

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

Submission Title: PSSK Proposal for High-data-rate In-body WBAN PHY (ETRI)

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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 PSSK for High-data-rate In-body WBAN.

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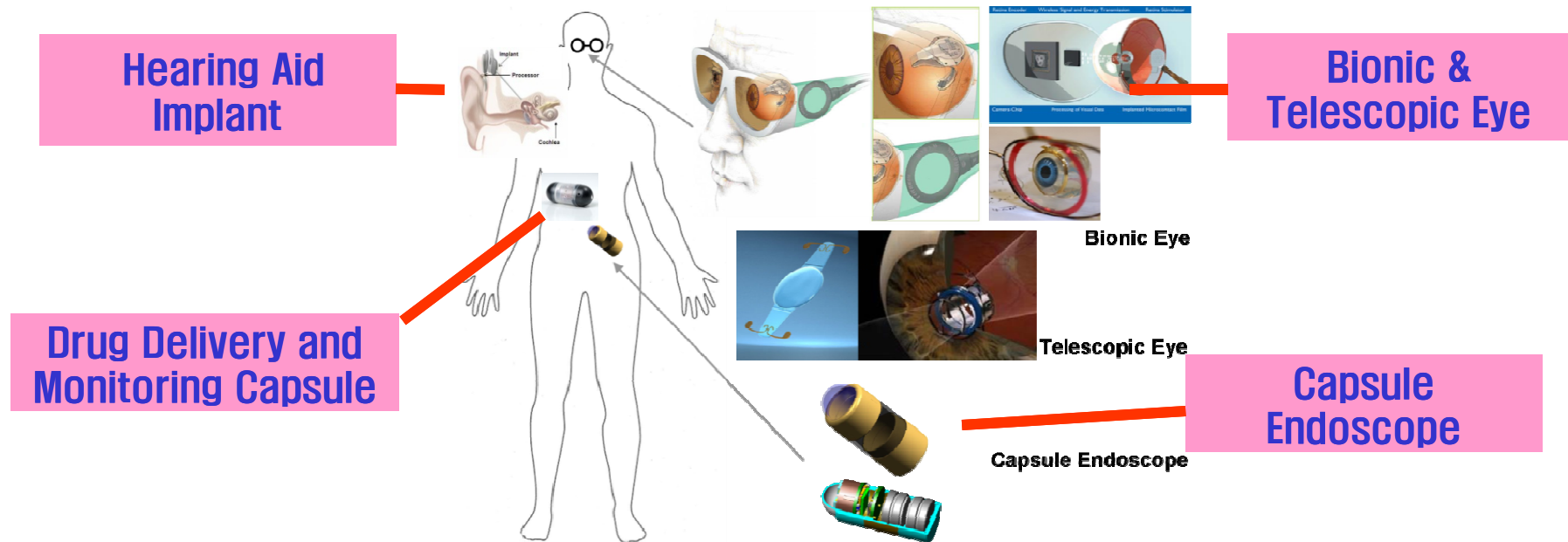
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Presentation Outline

- **Requirements**
- **Recommended Frequency Band**
- **Proposed PHY**
- **Reliability**
- **Link Budget**
- **Spectral Mask and Channelization**
- **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 2.3Mbps
 - Enlarge the image for specific symptom
 - HD image : up to 20Mbps



Requirements for High-data-rate In-body WBAN

Parameters	Requirement
Raw PHY data rate	10 Mbps, 20 Mbps
Transmission range	30 cm * / 3 m **
Reliability	BER < 10 ⁻⁶

* Due to the great signal strength attenuation by deeply-implanted devices in human body, transmission range is limited to several tens of centimeter.

