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

Submission Title: [**Channel ized, Optimum Pulse Shaped UWB PHY Proposal**]

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Re: [.]

[Response to call for Proposal]

Abstract: [This proposal addresses a complete implement able UWB PHY architecture within the FCC UWB rule, and taking into account of the potential feasibility in Silicon fabrication. The proposed PHY shall satisfy the basic 100 Mbps requirement, and the optional requirement of 480 Mbps..]

Purpose: [This proposal is submitted for consideration of IEEE802.15.3a PHY standard.]

Contents

1. 802.15.3a/4 requirements
2. Summary of the proposed PHY structure
3. Technical Rationale with Simulation Results
   – Channel planning
   – Gaussian wave shaping
   – Transmitter implementation
   – Receiver implementation
   – Performance
4. Q&A

1: Requirements
IEEE802.15.3a /4

- Doc.03029r0P802-15-TG3a and others as guideline
  - Physical Layer cost < Bluetooth i.e ~ $4.50
  - Raw over the air speed >100 Mbps and 480 Mbps optional.
  - Power consumption < 100mW
  - Range ≤10 m
  - Preamble length ~20 usec
- FCC Rule – FCC 02-48 UWB ruling

FCC 02-48 Ruling

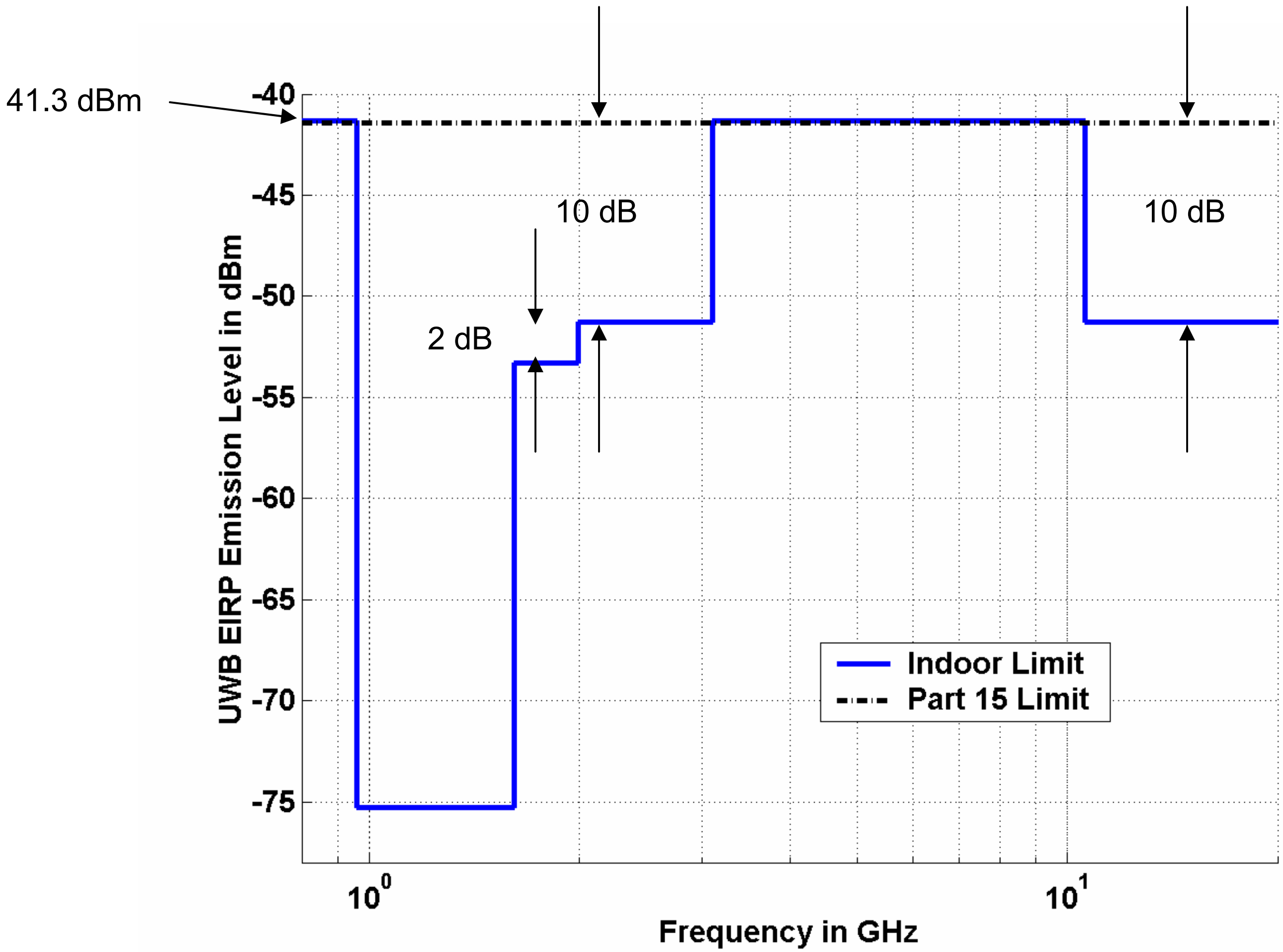
Salient points on Communications Applications

- (Clause 7) Spirit of this rule is for "pulse modulation of very narrow or short duration pulses". (note 7) Pulse duration of 0.1-2 nSec
- (Clause 32) Non pulse modulation is allowed
- (Clause 5/200) Must be indoor or handheld use only
- (Clause 5) Frequency band allowed :3.1 to 10.6 Ghz.
- (Clauses 22/ 30) Fractional bandwidth : ≥ 0.2 or (note 78) 500 Mhz (min)
- (Clause 68) peer to peer and 10 sec shut-down rule.
- ***(Clause209) Peak emission: < 20log(BW(Mhz))-14 or < 60 dB exceed average value. (*Bw=4.5Ghz*)

