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

Submission Title: ETRI's Proposal for In-body high data rate WBAN PHY

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Re: This document is ETRI's response to the Call For Proposal from the IEEE P802.15 Task Group 6 on BAN.

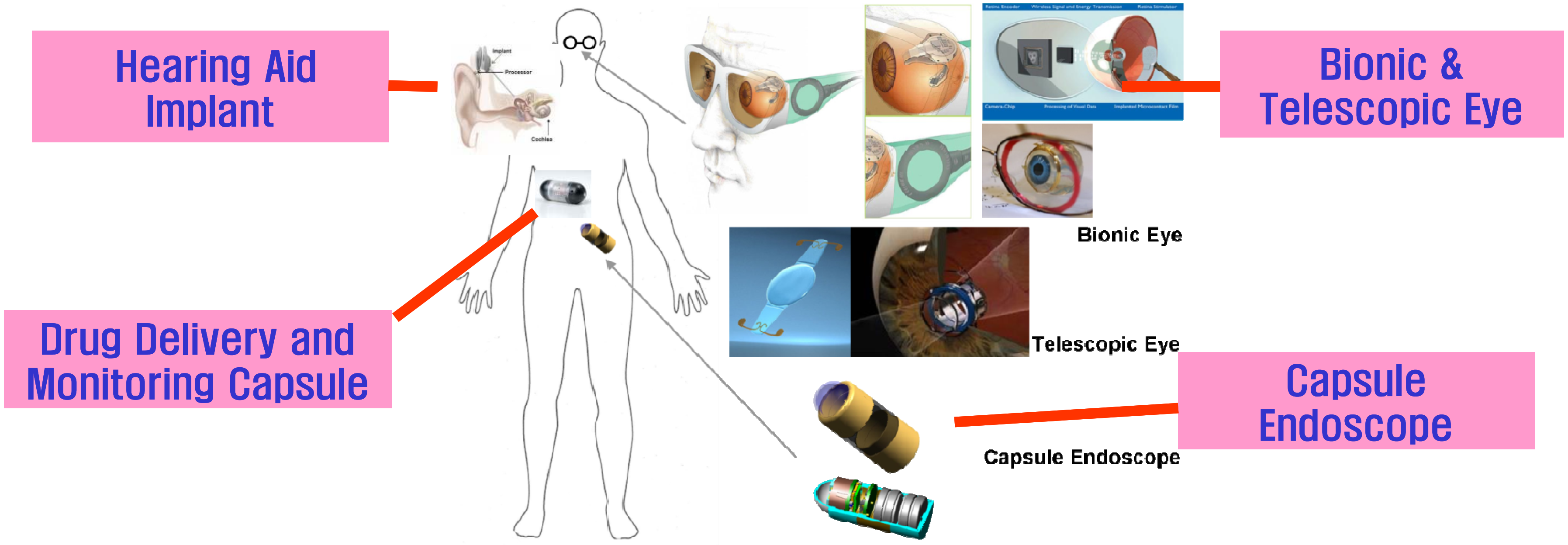
Abstract: This document presents High-data-rate In-body WBAN.

Presentation Outline

- **Requirements**
- **Proposed PHY**
- **Performance**
- **Link Budget**
- **Spectral Mask**
- **Conclusion**

Applications of High-data-rate In-body WBAN

- Applications of Implantable BAN
  - Capsule Endoscope
  - Drug Delivery & Monitoring Capsule
  - Bionic & Telescopic Eye
  - Implant Hearing Aid
- Image resolution
  - Image quality at least 2Mbps
  - Enlarge the image for specific symptom
  - HD image : up to 20Mbps



Key Features of Proposed PHY for High-data-rate In-body Communication

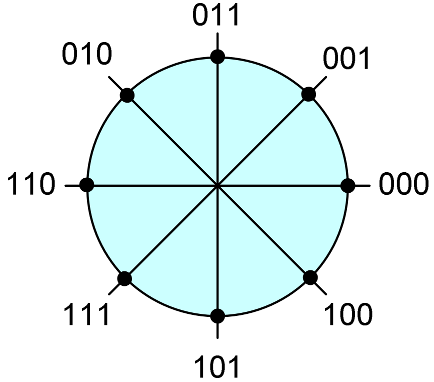
- Design objective
  - Power efficient modulation
  - Bandwidth efficient modulation
  - Overcome the disadvantage of Phase Shift Keying
    - Pros : Bandwidth efficient
    - Cons : Less power efficient than orthogonal modulations
- Phase-Silence Shift Keying (PSSK)
  - Compromise between Power efficient modulation and bandwidth efficient modulation
  - PSSK achieves this by using orthogonal phase spaces.