** For non deeply-implanted devices such as bionic eye, transmission range is up to 3 meters.

Considerations of Frequency Band

- No dedicated frequency band for implant device
- Zarlink (IEEE 802.15-08-162-00)
 - Frequency band: 400-440MHz band
 - Regulation problem
 - Band usage for other countries: land mobile or walkie-talkie
- Frequency considerations for implant device
 - Sub-900MHz band: due to in-body attenuation
 - Required bandwidth: at least 40MHz for 10Mbps or 20Mbps

FCC Regulation

- FCC Part15.209 (Radiated emission limits)
 - Unlicensed general requirements

Frequency (MHz)	Electric field strength (uV/m)	Measuring distance (m)	EIRP (dBm)
30 ~ 88	100	3	-55.3
88 ~ 216	150	3	-51.7
216 ~ 960	200	3	-49.2
Above 960	500	3	-41.25

Korea Regulation

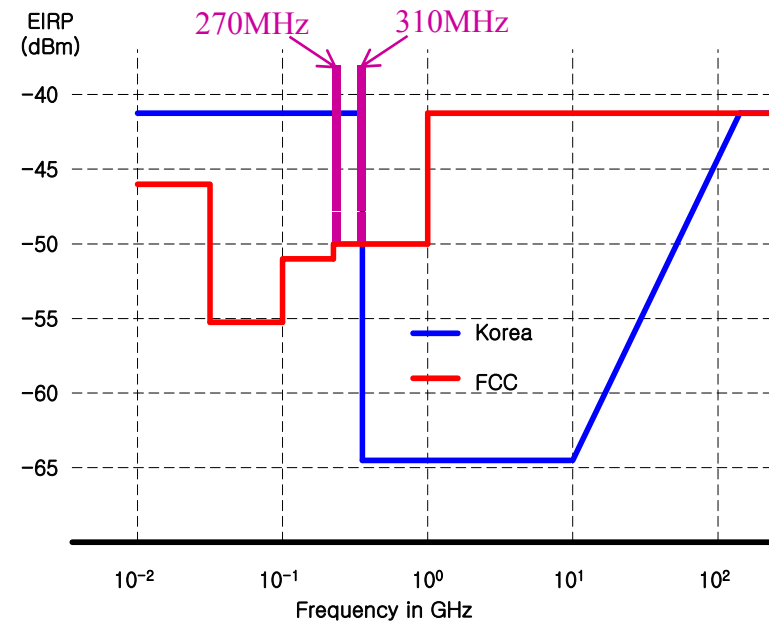
- Korea
 - Unlicensed general requirements

Frequency (MHz)	Electric field strength (uV/m)	Measuring distance (m)	EIRP (dBm)
~322MHz	500	3	-41.25
322MHz ~ 10 GHz	35	3	-64.35
10 GHz ~ 150 GHz	$3.5 \times f(\text{GHz})$ Max. 500	3	$-84.35 + 20\log(f)$

* Power regulation in Japan is the same as in Korea

Recommended Frequency Band

- Unlicensed low-power transmission
 - -49.2dbm(FCC)
 - -41.25dBm(Korea)
- Consideration of in-body transmission
 - Small antenna size
- Frequency band
 - 270~310MHz



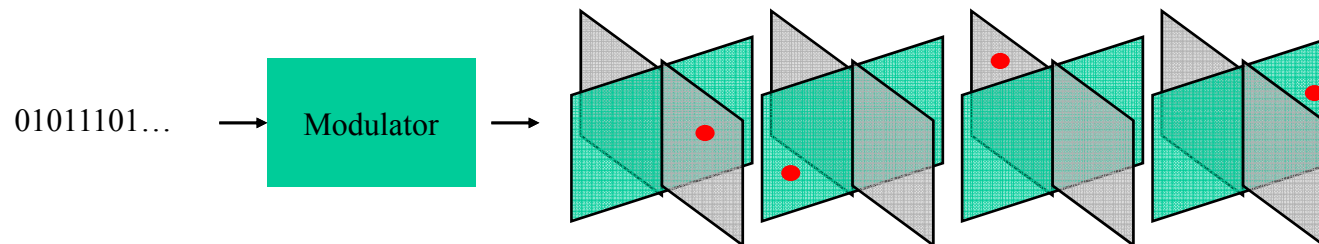
Trends of Wireless Implant Devices

- Implant wireless communication devices
 - Low-data-rate
 - Zarlink: 200/400/800kbps, FSK
 - High-data-rate
 - Capsule endoscope: Up to 3 Mbps, Several vendors and research institutes, FSK/OOK
- Modulation methods
 - FSK, PPM (Orthogonal modulations) are power efficient, but they have low bandwidth efficiency.
 - FSK, PPM are suitable for low-data-rate modulations.

