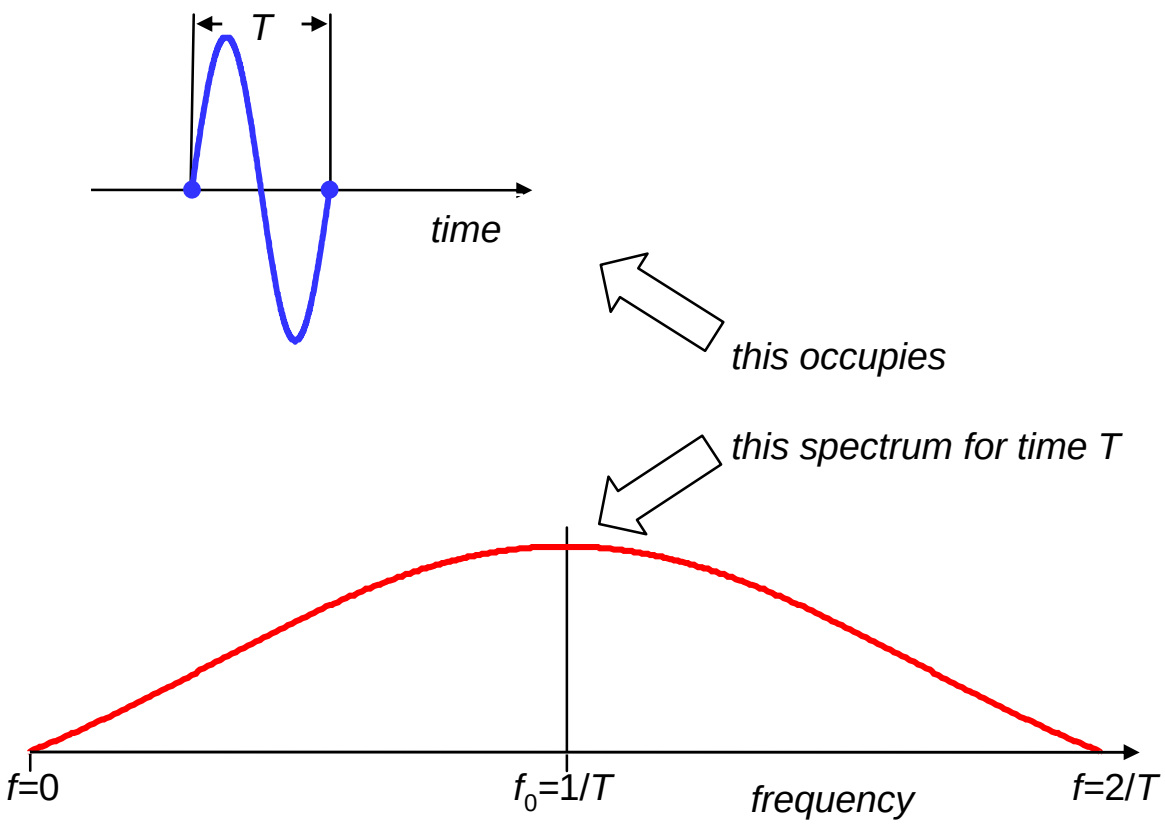
The shorter a signal is in time, the wider its spectrum is in frequency, for that duration in time



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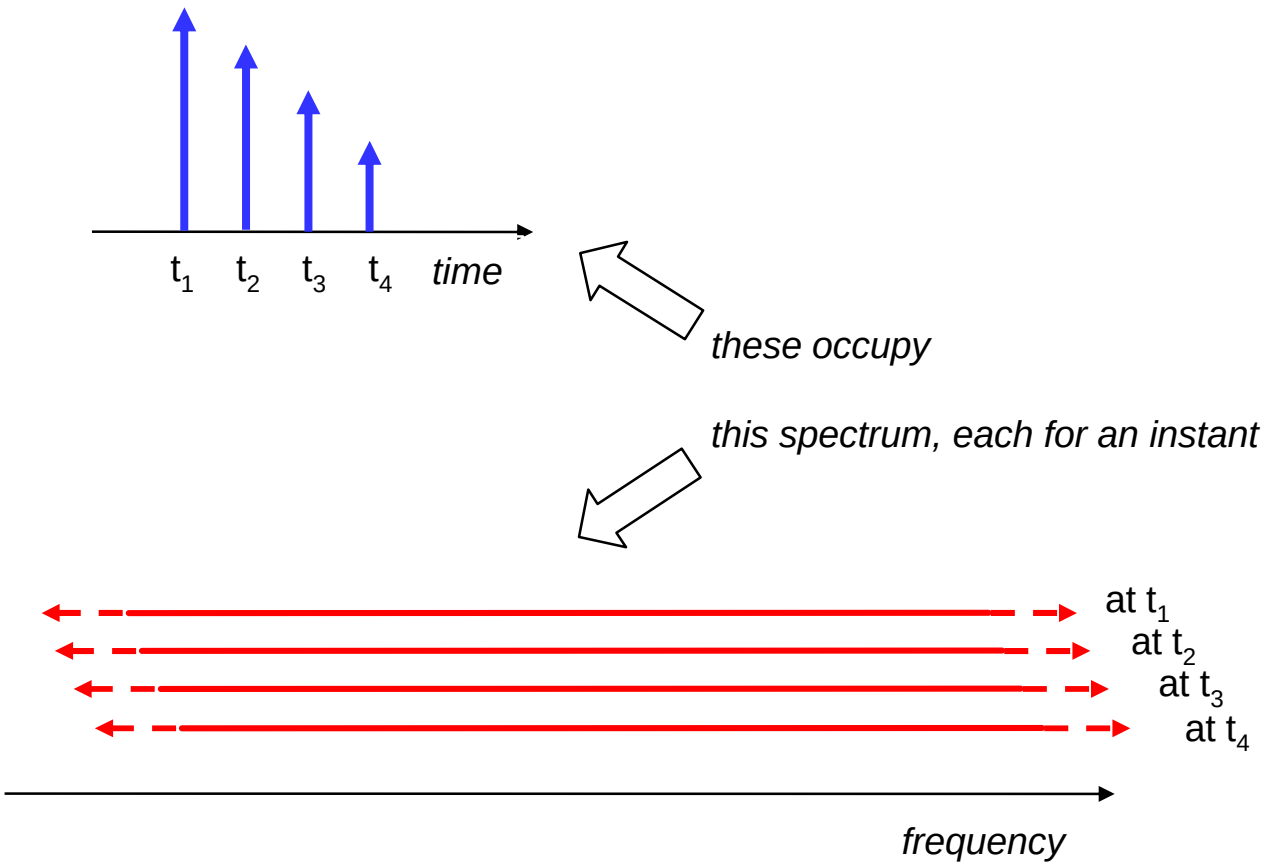
Separation of Signals in Time



Most UWB approaches will separate signals in <u>Time</u> and <u>Spectrum</u>

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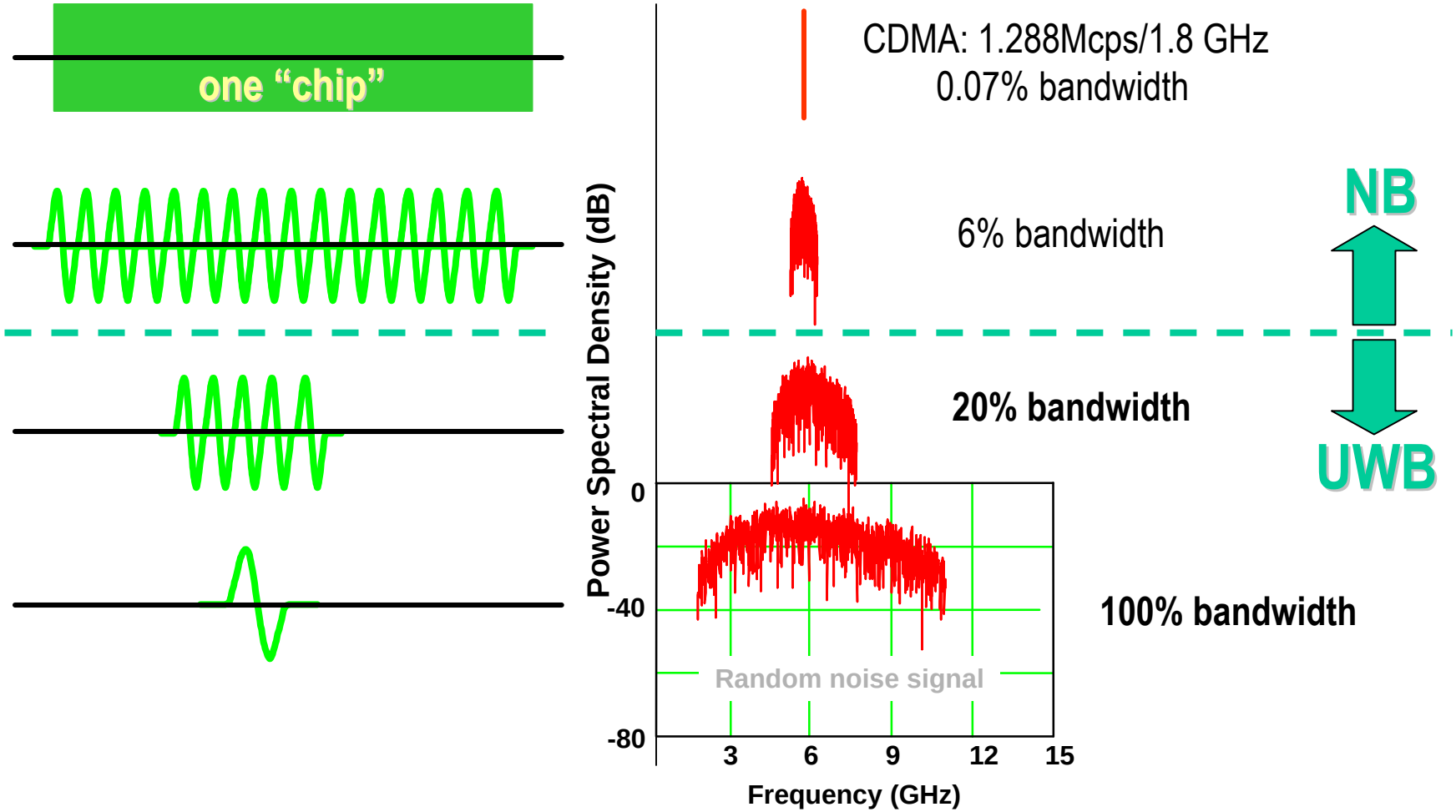
UWB: Large Fractional Bandwidth