Phase Silence Shift Keying (PSSK)

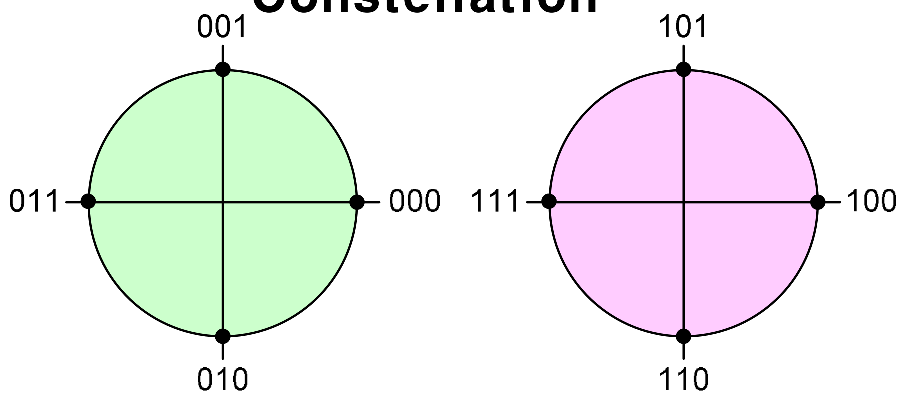
- Phase-Silence Shift Keying (PSSK)
  - Power efficient modulation
    - Zero-envelope period at each symbol
    - Less abrupt phase shift 180°than PSK
  - Bandwidth efficient than the orthogonal modulations (PPM, FSK, OOK)
  - Good performance
    - 8PSSK is 5.4 dB better than 8PSK
    - 8PSSK is 1.5 dB better than QPSK

8 - Phase Silence Shift Keying (8PSSK)