-------------- BW is defined as -10dB------------

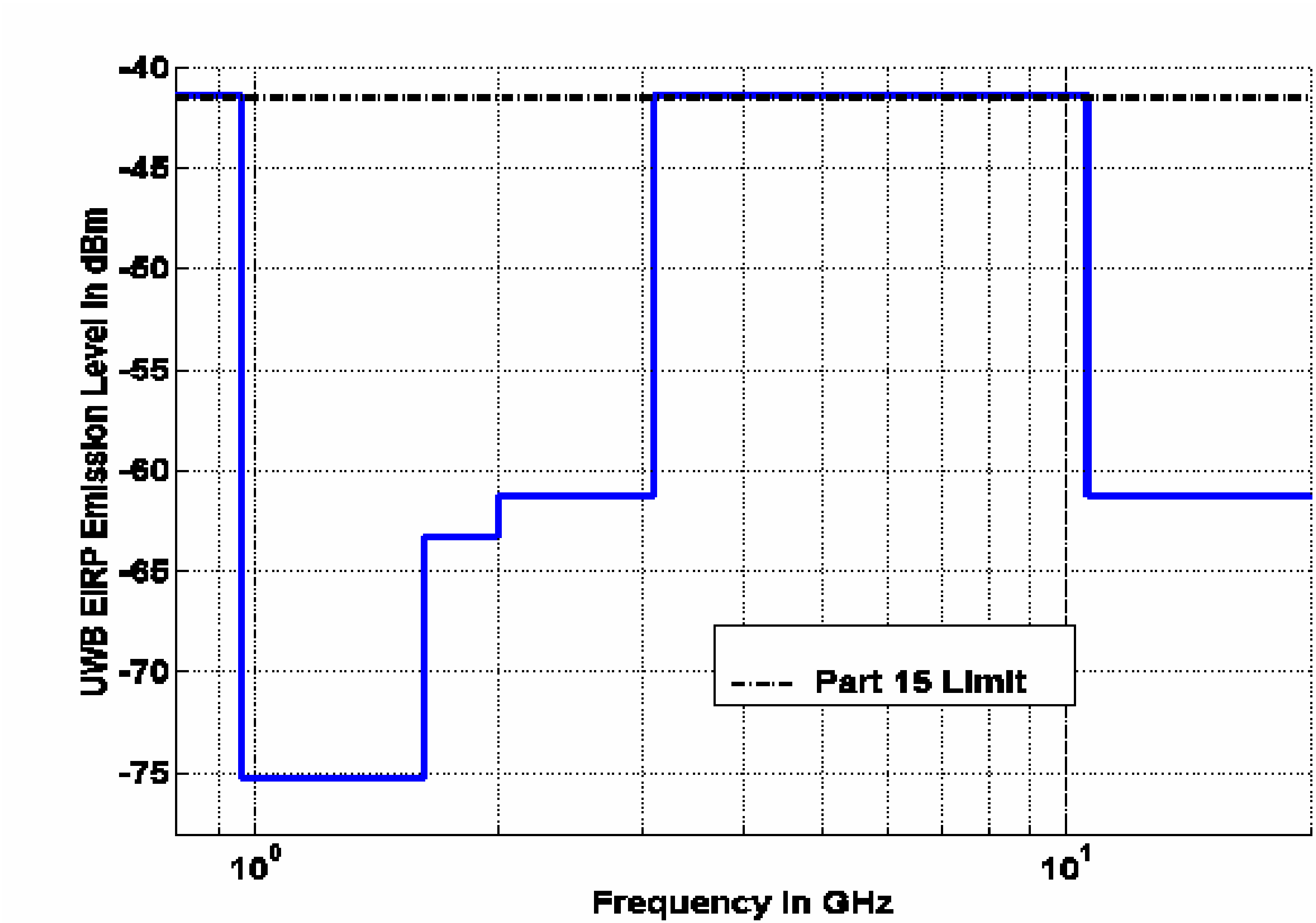
Indoor UWB spectrum mask

Clause 65



Handheld device Spectrum Mask

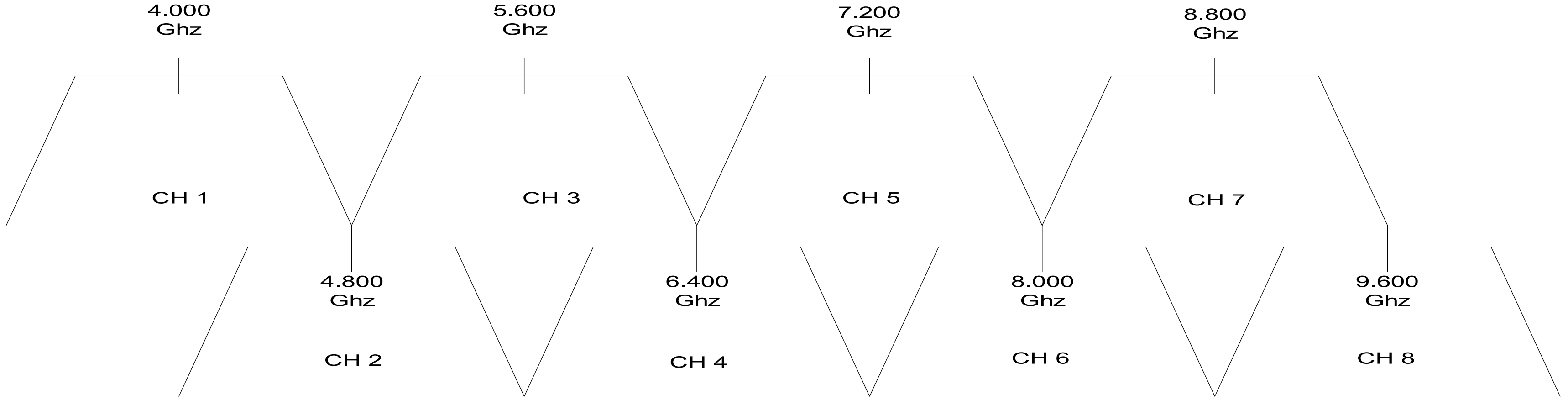
Clause 67



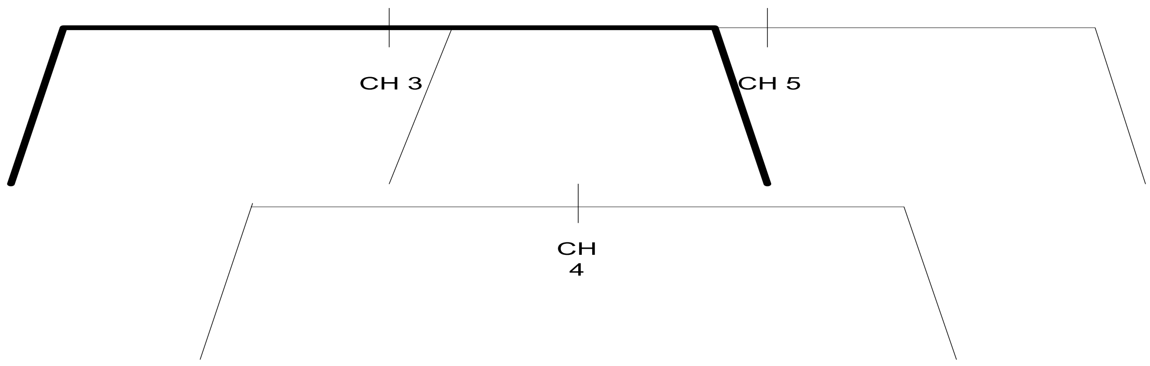
2. UWB PHY PROPOSAL Channel Plan

- Define 8 x 800 Mhz (-4.3 dB BW) channels to cover 3.1 to 10.6 Ghz
- Channels are: 4.000, 4.800, 5.600, 6.400, 7.200, 8.000, 8.800, 9.600 Ghz. (~1 Ghz from band edge.)
- Channels 3,4,5 and 6 can form turbo channels. Channel 4 and 5 can form super-turbo channels.
- Gaussian wave shaping with $1/\tau =$ 400 Mhz,Bit rate =200 Mbps
- Turbo wave shaping $1/\tau$ =1.2 Ghz, Bit rate=600Mbps
- Super Turbo wave shaping $1/\tau$ = 2.0 Ghz, Bit rate=1.0 Gbps