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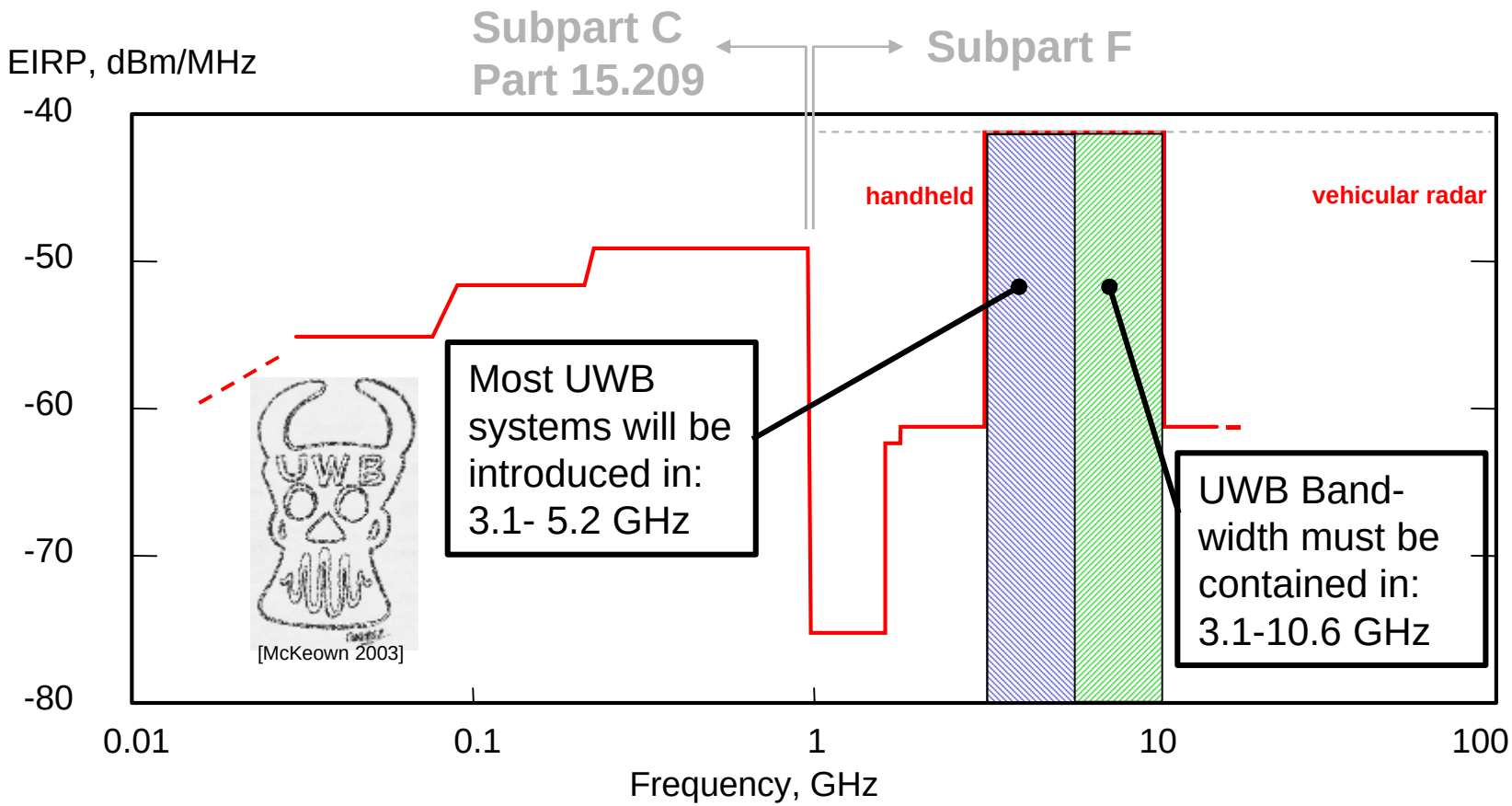
Actual UWB Emission Mask for ***Hand-held*** Systems



See: FCC First Report and Order, April 22, 2002 and latest US 47 CFR Part 15

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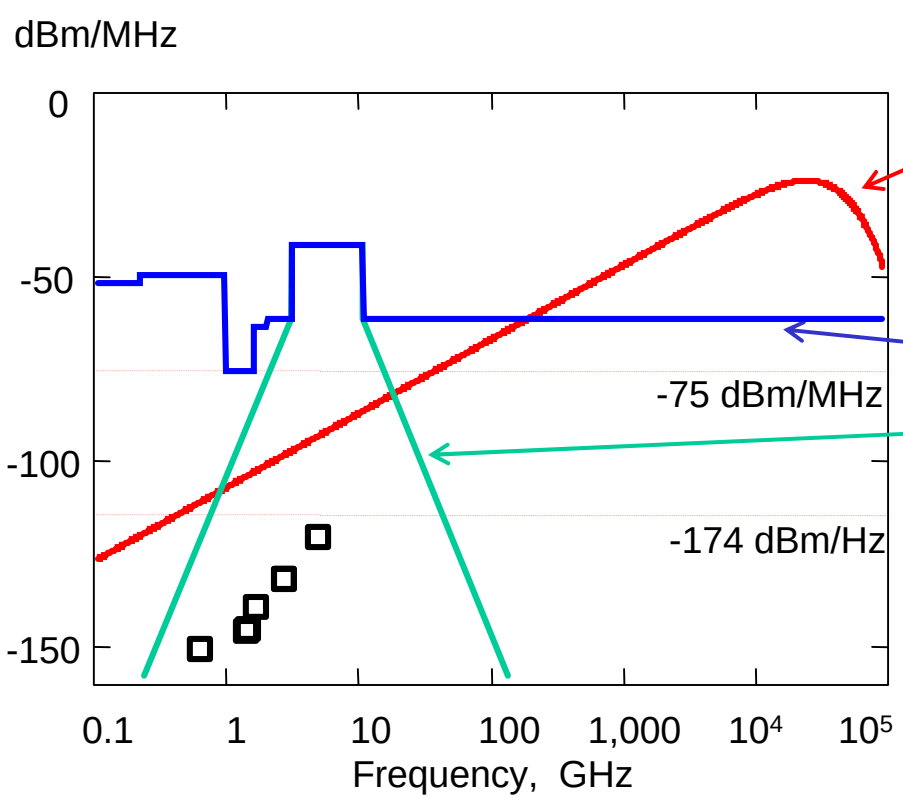
Sample “Issues” from a ITU-R: RAS

mini-glossary:

RAS – Radio astronomy service



“Black Body” radiation: one human being, relative to ambient

US FCC “handheld” rules

Proposed CEPT / ETSI ‘slope’ mask

- *“Calculation of the maximum tolerable e.i.r.p. per UWB device at 1 per km^2 ”*
  [from: DG2-2_chapter3.2_RAS_rev1.doc Table QQ]

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Many Variations of UWB Systems Possible:

*UWB = "more than 500 MHz BW"; "below -41.3 dBm/MHz"; "3.1-10.6 GHz"