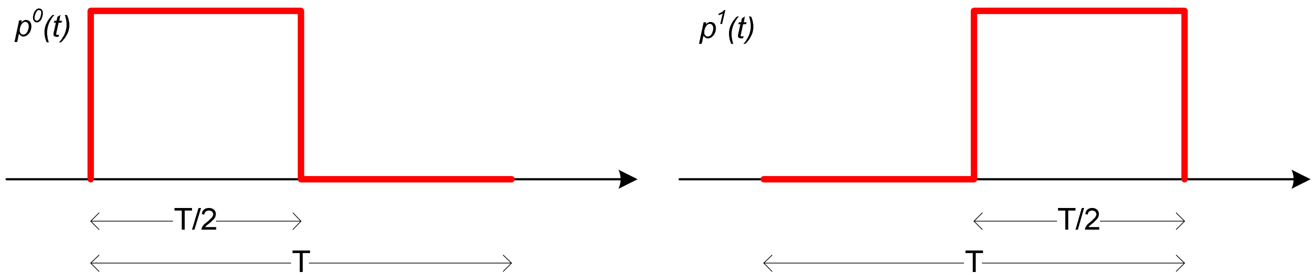
8PSK Constellation



8PSSK Constellation



$$S_m(t) = p^k(t)\cos(2\pi f_c t + 4\pi \mathrm{mod}(m, 0.5M)/\mathrm{M})$$



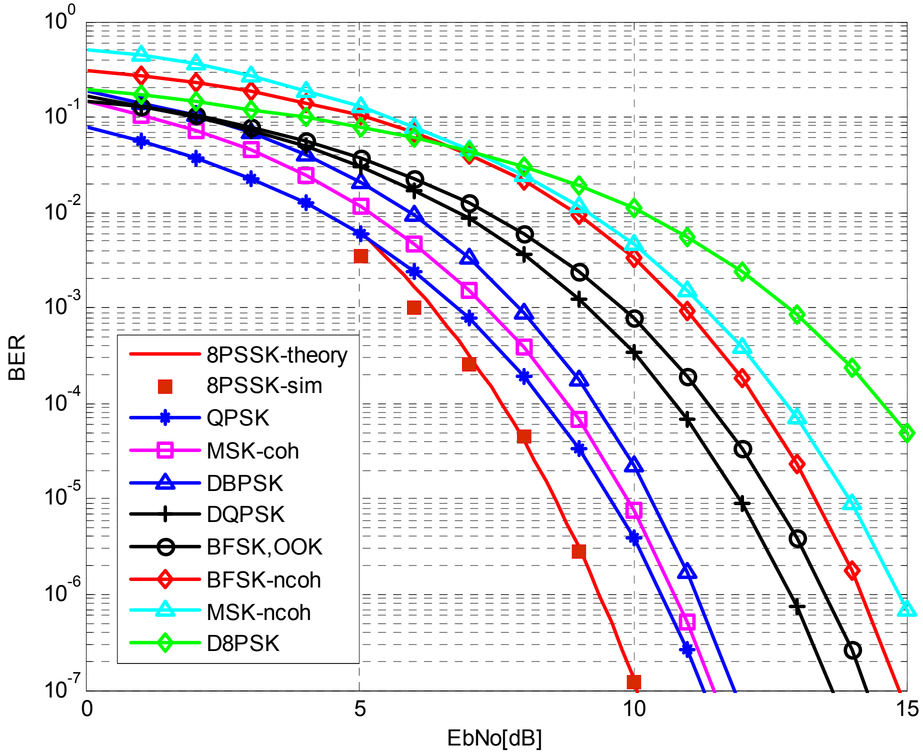
- Half silent period of symbol duration makes save transmit power for 3 dB.

8 - Phase Silence Shift Keying (8PSSK)

- 8 PSSK
  - Suitable for 10/20Mbps high data rate WBAN In-body systems
  - Low complexity / Low power/ High performance
    - Improve back-off characteristic for non-linearity analog devices
    - Simple differential receiver architecture is possible for non-coherent detection
    - Possible to share transceiver architecture with M-PSK or (M-DPSK)
    - 성능 관련
  - Square-Root Raised Cosine pulse is used for pulse shaping

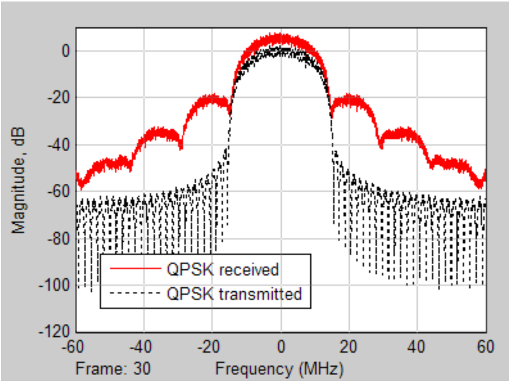
Freq. Band [MHz]	Modulation	Symbol Rate [Msps]	Pulse Shape	Bandwidth [MHz]	Data Rate [Mbps]
270 - 310	8-PSSK	1.92	SRRC	7.68	5.76
		3.84	SRRC	15.36	11.52
		7.68	SRRC	30.72	23.04

