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.

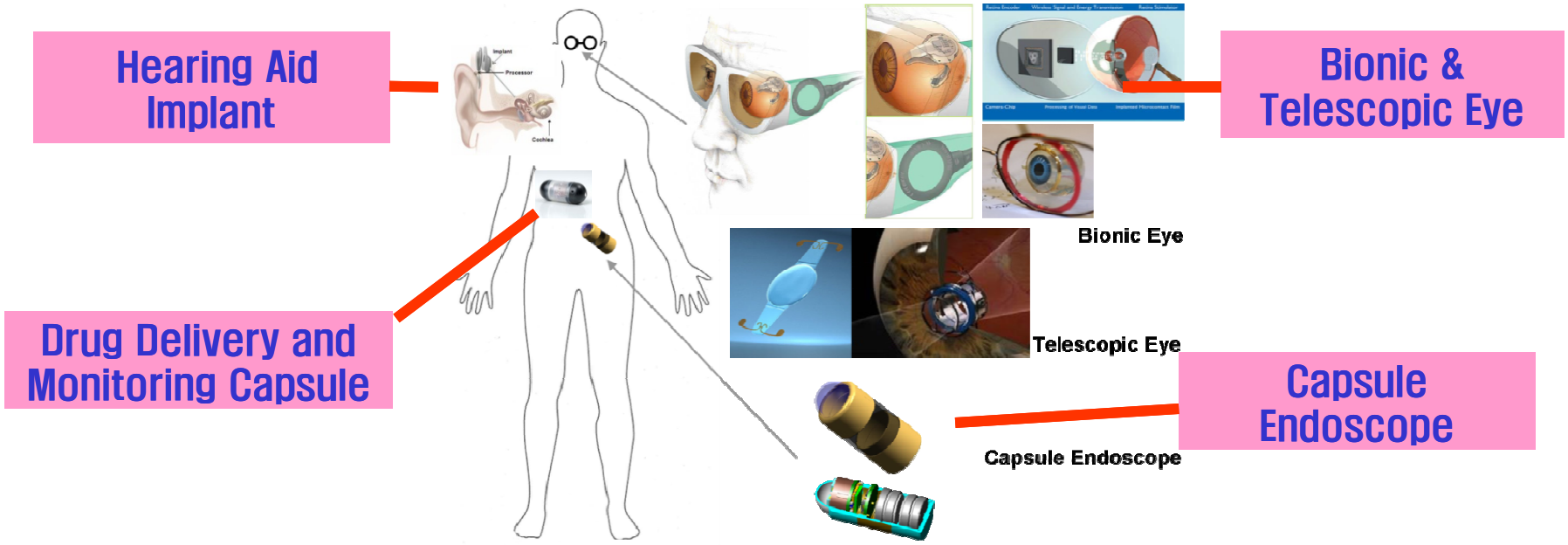
Abstract: This document presents PSSK for High-data-rate In-body WBAN.

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 2Mbps
  - 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 high-data-rate 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

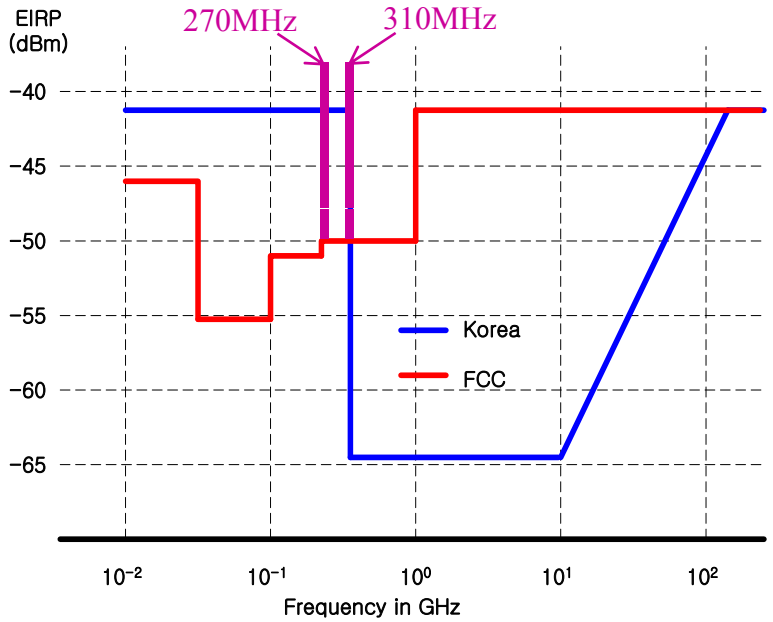
- Korea
  - Unlicensed general requirements