	BPSK	QPSK	8PSK	16PSK	32PSK
Bandwidth efficiency	0.5	1	1.5	2	2.5
	2BPPM	4BPPM	8BPPM	16BPPM	32BPPM
Bandwidth efficiency	0.5	0.5	$3/8=0.375$	$1/4=0.25$	$5/32=0.15625$
	Orth-BFSK	Orth-4FSK	Orth-8FSK	Orth-16FSK	Orth-32FSK
Bandwidth efficiency	1	0.25	$1/6=0.167$	$1/10=0.1$	$1/18=0.056$

Proposed PHY for High-data-rate In-body Communication

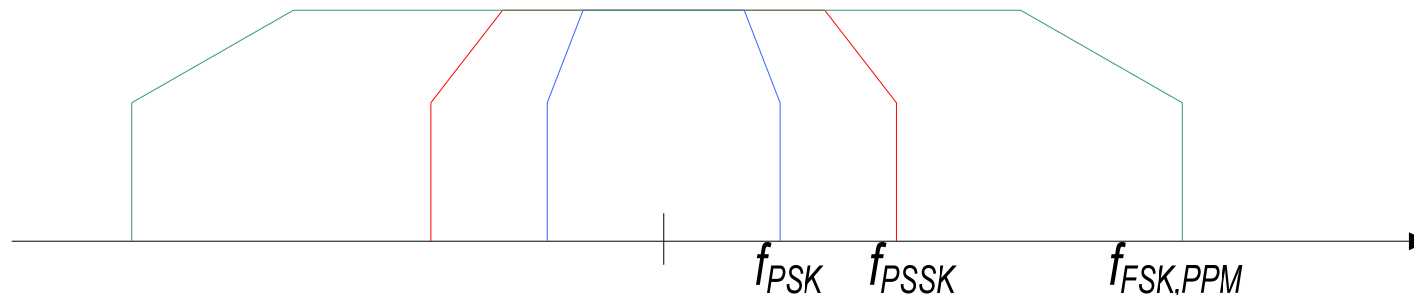
- Design objective
 - Power efficient modulation
 - (Frequency) bandwidth efficient modulation
 - > Overcome the disadvantage of Phase Shift Keying
 - Pros : Bandwidth efficient
 - Cons : Less power efficient than orthogonal modulations
- Phase-Silence Shift Keying (PSSK)
 - Compromise between Power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



* More details are presented in Appendix.

Comparisons of Modulations : Spectrum

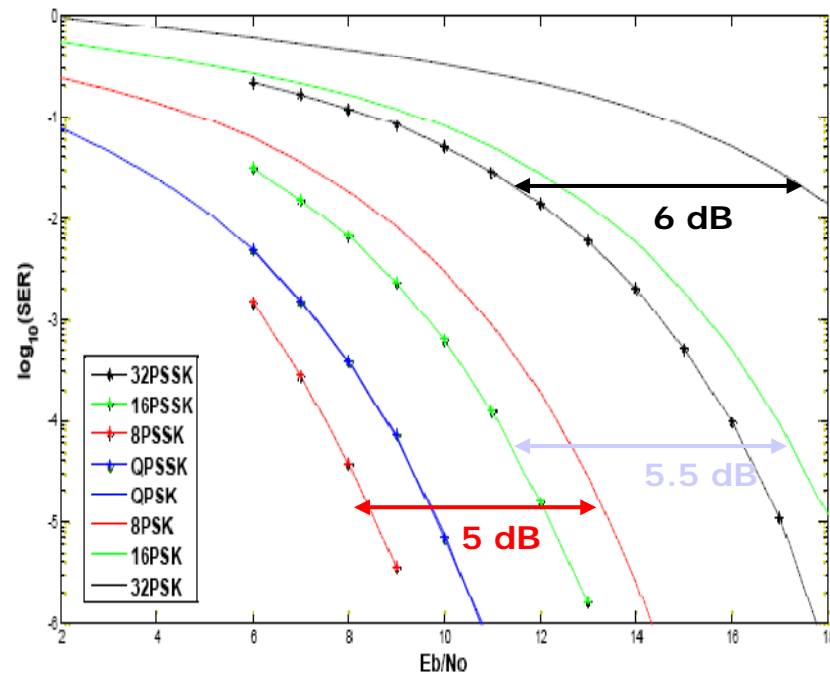
- Spectrum
 - Spectrum efficiency of FSK or PPM is unavailable to high-data-rate WBAN modulation.
 - PSK is the most bandwidth efficient modulation.
 - Bandwidth efficiency of PSSK is half of PSK.
- Signal-bandwidth comparison
 - $f_{\text{fsk,ppm}} : f_{\text{pssk}} : f_{\text{psk}} = (M+1)/2 : 2 : 1$