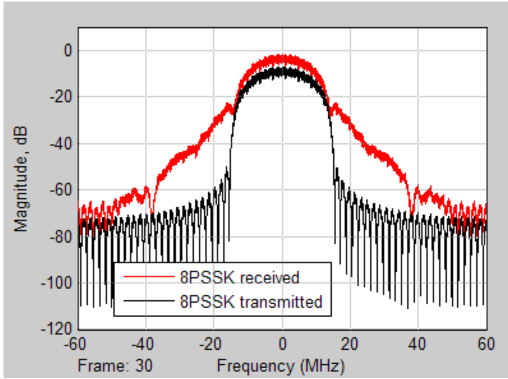
PSSK Performance

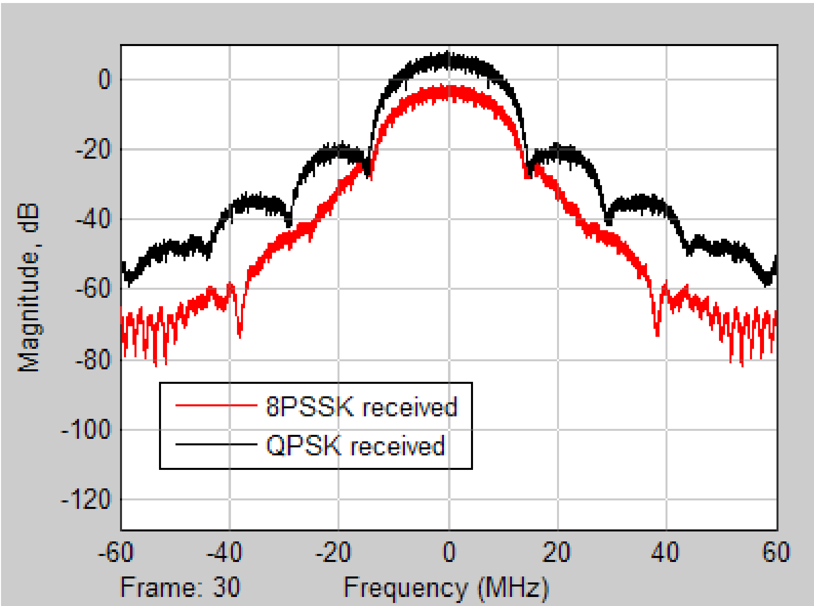


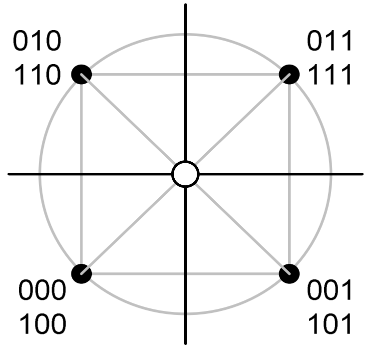
	8PSSK	QPSK	BPSK	2FSK	2FSK	MSK	MSK	GMSK
BW[bps/Hz]	0.75	1	0.5	0.4	0.25	0.75	0.75	0.88
BER [10^-6]	9dB	10.5dB	10.5dB	13.5dB	14.2dB	10.5dB	14.8dB	12.2dB
Receiver	Coh.	Coh.	Coh.	Coh.	Non-coh	Coh.	Non-coh	Coh.

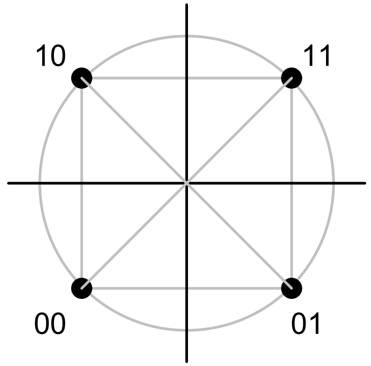
PSSK Performance





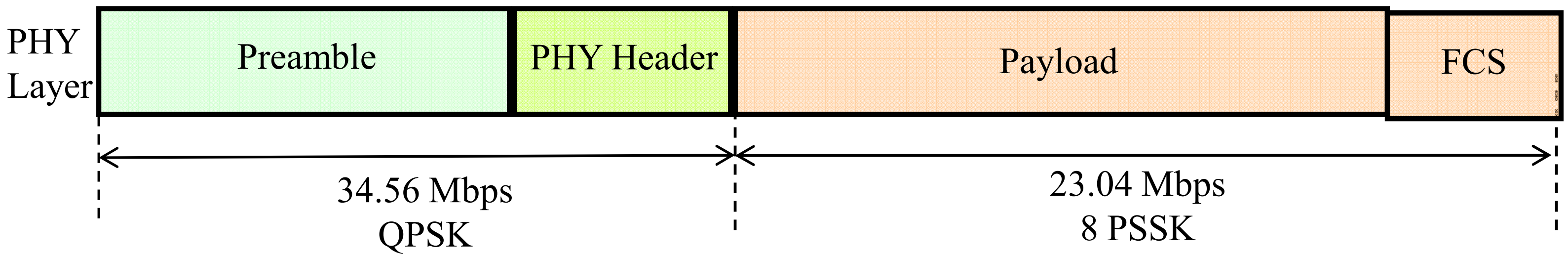






- Zero crossing rate due to phase shift 180º can be reduced to a quarter compared to that of the QPSK.
- Spectrum re-growth effect can be reduced.

Frame Structure



- Preamble
  - 16 Symbol CAZAC sequence
- PHY Header
  - 2 bytes
  - Frame length, rate, scrambling seed
- FCS
  - CCITT CRC-16

Preamble Code

- CAZAC sequence
  - Constant Amplitude Zero Auto-Correlation
  - Constant envelop for time and frequency domain

CAZAC sequence

CAZAC sequence element	Value
C_0	+1+j
C_1	+1+j
C_2	+1+j
C_3	+1+j
C_4	-1+j
C_5	-1-j
C_6	+1-j
C_7	+1+j
C_8	-1-j
C_9	+1+j
C_{10}	-1-j
C_{11}	+1+j
C_{12}	+1-j
C_{13}	-1-j
C_{14}	-1+j
C_{15}	+1+j