Channel Plan

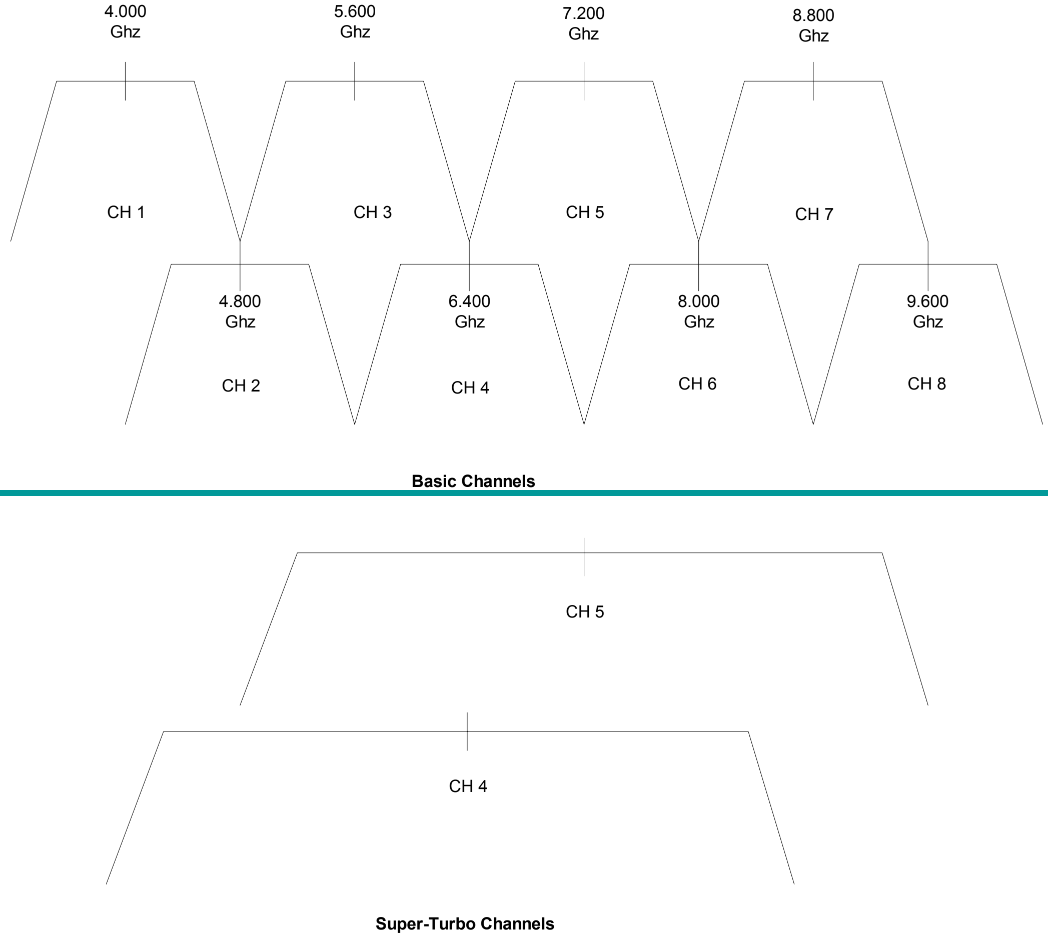


Basic Channels

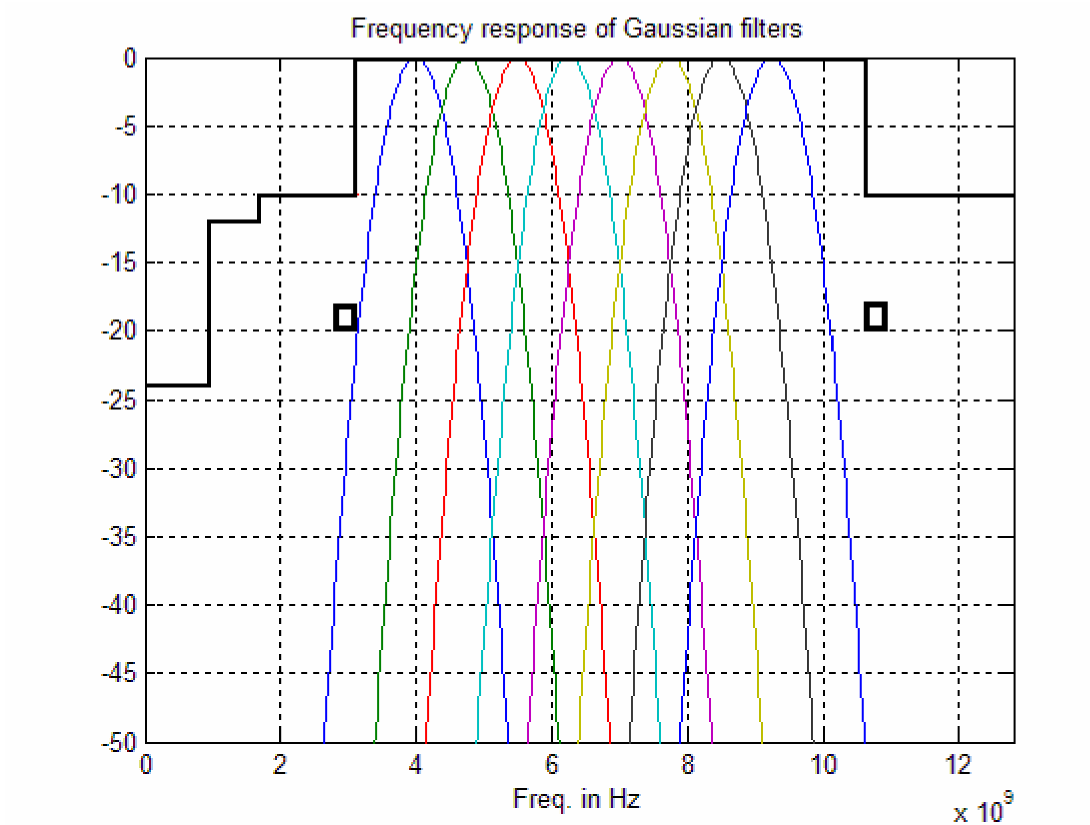


Turbo Channels

Super-Turbo Channels



Basic 8 by 800 Mhz Channel Plan with indoor & Handheld limits



Gaussian Wave-Shaping

- Any signal processing must consider implementation feasibility.

- At microwave frequency, it was concluded that Gaussian filter is most optimum in terms implementation.
  - Well behaved in time domain response
  - Frequency response has linear phase
  - Best detection by rectification