UWB Technique	*MB-OFDM*	*MB- Impulses*	*DS-UWB*
Bands	3 to 13	3 to 13	2
Bandwidths	504 MHz (aggregation of 122 carriers)	550 MHz (1.8 ns impulses)	1.34 GHz (0.7 ns impulses), 2.68 GHz (0.35 ns impulses)
Frequency ranges	3.168 GHz – 4.752 GHz 4.752 – 10.296	3.325 GHz – 4.975 GHz, 4.975 GHz – 10.475 GHz	3.1 GHz – 5.15 GHz 5.825 GHz – 10.6 GHz
Modulation Scheme	OFDM, QPSK	M-ary Bi-Orthogonal Keying (M-BOK), QPSK	BPSK and 4-BOK
Error correction	Convolutional code	Convolutional code	Convolutional code, Reed-Solomon code
Code rates in 3.1 to 5.2 GHz	11/32 rate at 110 Mbps, 5/8 rate at 200 Mbps, ¾ rate at 480 Mbps	6/32 rate at 110 Mbps, 5/16 rate at 200 Mbps, ¾ rate at 480 Mbps	½ rate at 110 Mbps, RS(255,223) at 200 Mbps, **no FEC: 1.320 Gbps**
Link margin*	5 dB at 10 m / 110 Mbps, 11 dB at 4 m / 200 Mbps, 6 dB at 4 m / 480 Mbps	6 dB at 10 m / 108 Mbps, 8 dB at 4 m / 288 Mbps, 4 dB at 4 m / 577 Mbps	6 dB at 10 m / 110 Mbps, 11 dB at 4 m / 220 Mbps, 6 dB at 4 m / 500 Mbps
wavelet period	312.5 ns OFDM symbol	3 ns	0.7 ns (Low band), 0.35 ns (High band)
STEALTH	**No stealth capability**	**wideband impulse/hopping**	**wideband impulse/PN code**
REF:	**www.multibandofdm.org**	**timederivative.com/pubs.html**	**www.uwbforum.org**

Similar performance in AWGN

**OFDM masquerades as UWB under loose FCC definition*

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Many Variations of UWB Systems Possible:

	OFDM	***DS-UWB***	***TD/FDMA Pulses***	***TM-UWB***	***TDR-UWB***
Bands	3 to 13	2	3 to 13	1	1
Bandwidths	3×504 MHz up to 13×504 MHz	1.5 and 3.6 GHz	3×550 MHz up to 13×528 MHz	2 GHz	2 GHz
Frequency ranges, GHz	3.1 – 4.8 4.8 – 10.6	3.1 – 5.15 5.825 – 10.6	3.1 – 5.0 4.9 – 10.6	3.1 – 5.2	3.1 – 5.2
Modulation	OFDM-QPSK	*M*-BOK, BPSK	*M*-BOK, QPSK	TM-PPM	DPSK
Modulation efficiency: 10^{-3} BER	6.8 dB	4.1–6.8 dB	6.1–6.8 dB	7–10 dB	9–12 dB
Error correction codes	Convolutional	Convolutional and Reed-Solomon	Convolutional and Reed-Solomon	various	various
Capabilities	10m at 110 Mbps 7m at 200 Mbps 3m at 480 Mbps	10m at 112Mbps 7m at 224Mbps 2m at 1,368 Mbps	10m at 108Mbps 7m at 288Mbps 3m at 577Mbps	40m at 10 Mbps 10m at 40 Mbps	30m at 10 Mbps

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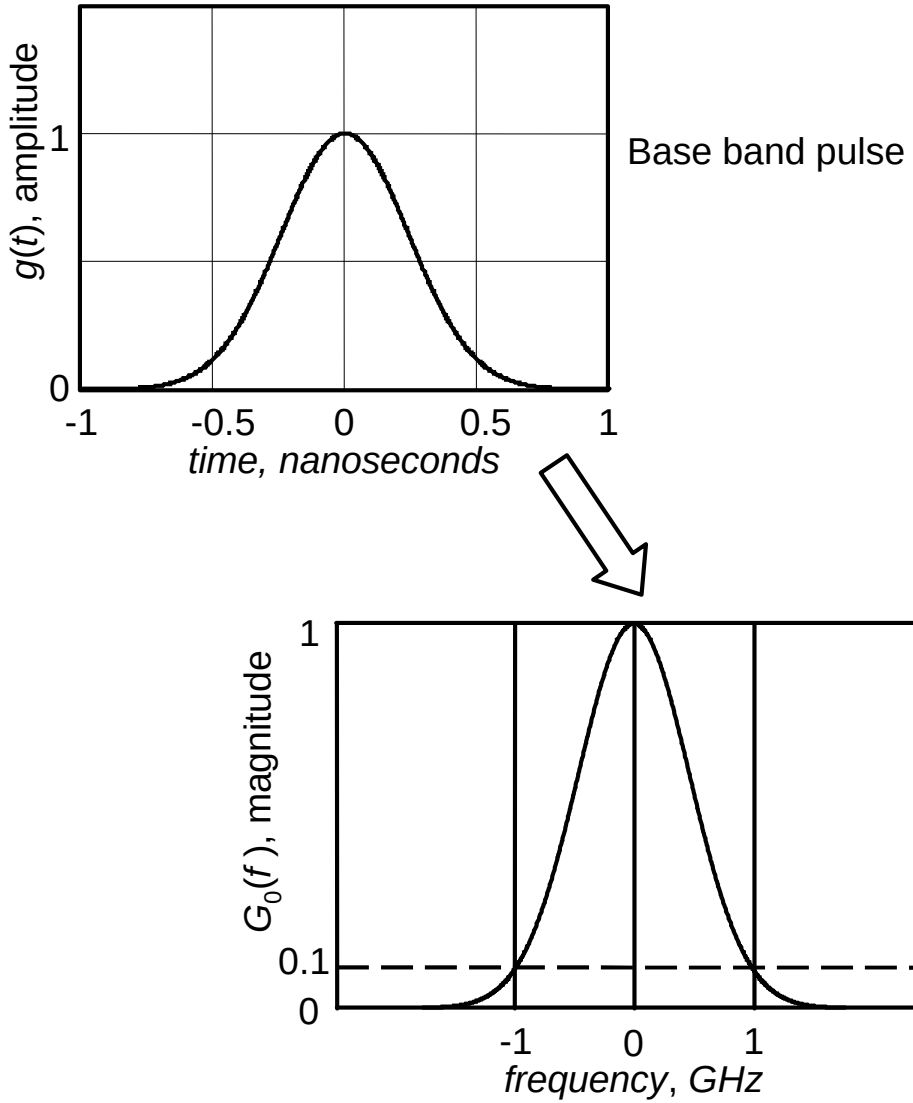
Base band pulse and its spectrum



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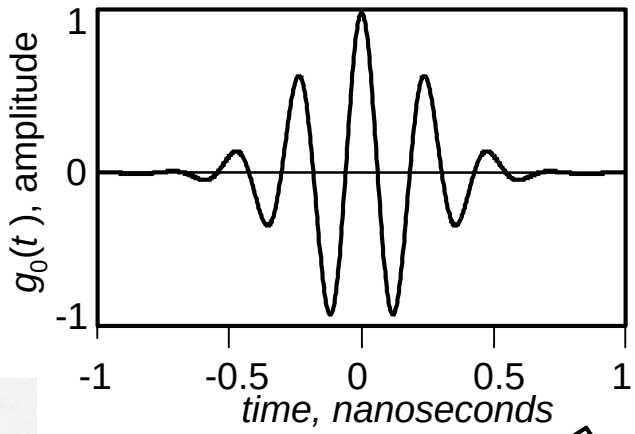
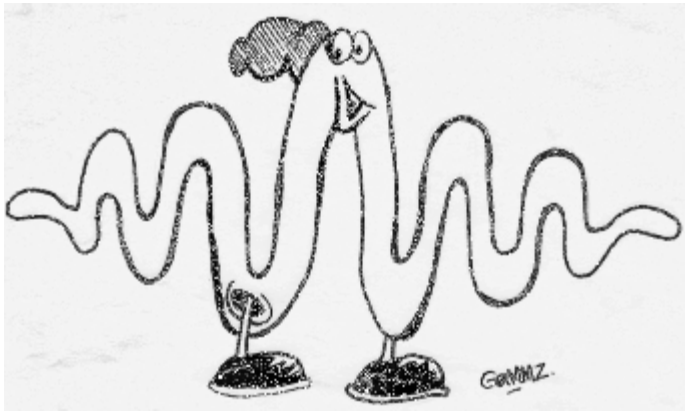
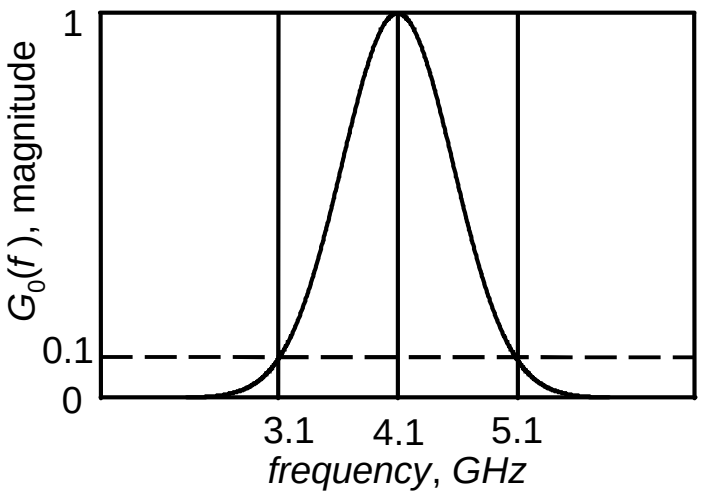
Frequency shifted pulse and its spectrum