CRC

CCITT CRC-16 CALCULATOR

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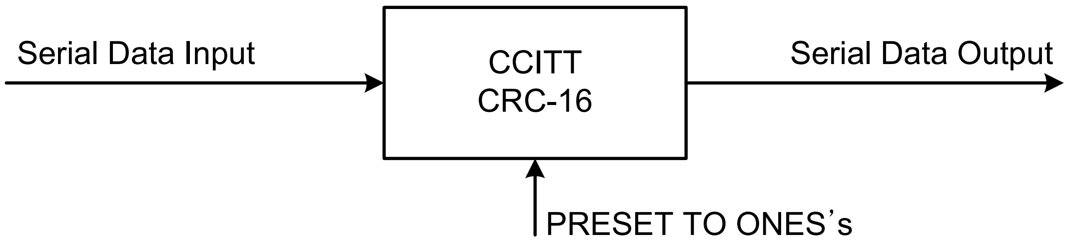
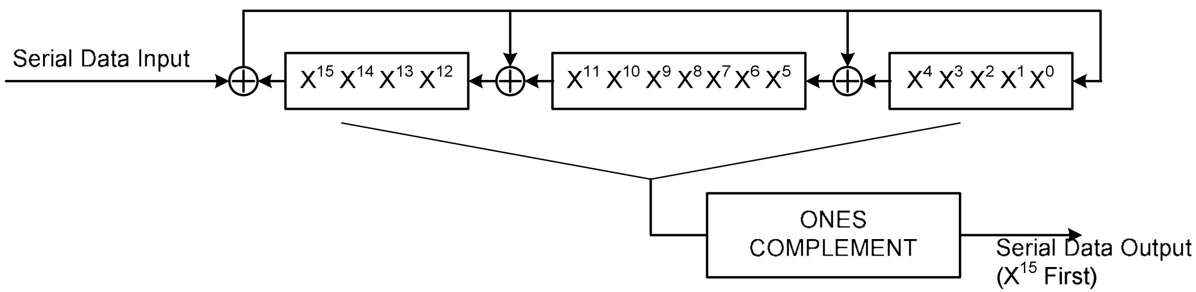


1. Preset registers to all ones
2. Shift serial data input through the shift register
3. Take ones complement of the remainder
4. Transmit out serial X^{15} first

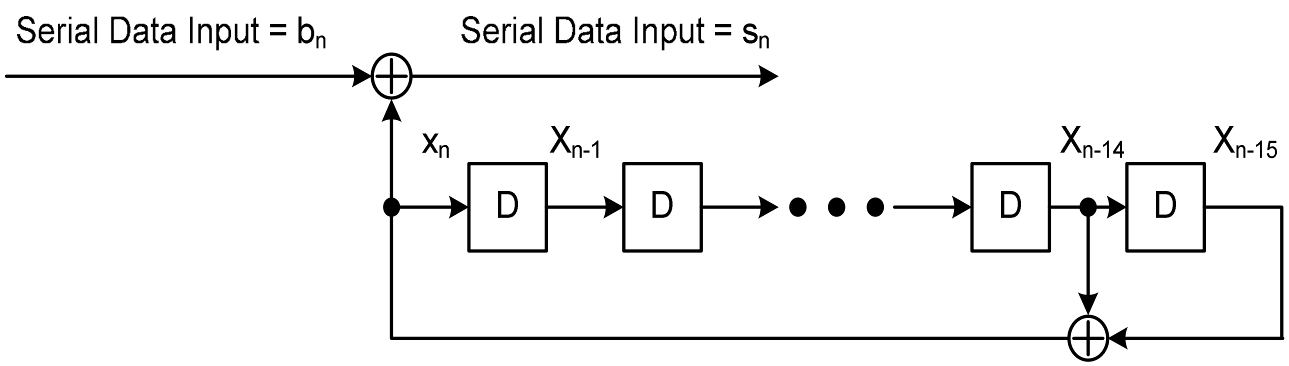
CCITT CRC-16 POLYNOMIAL : G(x) = $X^{16} + X^{12} + X^5 + 1$