  - Favorable in FCC calculation of power, ie maximizing effective transmit power allowed.

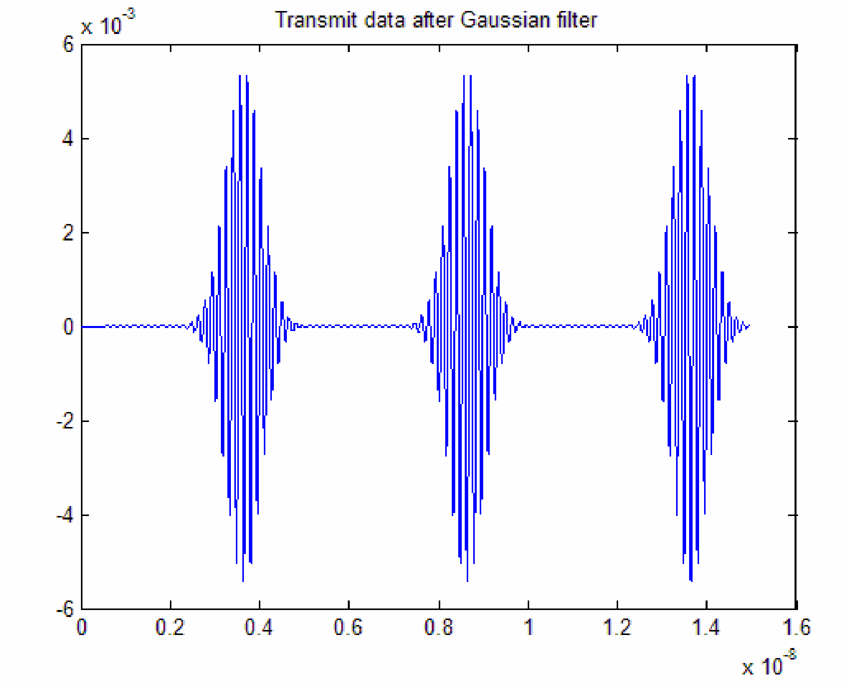
Proposed Gaussian Filtering Specification

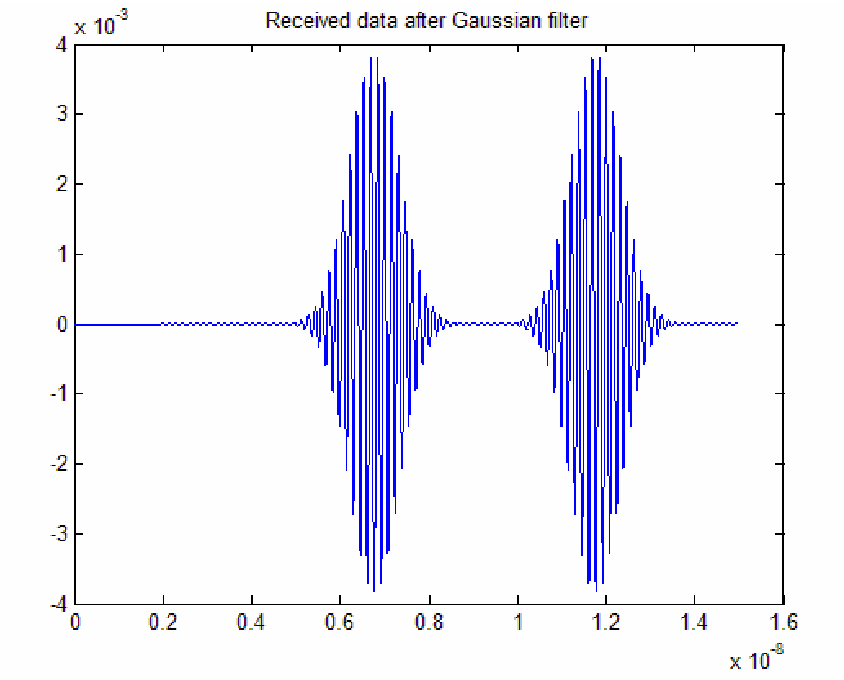
- Frequency response: $$H(\omega) = \tau \cdot \sqrt{2\pi} \cdot e^{-0.5(\tau\omega)^2}$$
- Impulse response: $$h(t) = e^{-0.5\left(\frac{t}{\tau}\right)^2}$$

- $1/\tau =$ 400 Mhz for basic channel rate
- $1/\tau =$ 1200 Mhz for turbo channel rate
- $1/\tau =$ 2000 Mhz for Super turbo channel rate

- $1/\tau$ point represents - 4.3 dB bandwidth
- At -10 dB bandwidth $\omega = 1.517 * 1/\tau$