Base band pulse multiplied by $\cos(2\pi ft)$



[McKeown 2003]



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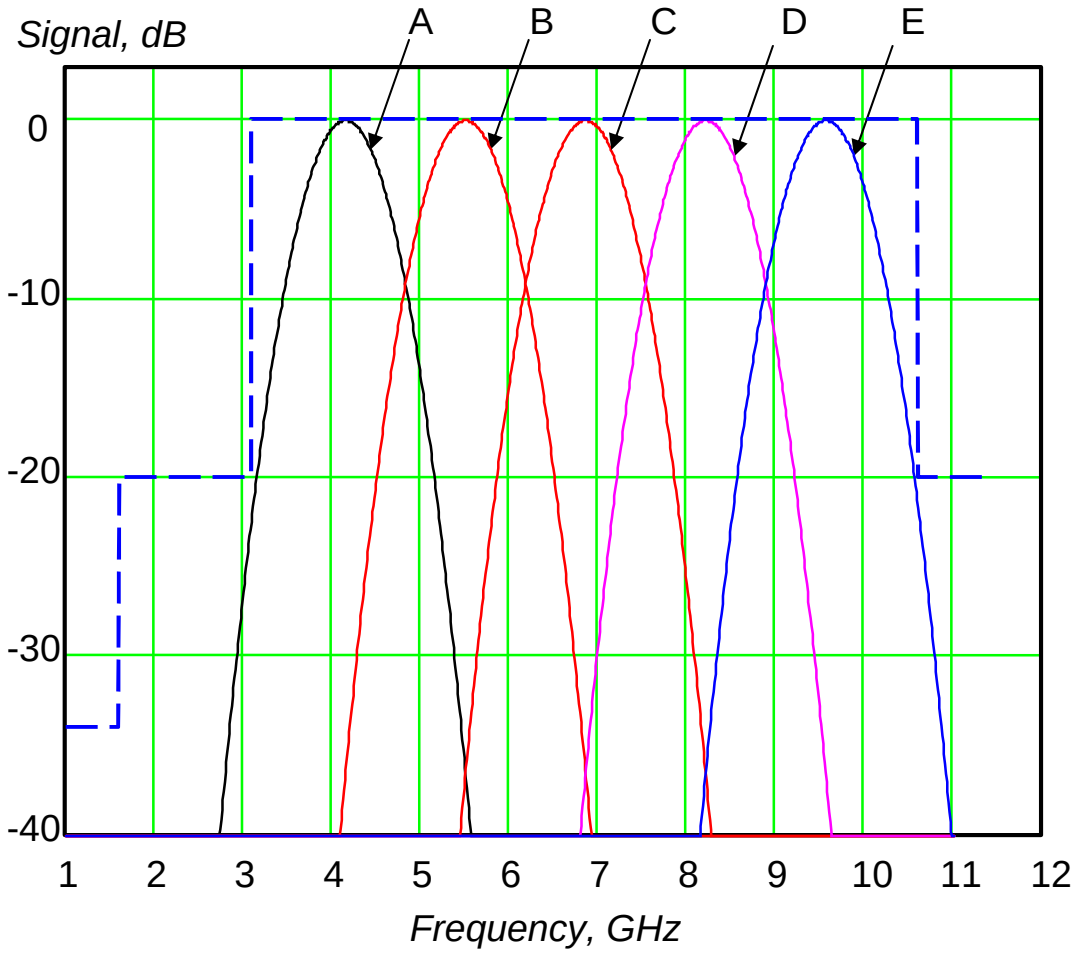
A band plan for wide-band UWB channels



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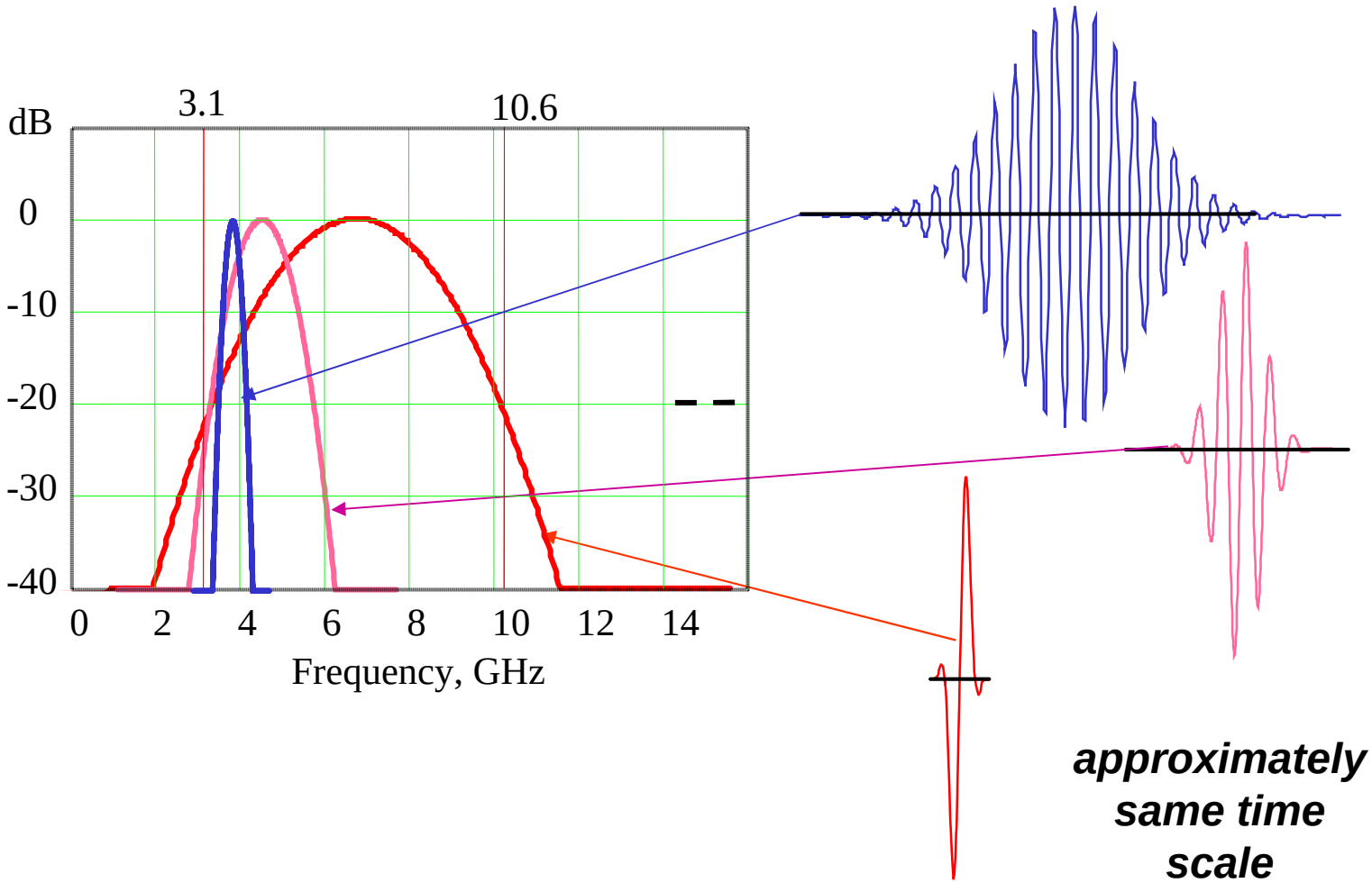
UWB Signals and Their Spectra