CCITT CRC-16 Implementation

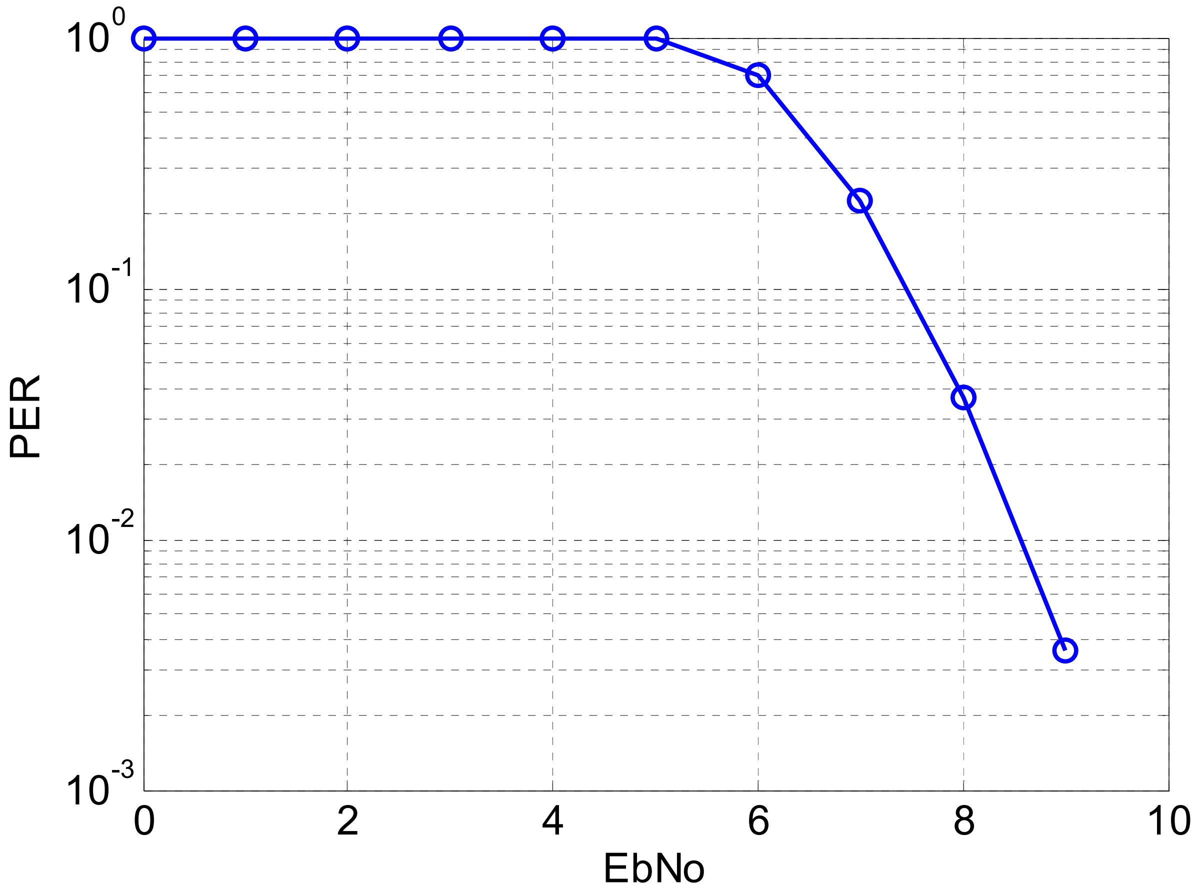
Scrambling

- PRBS generator
  - $g(D) = 1 + D^{14} + D^{15}$ $x_n = x_{n-14} \oplus x_{n-15}$