Gaussian TX to RX pulses at 200 Mbps



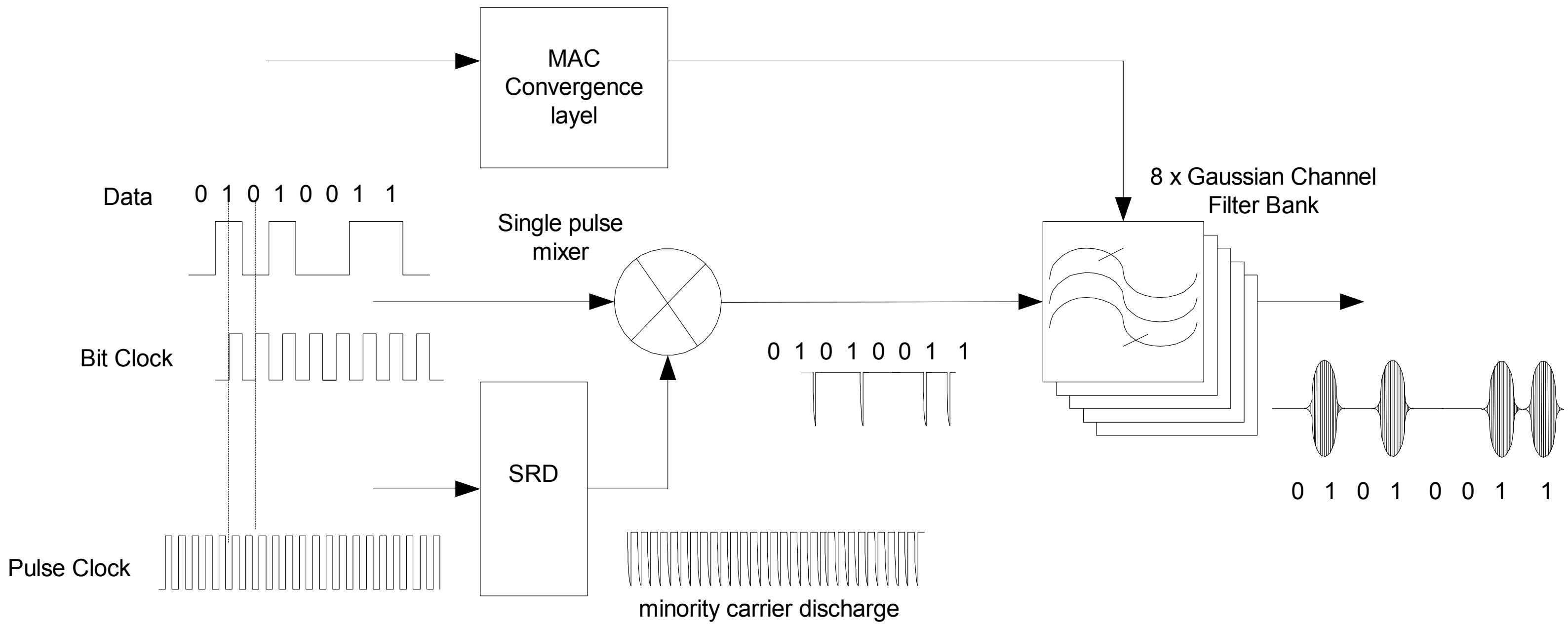


PHY Specifications Summary

- 8 basic channel at 800 Mhz bandwidth
- Gaussian wave-shaped pulses
- 200 Mbps basic raw OTA bit rate
- 20 uSec preamble with continuous pulses
- Raw OTA bit rate may be coded (TBD)

3. Technical Justifications.

- Behavior Model and suggested transmitter implementation



UWB Transmitter

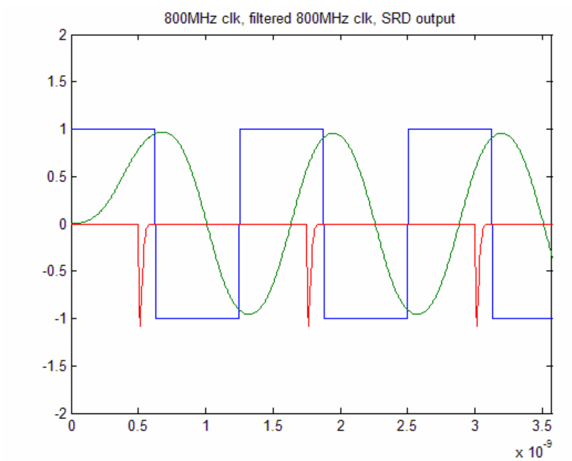
The governing relationships for low cost hardware implementation

- Pulse Clock rate = modulo (Basic bit rate)
- Channel Plan = modulo (Pulse Clock rate)
- Channel bandwidth = modulo (Basic bit rate)
- High speed mode rate = odd modulo (Basic bit rate)

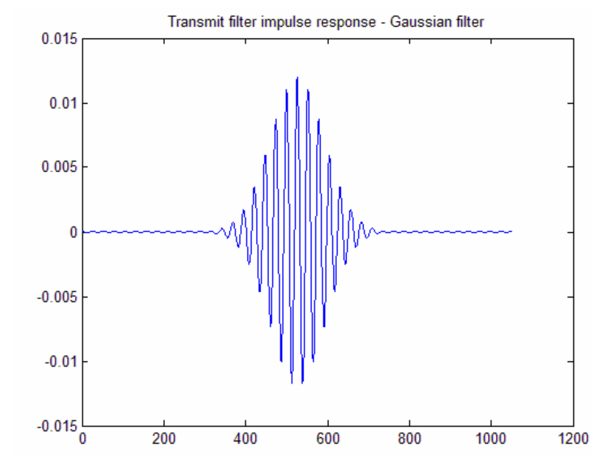
It can be seen that the proposed numbers are close to optimum under these conditions