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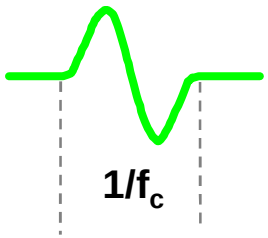
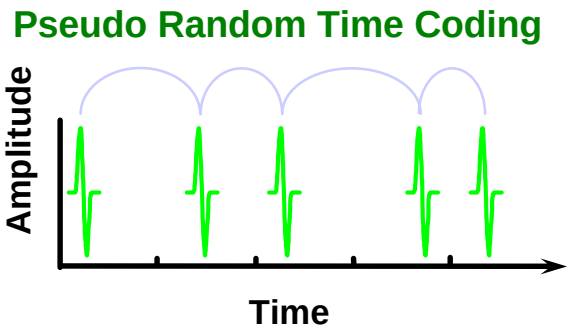
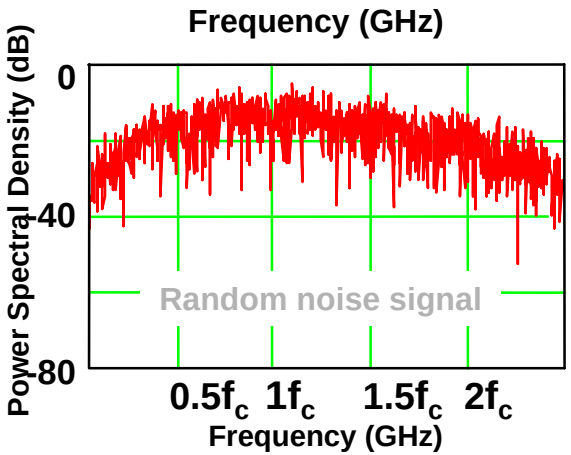
UWB Modulation

- Millions to billions of pulses per second

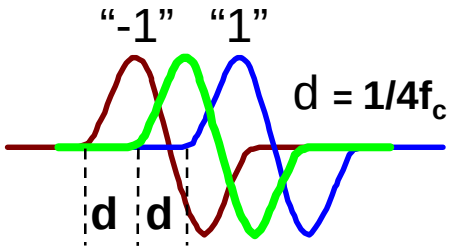


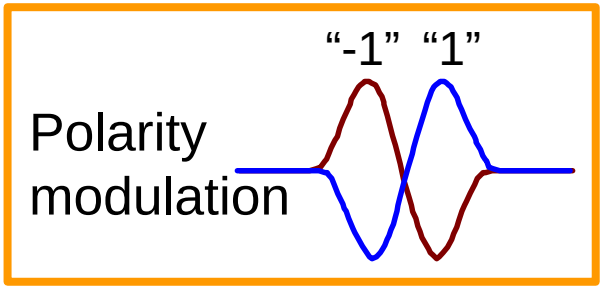
- Can be <u>time coded</u> to make noise-like
  - Channelization
  - Smoothes spectrum





- Pulse position and polarity modulation





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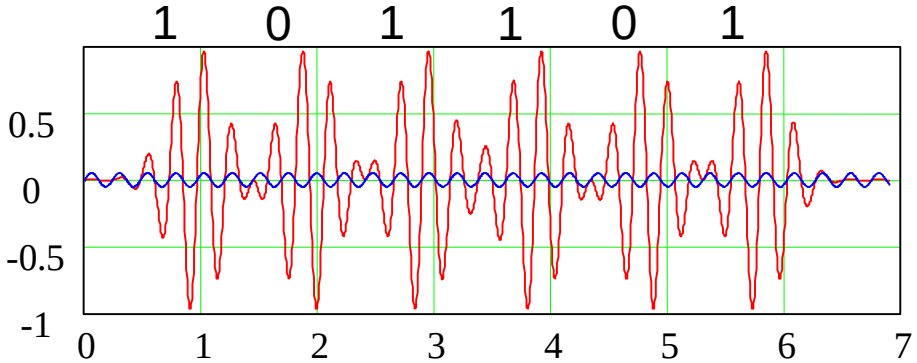
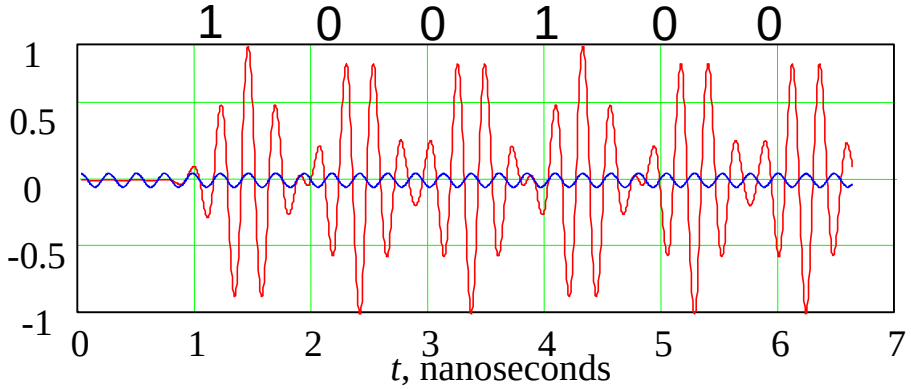
High Rate Modulated UWB Signal

- Polarity modulated impulses sent at $f_0/4$ =1.04 Gpps; can use codes which encode 1 and 0

Sine modulated



Cosine modulated and offset



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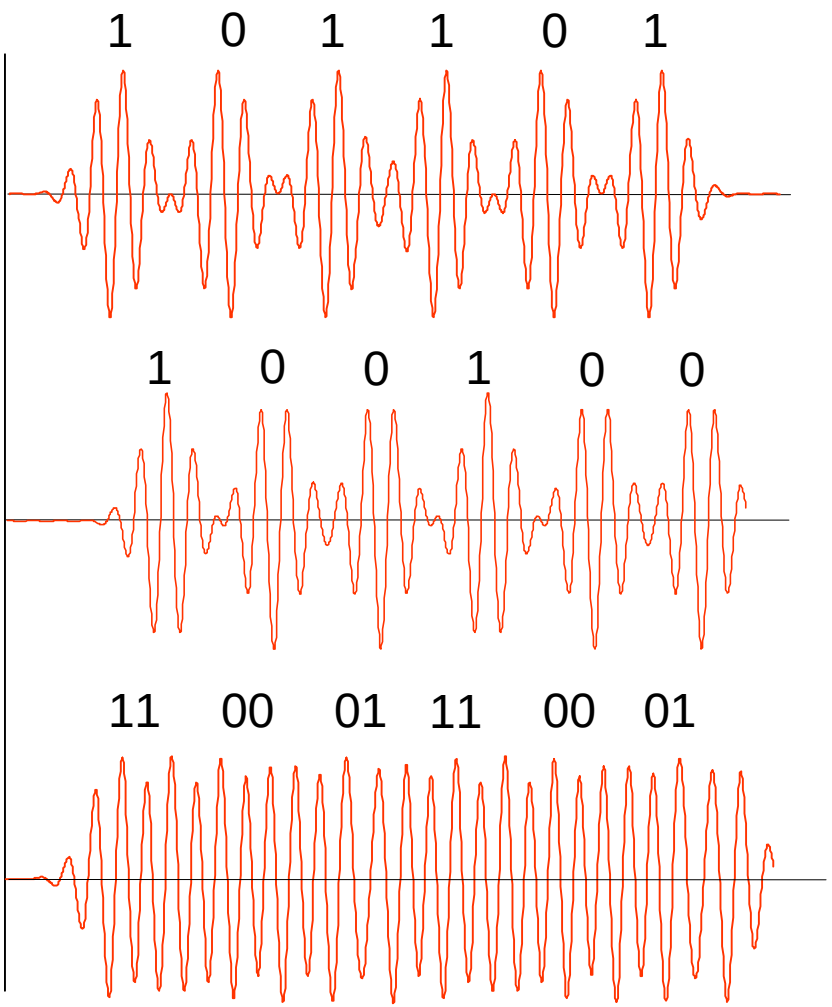
High Rate Modulated UWB Composite OQPSK Signal

<u>Sine modulated</u> peak-to-average is 4 dB

<u>Cosine modulated and offset</u> peak-to-average is 4 dB

<u>Composite</u> peak-to-average is 1 dB

(<u>sine wave</u> peak-to-average is 0 dB)