Comparisons of Modulations : Power

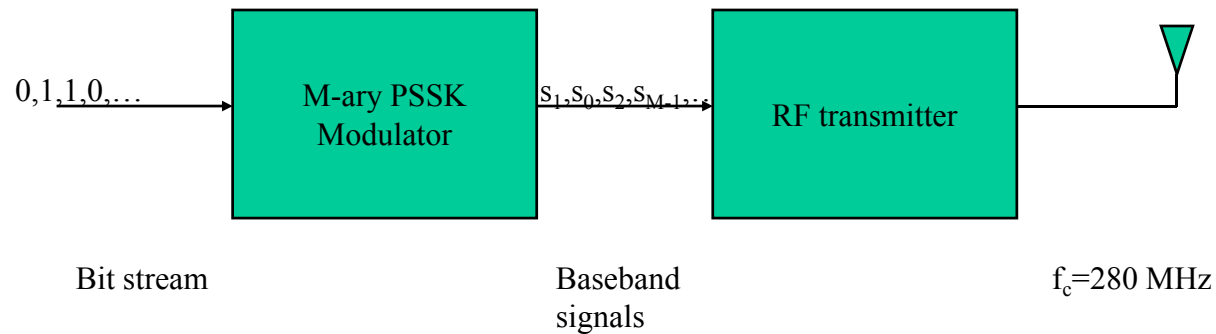
- Signal-power comparison

- PSSK is more power efficient by 5 to 6 dB than PSK.
- FSK is more power efficient by 6 dB than PSK for $M=8$
 - As M increases, FSK gets more power efficient than PSK