Brief TX simulation results comic-strip

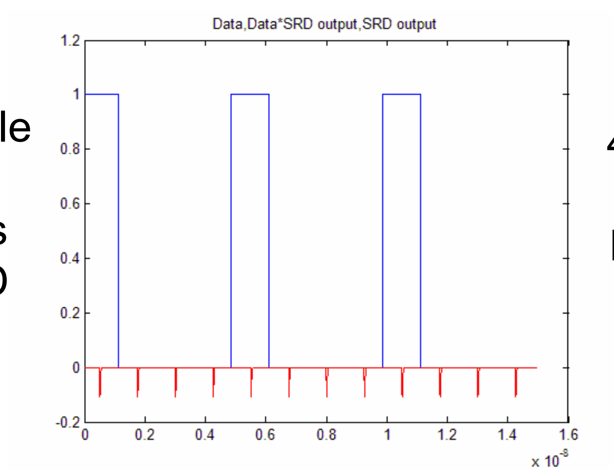
1. 800Mhz Pulse Clock In SRD Circuit



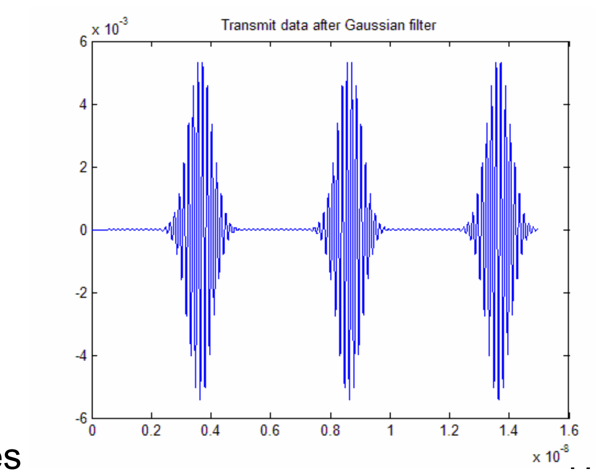
3. Gaussian Impulse Response



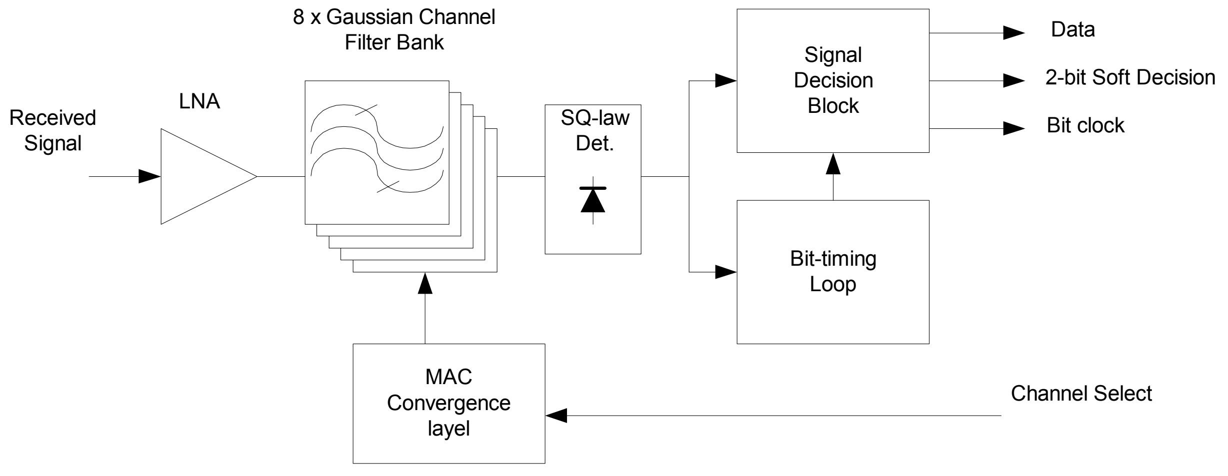
2. Input of Single Pulse Mixer With 200Mbps Data and SRD output



4. Post filter 200Mbps Data output

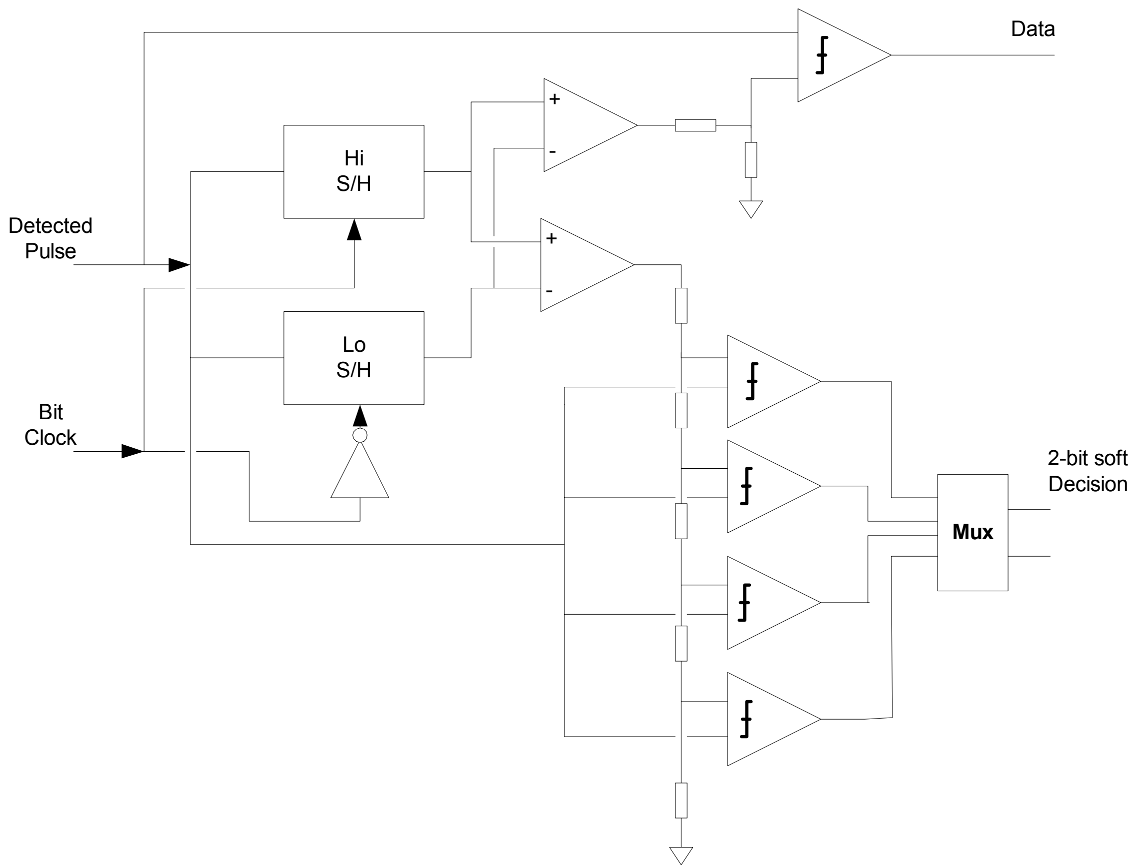


Behavior model and Suggested RX implementation (Hi-tech Crystal-set)