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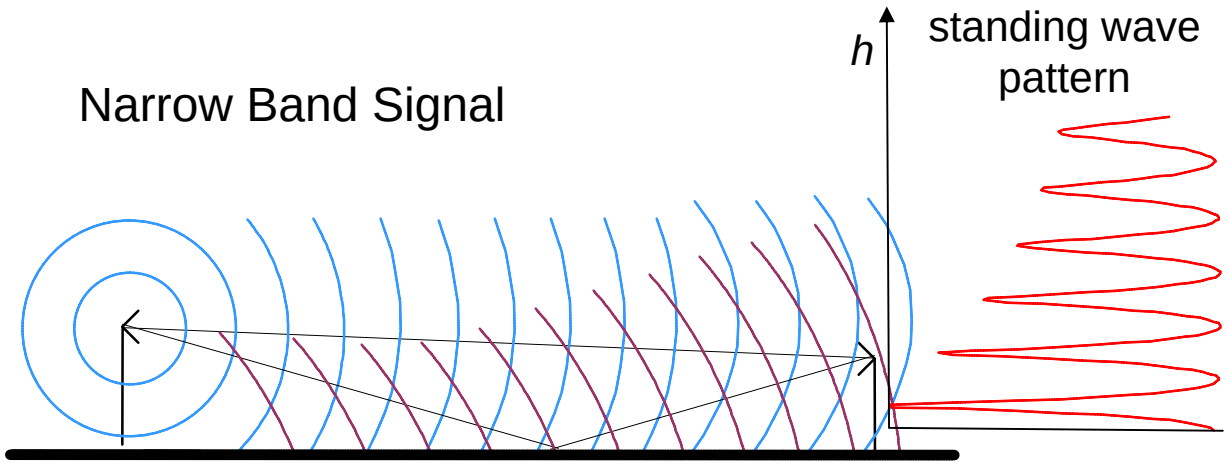
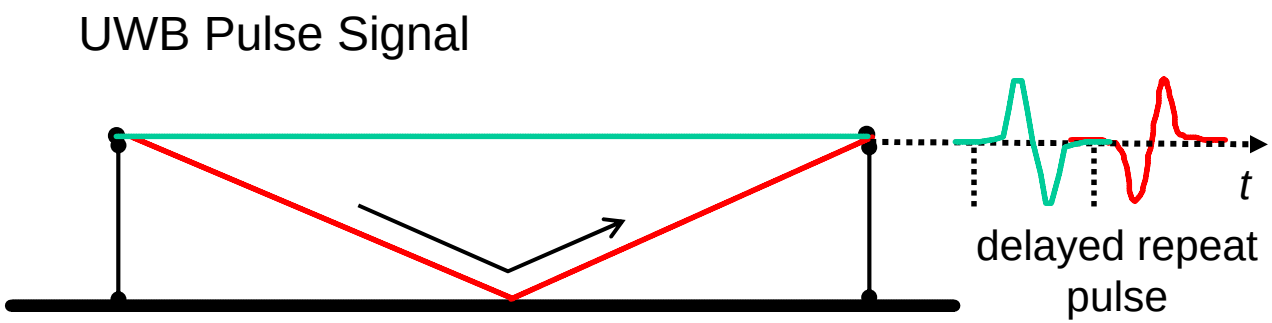
Narrow Band and UWB Compared





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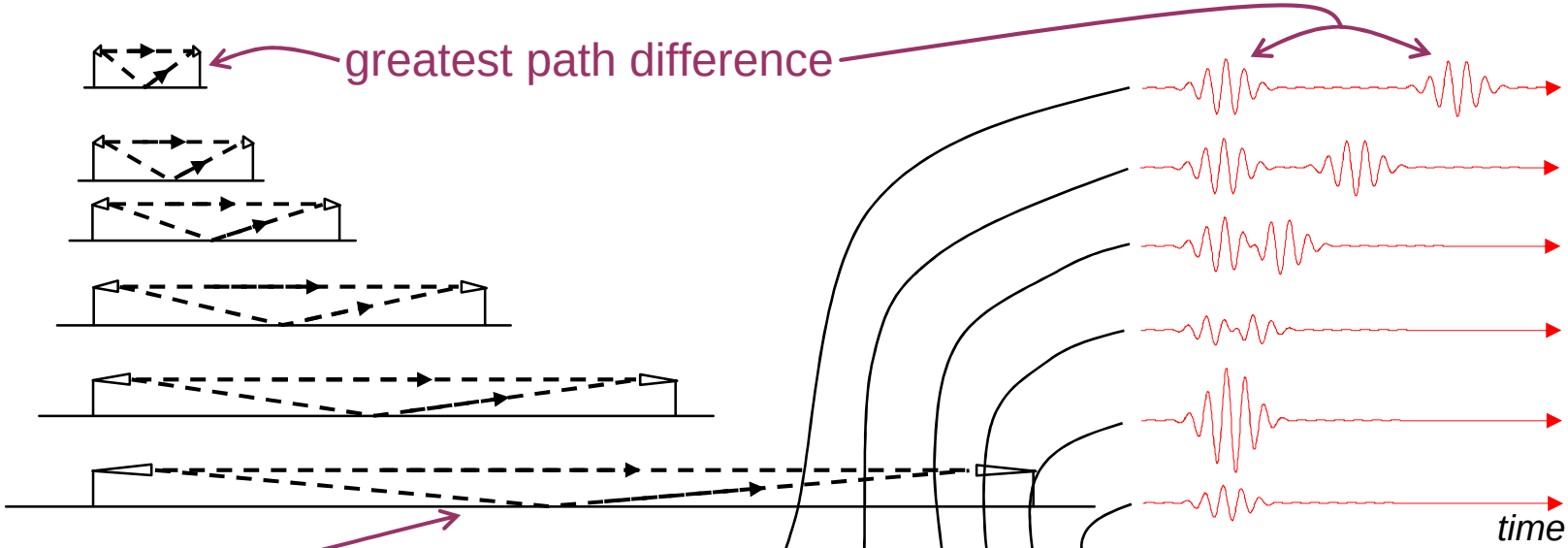

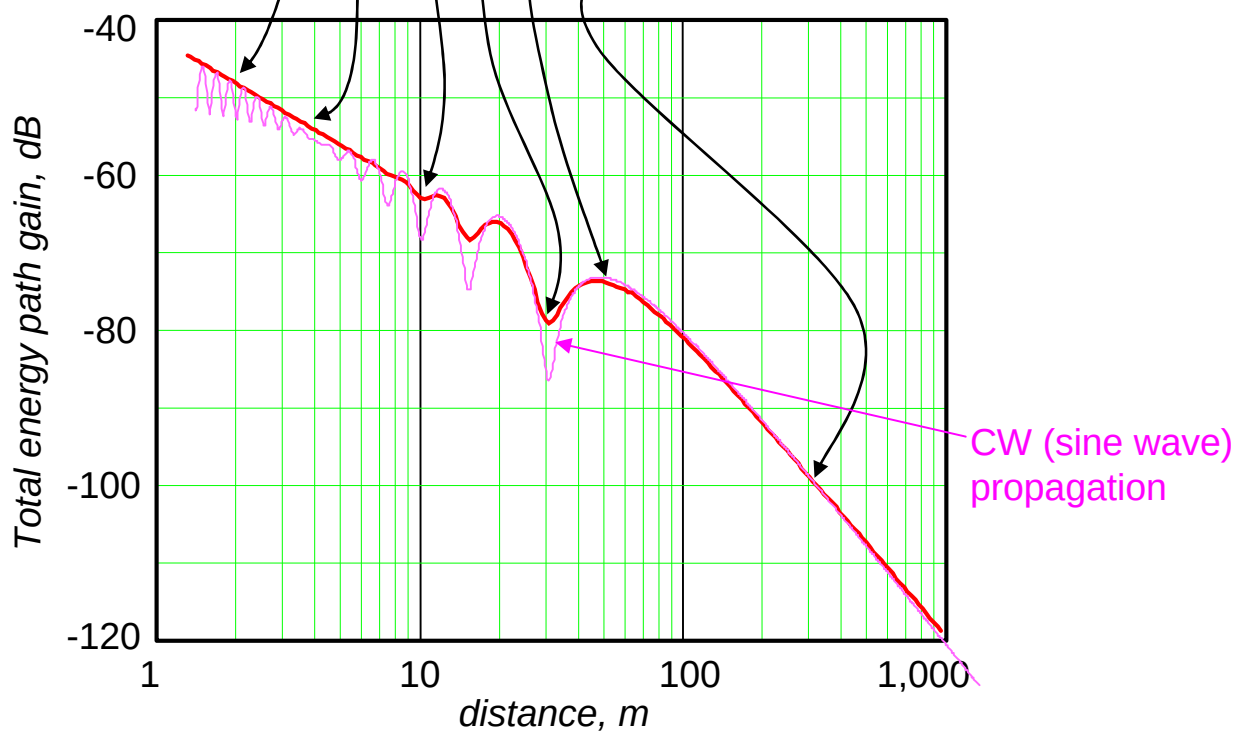

<u>This geometry</u>:

$h_1 = h_2 = 1\text{m}$

$f_m = 4.5\ \text{GHz}$

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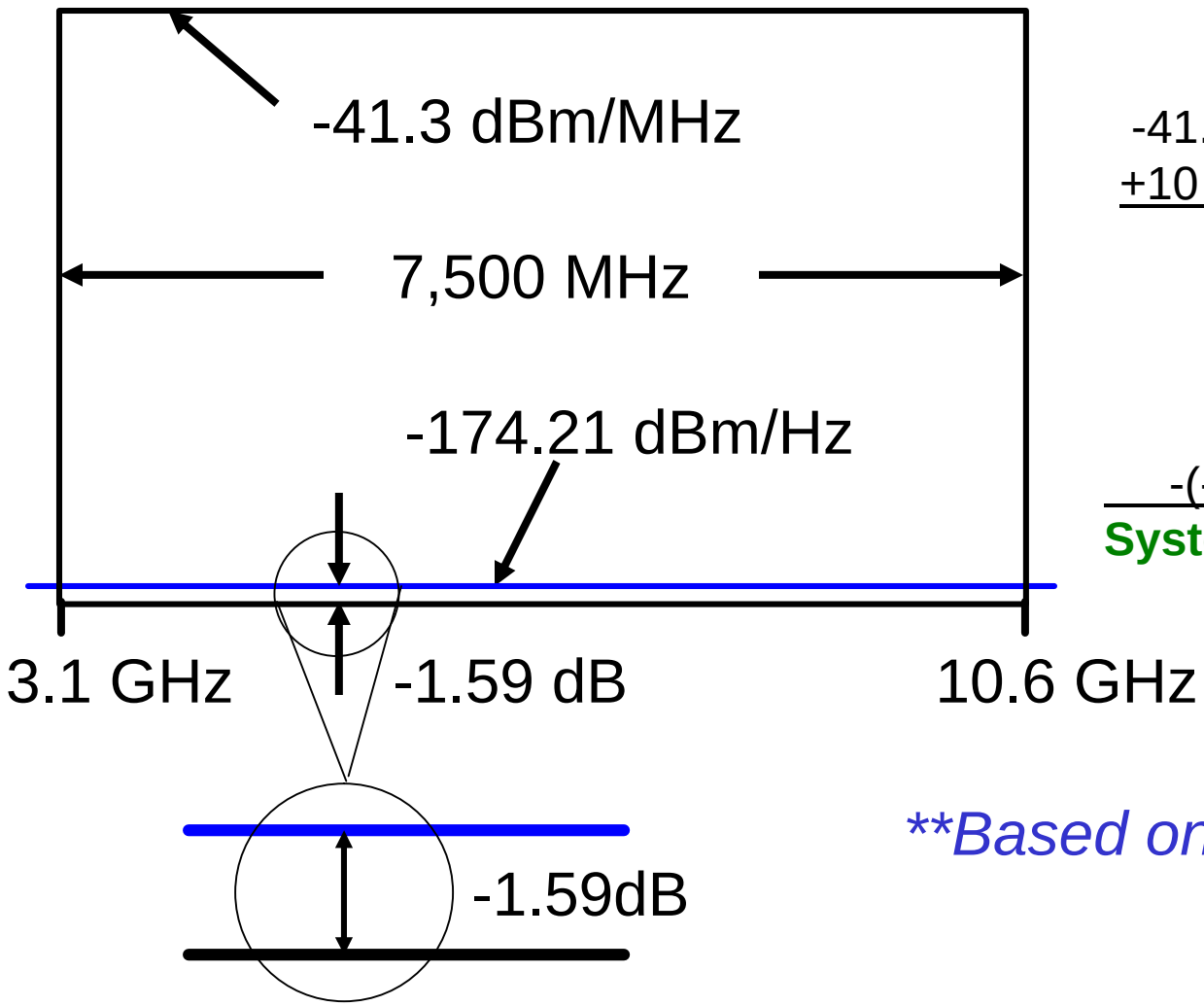
A Fundamental UWB Limit: 173 dB/Hz System Gain**



-41.3 dBm / MHz
+10 log(7.5x10^3) MHz
-2.5 dBm EIRP

-2.5 dBm EIRP
-(-1.59) dB SNR
-(-174.21) dBm/Hz .

System Gain = 173 dB/Hz

***Based on FCC regulations*

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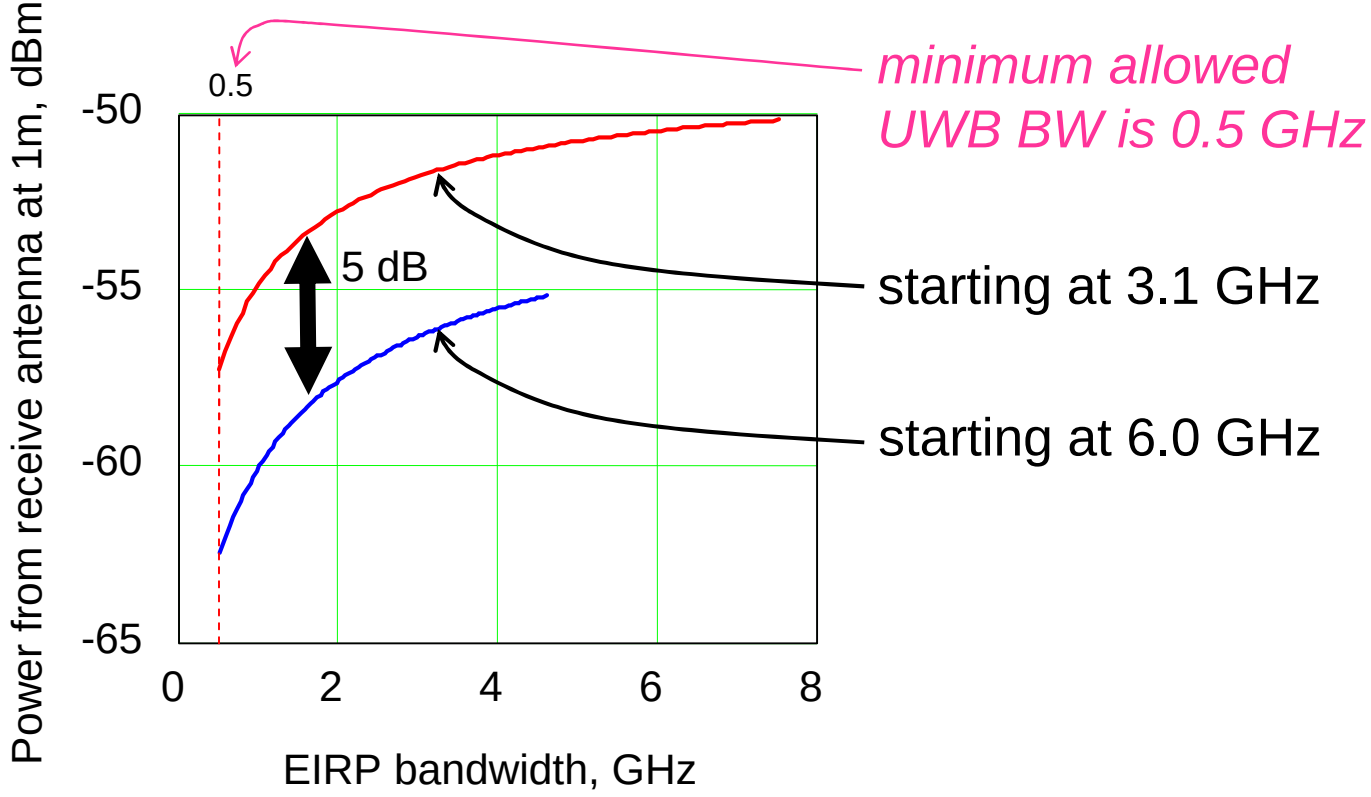
Received Power Depends on the Transmitted 'EIRP Bandwidth'