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×f(GHz) Max. 500	3	-84.35 + 20log(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



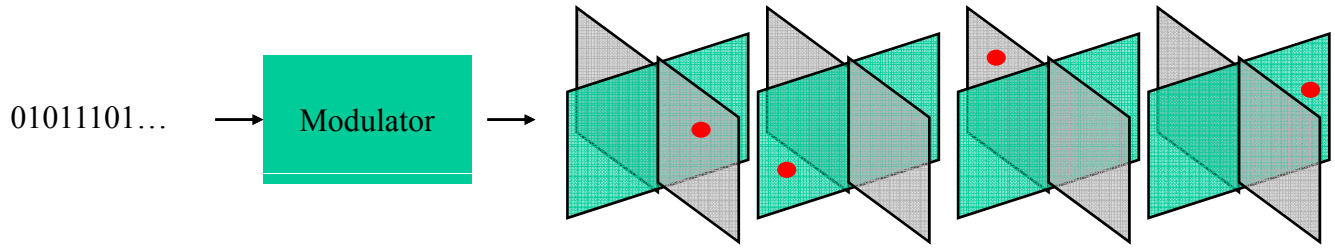
Trends of Wireless Implant Devices

- 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)
    - Power efficient, but they have low bandwidth efficiency
    - 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

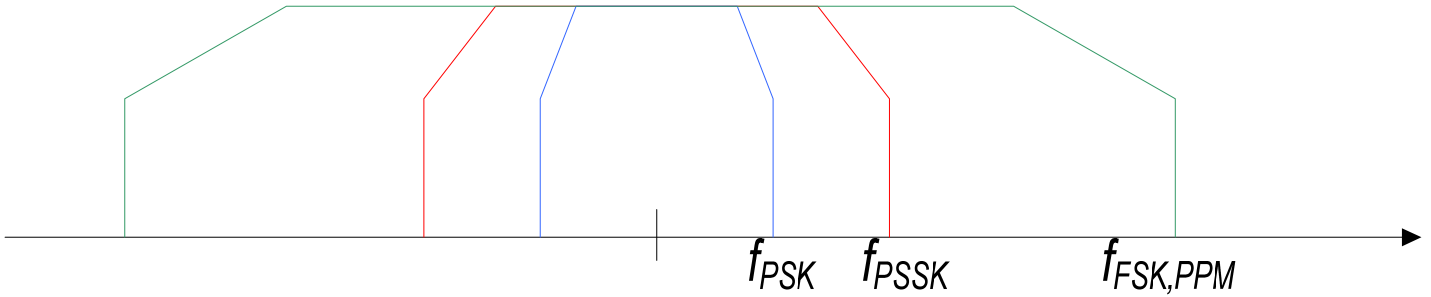
Proposed PHY for High-data-rate In-body Communication

- Design objective
  - Power efficient modulation
  - 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.