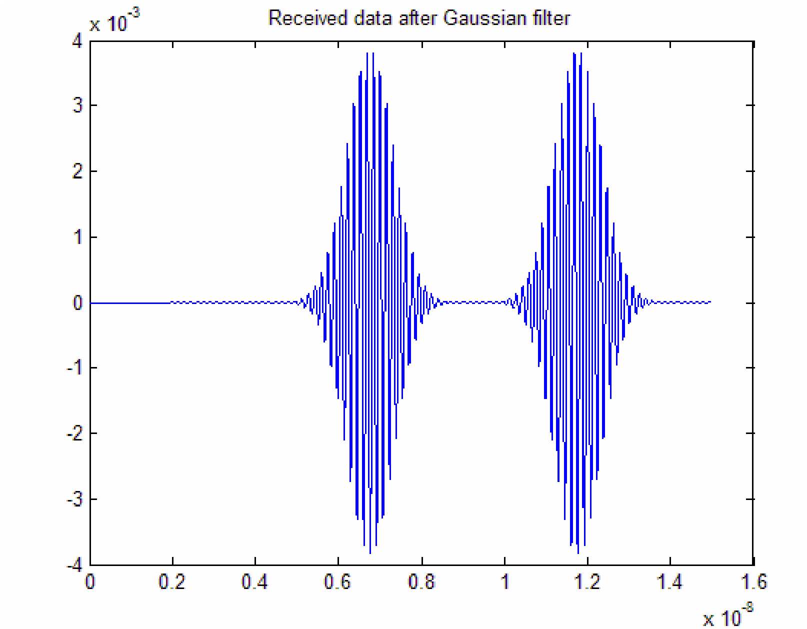


Simple UWB "Crystal Radio" receiver

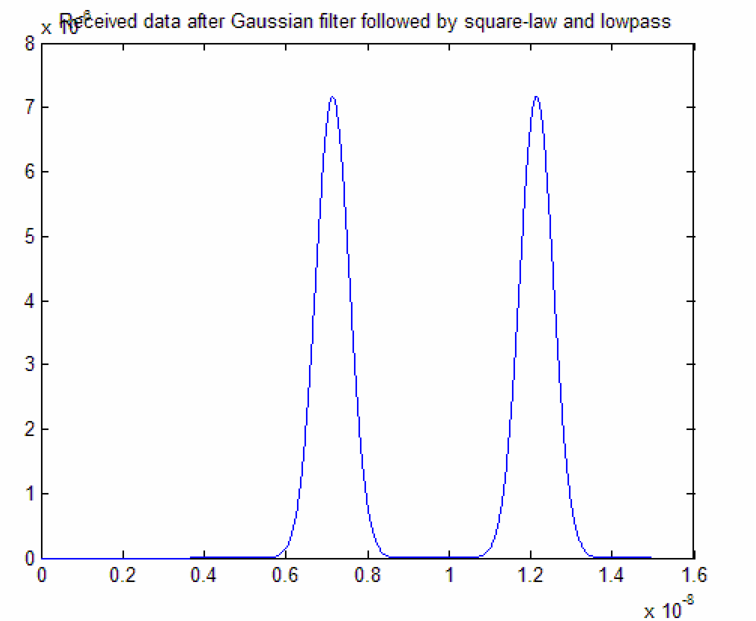
Suggested Signal processing Block for Hard and Soft Decision Detection



Brief RX simulation results comic-strip



1. 200 Mbps Data received after Gaussian Filter

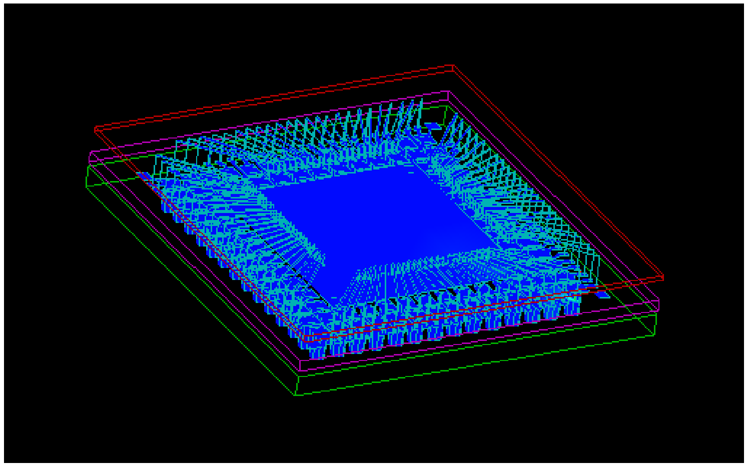


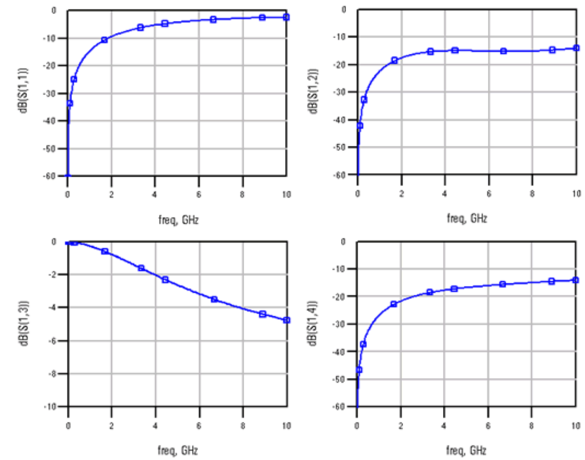
2. Detected Signal after low pass filter