Raw PHY Data-rate

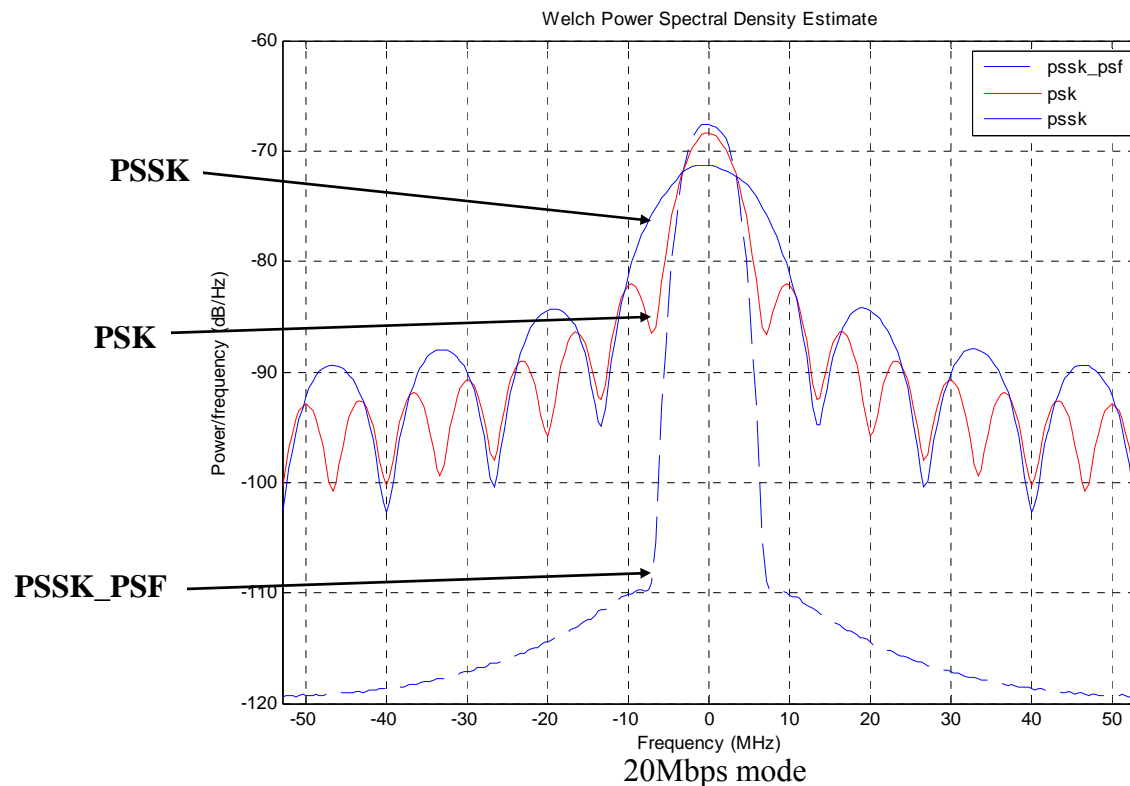
- PSSK Transmitter



- Data rate: 10 Mbps or 20 Mbps

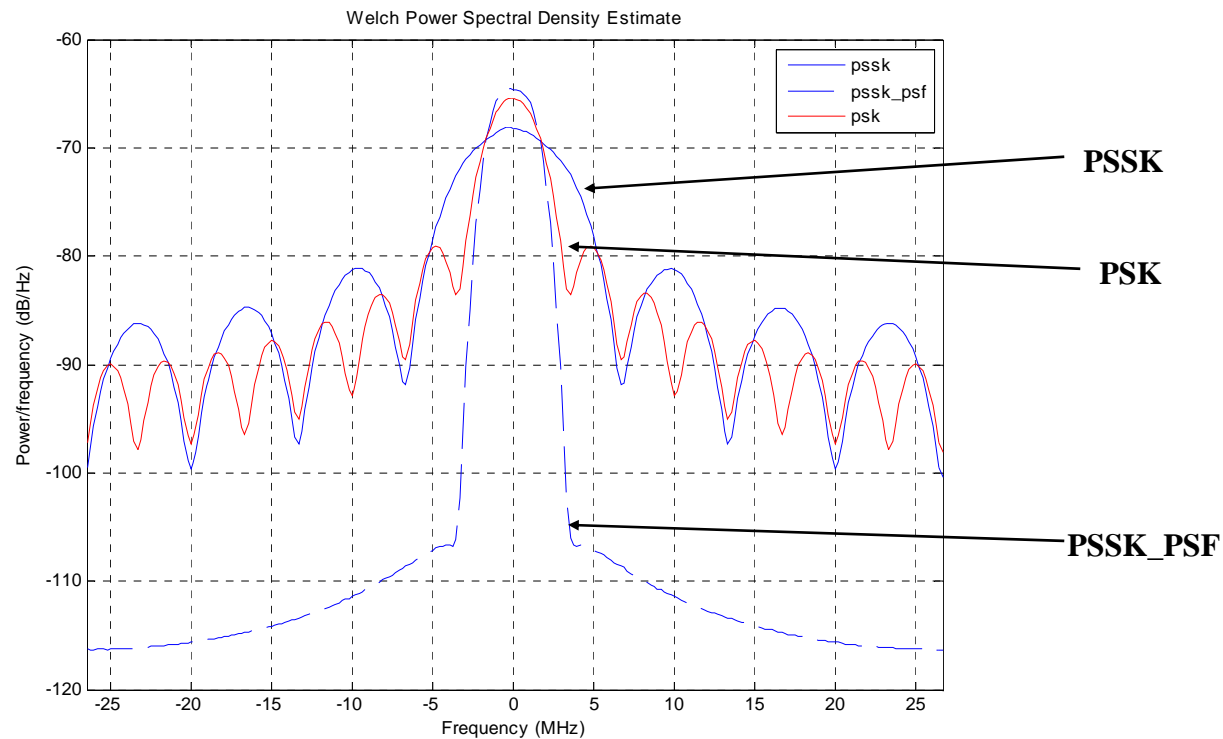
Mode of Data-rate and Spectrum

- 20 Mbps mode (8-ary PSSK)
 - 3 dB Bandwidth: 11.6 MHz / 5.8 MHz (without / with pulse-shaping)