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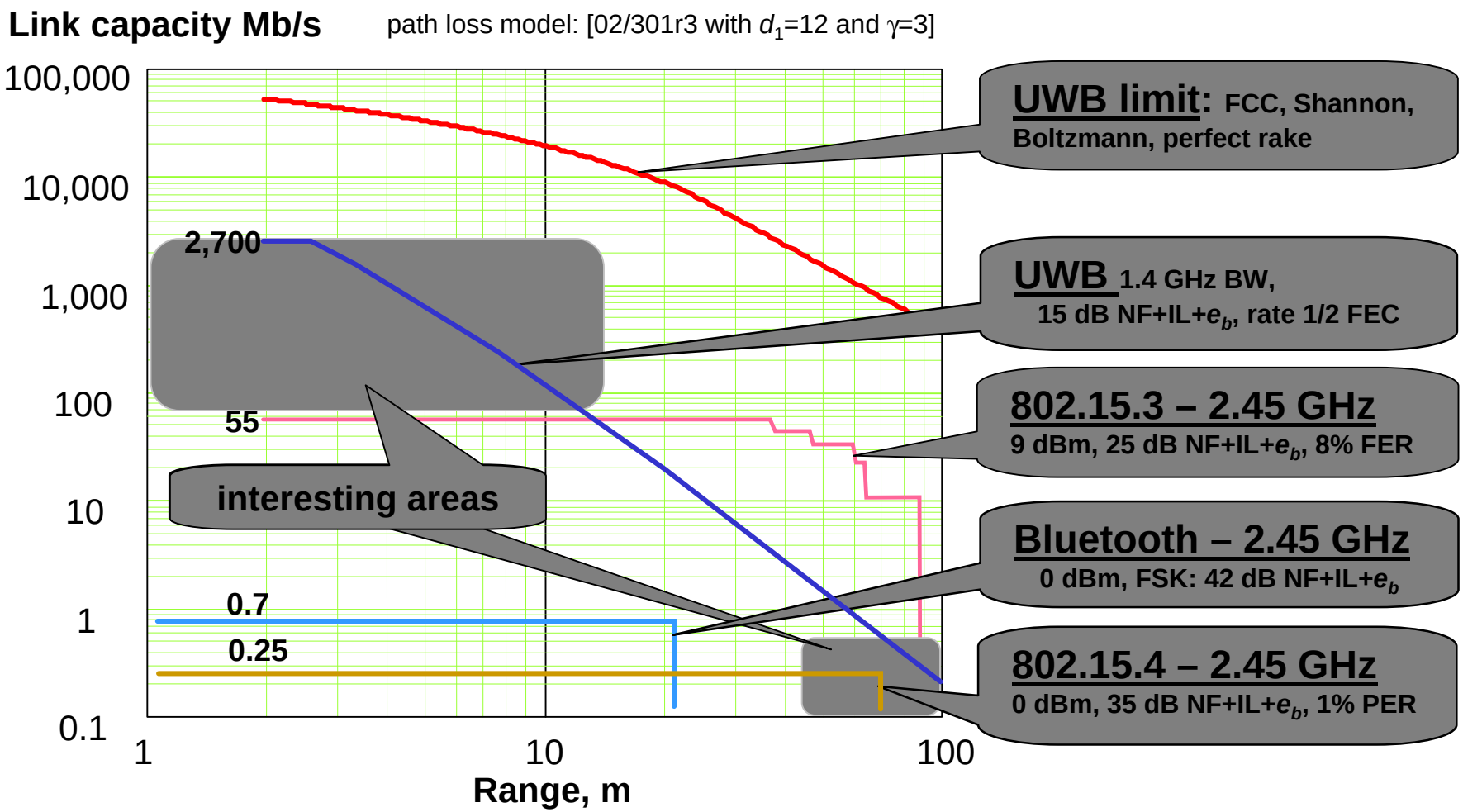
Link Capacity: UWB and PANs



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Link Budget Example: UWB at Moderate Data Rate

USA FCC

Consider: 220* Mb/s system, modulation efficiency 5.6 dB, 10 dB noise figure + losses, 1.4 GHz power BW, 0 dBi antennas

System Gain	**System Gain Limit**		**173.0 dB/Hz**
10 log(symbol bandwidth)	-10 log(220×10^6)	=	-83.4 dBHz
symbol modulation efficiency	$-e_b$ = 5.6 - (- 1.59)	=	-7.2 dB
System losses, (noise figure, implementation loss, ...)	-System losses	=	-10.0 dB
10 log(actual RF BW/7.5 GHz) [or actual EIRP+2.55 dBm]	10 log(1.4 / 7.5)	=	-7.3 dB
Antenna gain or loss	Antenna:	=	0 dBi
Path attenuation	**Left for Path attenuation: 65.1 dB** (10 m in free space at 4.1 GHz)		

*includes 0.5 rate error correction for 110 Mb/s throughput

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Link Budget Example: UWB at Longer Range

Consider: 100 kb/s system, Antipodal modulation: 10^{-3} BER, 8 dB noise figure + losses, 3.5-6.5 GHz, 0 dBi antennas

System Gain	**System Gain Limit**		**173.0 dB/Hz**
10 log(symbol bandwidth)	-10 log(10^5)	=	-50.0 dBHz
symbol modulation efficiency	$-e_b$ = 5.6 - (- 1.59)	=	-7.2 dB
System losses, (noise figure, implementation loss, ...)	-System losses	=	-8.0 dB
10 log(actual RF BW/7.5 GHz) [or actual EIRP+2.55 dBm]	10 log(3 / 7.5)	=	-4.0 dB
Antenna gain or loss	Antenna:	=	0 dBi
Path attenuation	**Left for Path attenuation: 104.8 dB** (700 m in free space at 4.5 GHz)		

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Link Budget Example: UWB at High Data Rate

Consider: 500 Mb/s system, Antipodal modulation: 10^{-2} BER, 8 dB noise figure + losses, 3.5-6.5 GHz, 0 dBi antennas

System Gain	**System Gain Limit**		**173.0 dB/Hz**
10 log(symbol bandwidth)	-10 log(500×10^6)	=	-87.0 dBHz
symbol modulation efficiency	$-e_b$ = 4.3 - (- 1.59)	=	-5.9 dB
System losses, (noise figure, implementation loss, ...)	-System losses	=	-8.0 dB
10 log(actual RF BW/7.5 GHz) [or actual EIRP-2.55 dBm]	10 log(3 / 7.5)	=	-4.0 dB
Antenna gain or loss	Antenna:	=	0 dBi
Path attenuation	**Left for Path attenuation: 68.1 dB**		

(13 m in free space)

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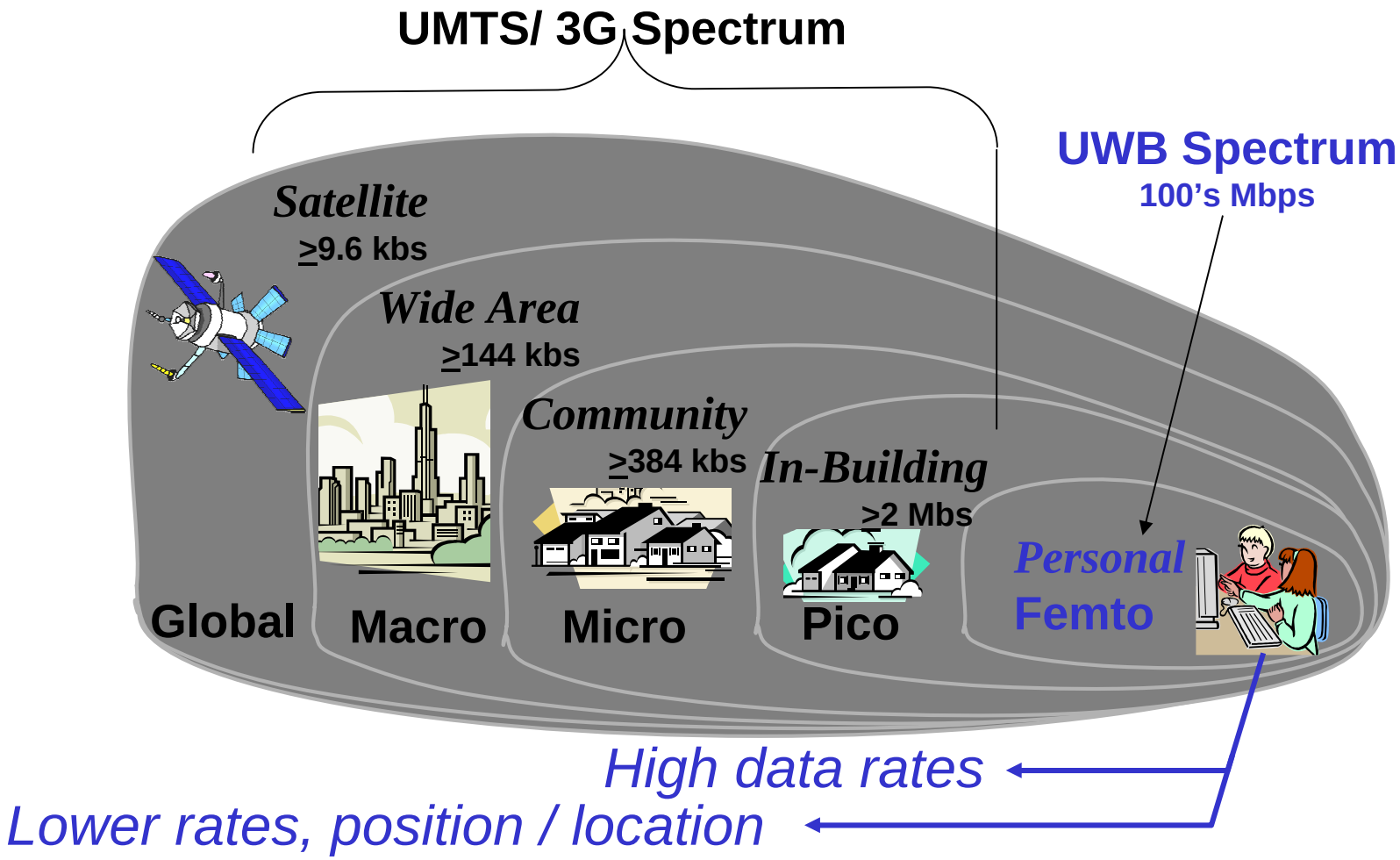
UWB's Two-Pronged Fit in Future Wireless Systems



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Other Aspects

- Some UWB technologies are capable of stealthy operation (LPI/LPD)
- Impulse UWB systems can support positioning
- Effective radar and motion detectors have been developed

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