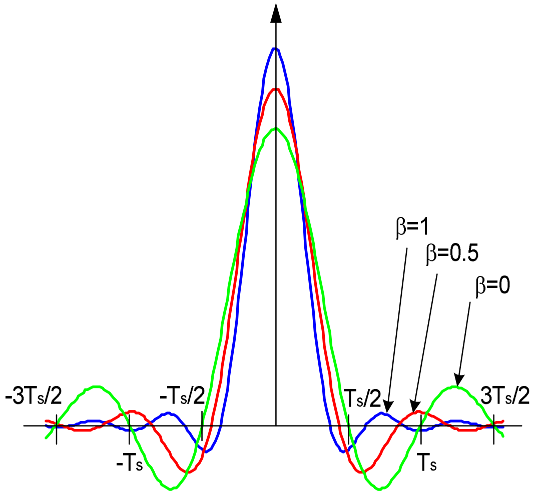
Performance

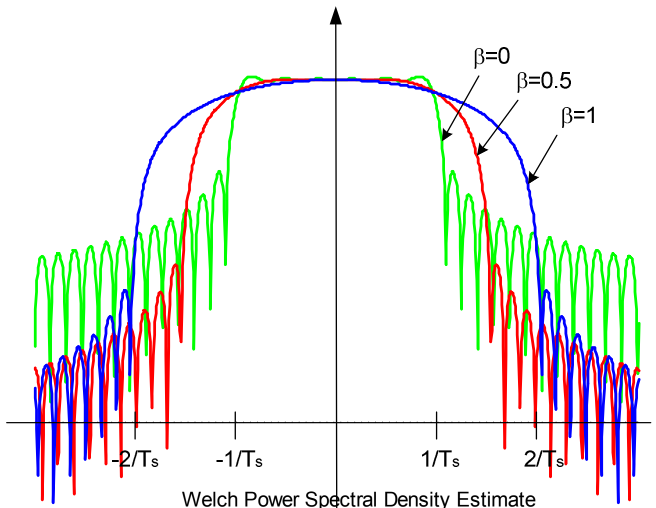
- We can achieve 10% PER about 7 dB for EbN0