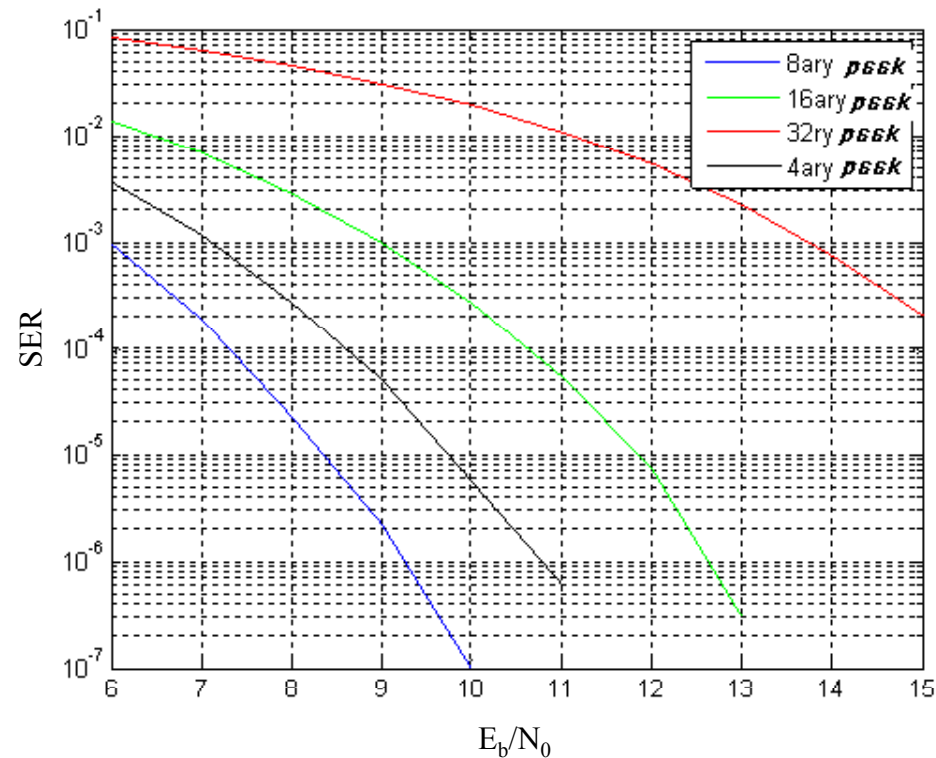
Mode of Data-rate and Spectrum

- 10 Mbps mode (8-ary PSSK)
 - 3 dB Bandwidth: 5.8 MHz / 2.9 MHz (without/with pulse-shaping)



Reliability

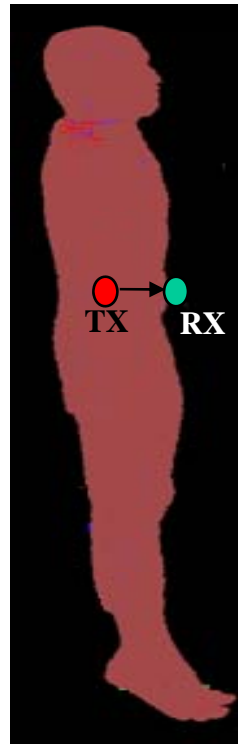
- Bit error rate over AWGN channel
 - 8-ary PSSK has $\text{SER}=10^{-6}$ when $E_b/N_0=9\text{dB}$