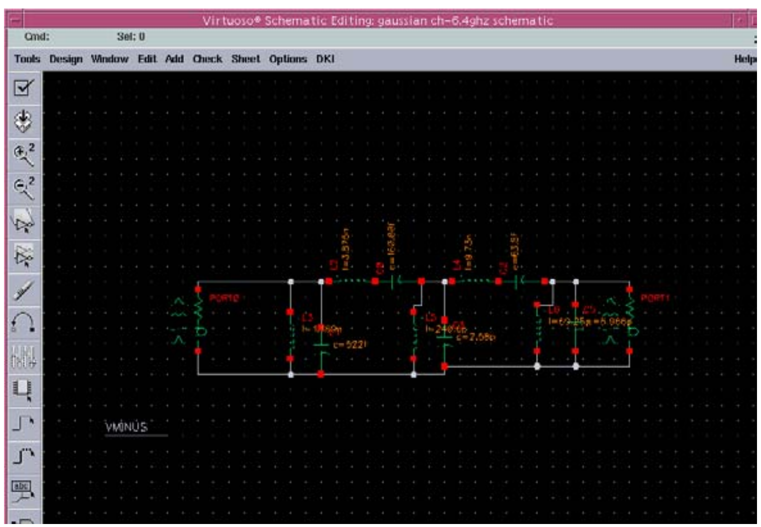
Considerations on implementation barriers

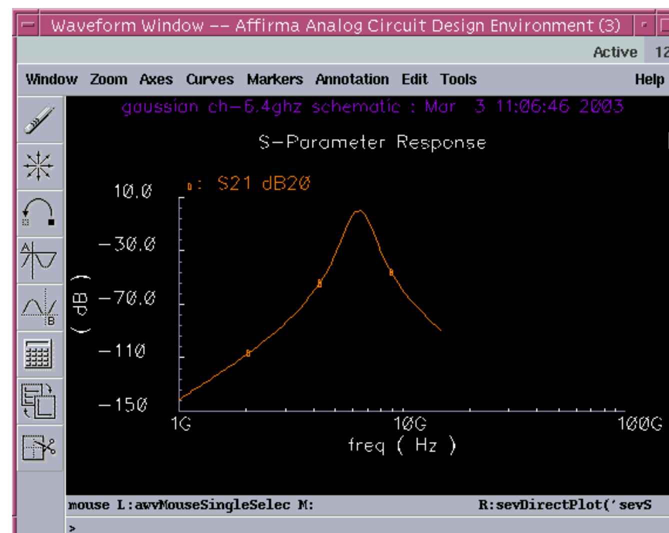
- $1.50~2.50 of Silicon, package and test cost should have no barriers -> retail cost ~$5.00☺
- High frequency board material (texflon, allumina, LTCC, etc) cost may be a concern.
- Packaging will be tricky but not insurmountable

Misc. Checks…Can we build this IC..









Performance Attainable

- 200Mbps Bit rate scalable up to 1.0 Gbps.

and Scalable down to any speed by code spread without any PHY Layer change.

- Optimum raw bit speed with 1.2 nSec delay spread protection.
- Adjacent Channel rejection of 7 dB
- Alternate Channel rejection of 22 dB
- >10 meter Range in benign Propagation environment.

Range, NF and the rest of it…

Assumptions:

- Propagation index is linearly increasing from 2.0 to 2.5 as from 1m to 10 m range.
- FCC Peak power allowance 20log(BW)-14
- Amplitude Noise capture threshold for S/N is 10.5 dB
- NF = 6 dB at 20 dB gain block
- Channel 5 is used -> 7.2 Ghz

Burst Channel Performance

P_pk/P_av=14.5 dB

Range (m)	BW (Mhz)	Channel type	Path Loss	Noise Floor (dBm)	FCC Peak power allowance	Eff. Peak power (dBm)	Bit Rate Mbps	S/N (dB)
3	800	Basic	-60	-79	48	+6.7	200	25
5	800	Basic	-65	-79	48	+6.7	200	20
10	800	Basic	-75	-79	48	+6.7	200	(11)
10	2400	Turbo	-75	-74	57	+15.7	600	15
10	4000	Super-Turbo	-75	-72	60 (61.5)	+18.7 (61.5)	1000	16

Continuous Channel Performance

P_av=const at -41.3 dBm

Range (m)	BW (Mhz)	Channel type	Path Loss	Noise Floor (dBm)	FCC Peak power allowance	Eff. Peak power (dBm)	Bit Rate Mbps	S/N (dB)
3	800	Basic	-60	-79	48 (32)	-7.3	3	11
5	800	Basic	-65	-79	48 (37.5)	-3.8	1	11
10	800	Basic	-75	-79	48 (47)	+5.7	0.1	11

Continuous Channel Performance

P_av=const at -41.3 dBm

Range (m)	BW (Mhz)	Channel type	Path Loss	Noise Floor (dBm)	FCC Peak power allowance	Eff. Peak power (dBm)	Bit Rate Mbps	S/N (dB)
3	2400	turbo	-60	-74	57 (36.5)	-4.8	3.4	11
5	2400	Turbo	-65	-74	57 (42.5)	-1.2	1	11
10	2400	Turbo	-75	-74	57 (51.5)	+10.2	0.12	11

Continuous Channel Performance

P_av=const at -41.3 dBm

Range (m)	BW (Mhz)	Channel type	Path Loss	Noise Floor (dBm)	FCC Peak power allowance	Eff. Peak power (dBm)	Bit Rate Mbps	S/N (dB)
3	4000	Super turbo	-60	-72	60 (38.5)	-2.8	3.5	11
5	4000	Super Turbo	-65	-72	60 (44.5)	+3.2	1	11
10	4000	Super Turbo	-75	-72	60 (51.5)	+12.2	0.12	11

Table Entry Calculation Example

$d0 := 1 \quad fc := 7.2 \cdot 10^9 \quad d := 5 \quad n := 2 + 0.05 \cdot d \quad Nf := 6$

$Bw := 800 \cdot 10^6 \quad \lambda := \frac{3 \cdot 10^8}{fc} \quad Lo := 0$

$No := 174 - 10 \cdot \log(Bw) - Nf - Lo$

$No = 78.969$

Path loss

$PL := 20 \cdot \log\left(\frac{4 \cdot \pi \cdot d0}{\lambda}\right) + 10 \cdot n \cdot \log\left(\frac{d}{d0}\right)$

$PL = 65.315$

$rate\_reduction := 200$

$SN := No - 41.3 - PL + pkreal + 10 \cdot \log(rate\_reduction)$

$SN = 9.864$

FCC peak power allowance

$pk := 20 \cdot \log\left(1.5 \cdot \frac{Bw}{10^6}\right) - 14$

$pk = 47.584$

Calculated Peak to Average:

$pkreal := 14.5$