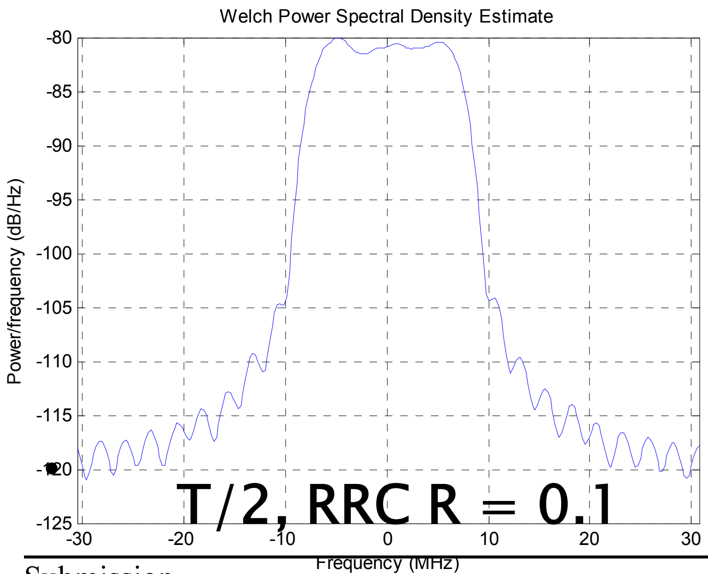


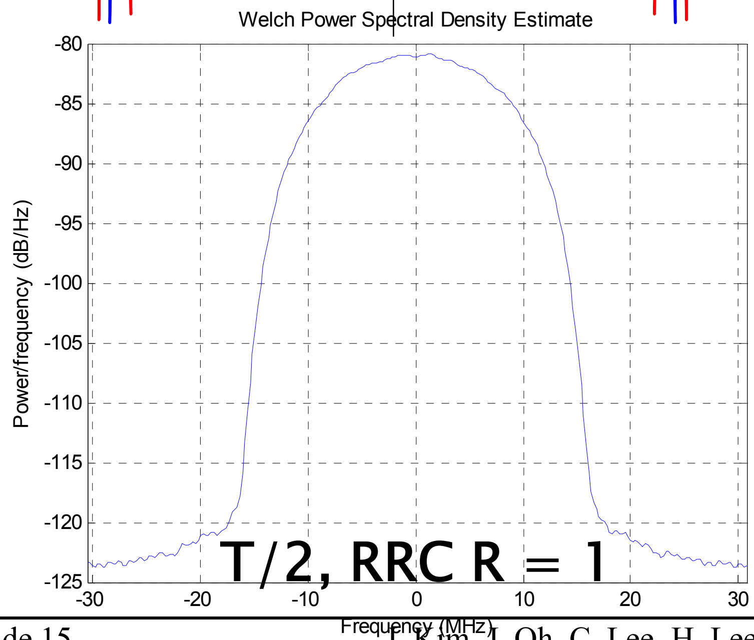
Power Spectrum

- 20 MHz data rate



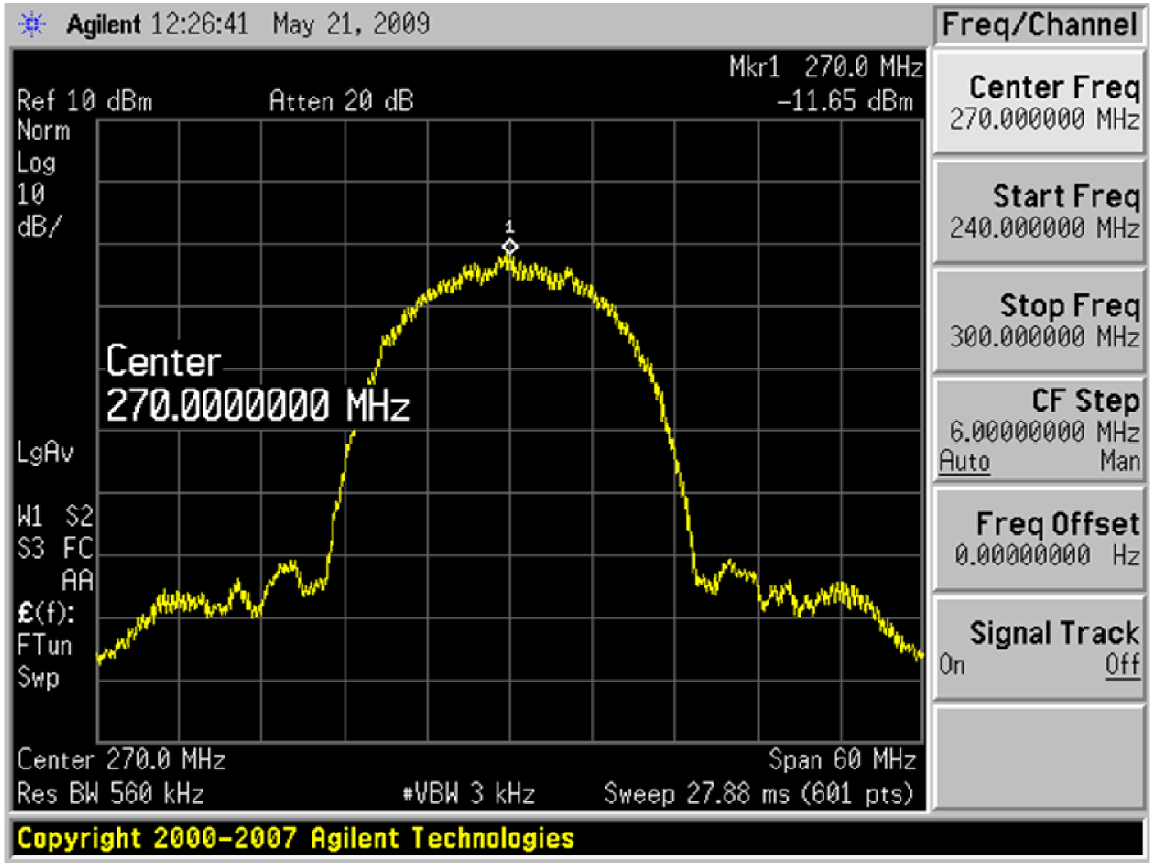






Power Spectrum

- 20 MHz data rate



Link Budget

Comparison of In-body High Data Rate Link Budget			
No	Parameters	Unit	8PSSK
1)	Bit rate [R]	Mbps	20
2)	Symbol Period [Tb]	nS	150
3)	In-body Distance [di]	cm	15
4)	Channel Bandwidth [BW]	MHz	26.6
5)	Average TX Power [Pt_avg]	dBm	0.0
6)	Pulse-on duration [Tp]	nS	75.0
7)	Duty Gain [Dg]	dB	3.0
8)	Peak TX Power [Pt]	dBm	3.0
9)	TX antenna gain [Gt]	dBi	-10.0
10)	In-body Path loss [L]	dB	70.0
11)	RX antenna gain [Gr]	dBi	0.0
12)	RX power [Pr]	dBm	-77.0
13)	Receiver AWGN noise floor [N]	dBm	-99.8
14)	RF noise figure [Nf]	dB	5.0
15)	Average noise power [Pn]	dBm	-94.8
16)	Minimum EbNo [EN]	dB	9.0
17)	Minimum SNR [S]	dB	7.8
18)	Implementation loss [I]	dB	3.0
19)	Link Margin [LM]	dB	7.0
20)	Rx Sensitivity Level [Pmin]	dBm	-84.0

Conclusion

- PSSK was proposed for high-data-rate WBAN PHY.
- PSSK Proposal summary
  - Frame structure
  - Performance
  - Spectrum
  - Link margin