Link Budget

TX-to-RX Distance: 20 cm

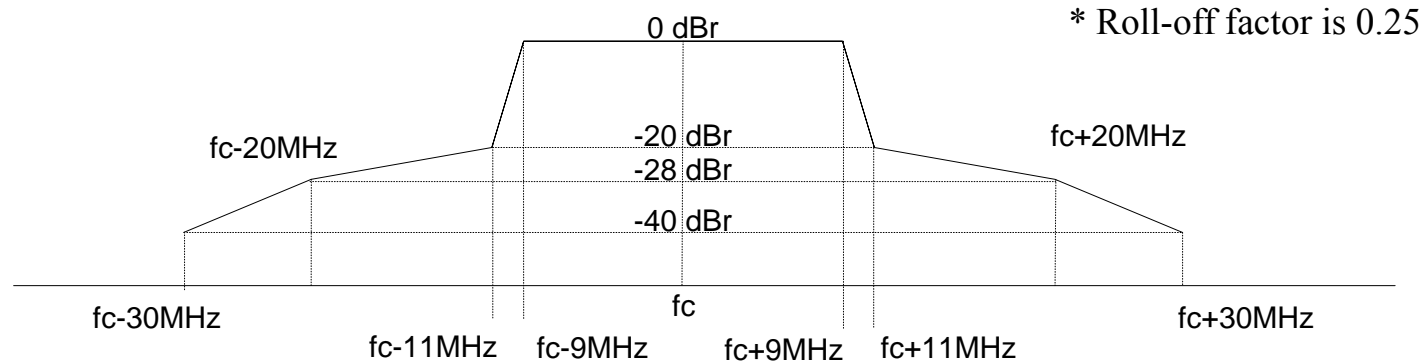
- Transmitter in a body
- Receiver on the skin
- Multiple receiver antenna
 - Diversity gain
- Range of Tx power
 - -49~0dbm
 - According to the depth of implanted transmitter



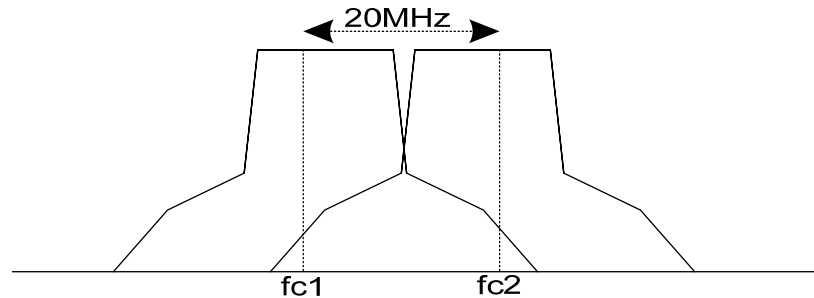
Parameters	Values (20Mbps)	Values (10Mbps)	Unit
Transmit Power	0	0	dBm
TX Antenna Gain	-10	-10	dBi
Body Attenuation	-65	-65	dB
RX Antenna Gain	0	0	dBi
Noise Figure	-5	-5	dB
Implementation Loss	-3	-3	dB
kTB noise	-106	-110	dB
SNR	23	27	
Link Margin	9	13	dB

Spectral Mask and Channelization

- Spectral mask



- Bandwidth per channel



Conclusion

- PSSK was proposed for PHY for high-data-rate WBAN.
- PSSK summary
 - Data rate
 - 10 Mbps, 20 Mbps
 - Channel
 - 2 channels
 - Bandwidth (with pulse shaping)
 - 5.8 MHz (for 20MHz), 2.9MHz (for 10MHz)
 - Link margin
 - If transmit power is 0 dBm, link margin is 9 dB (for 20Mbps) and 13 dB (for 10Mbps.)
 - Due to the attenuation in body, transmission power may be -49~0dbm