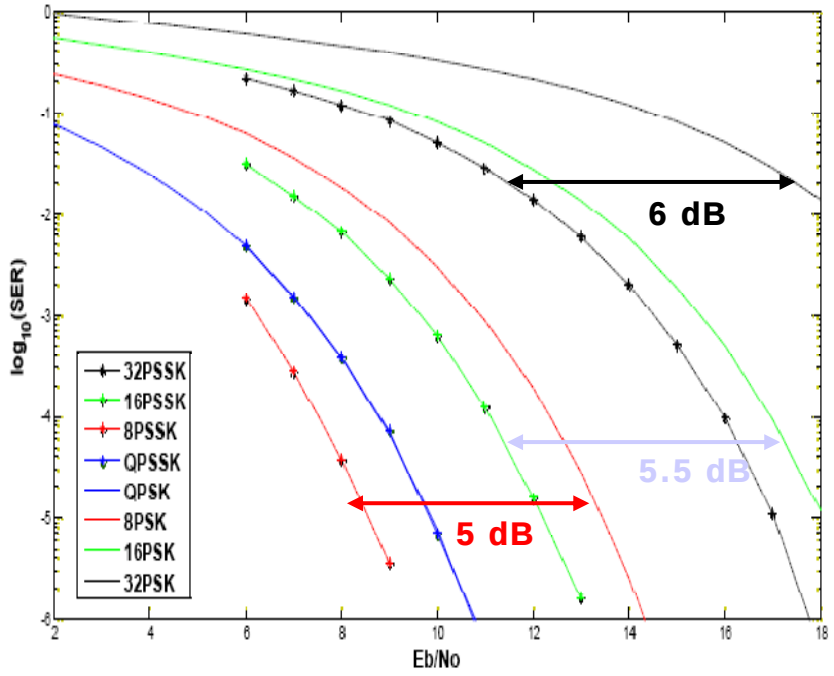
Comparisons of Modulations : Bandwidth

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



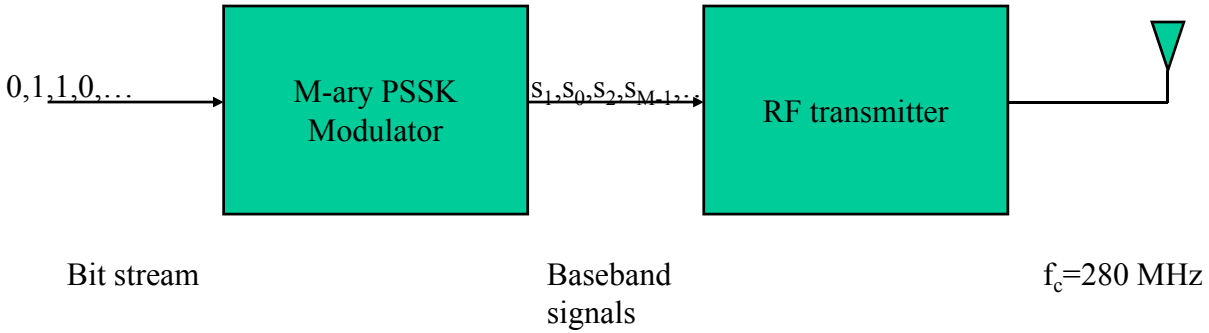
Comparisons of Modulations : Power

- 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

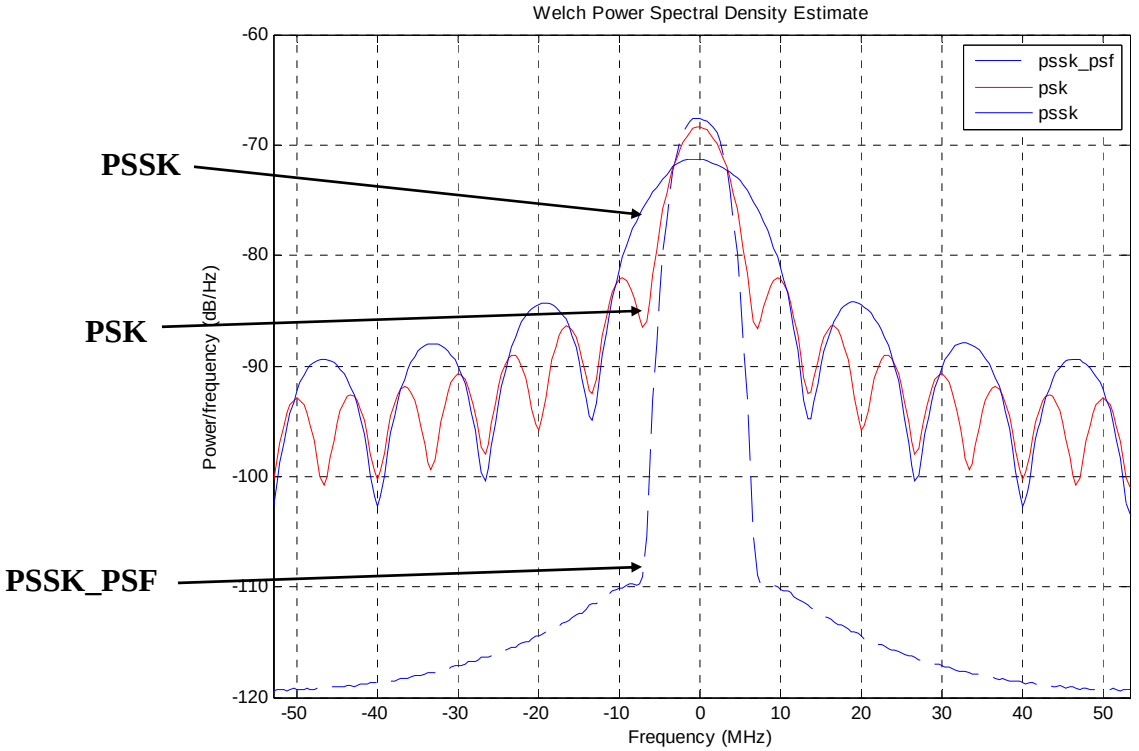
- PSSK Transmitter



- Data rate: 10 Mbps or 20 Mbps

Mode of Data-rate and Spectrum

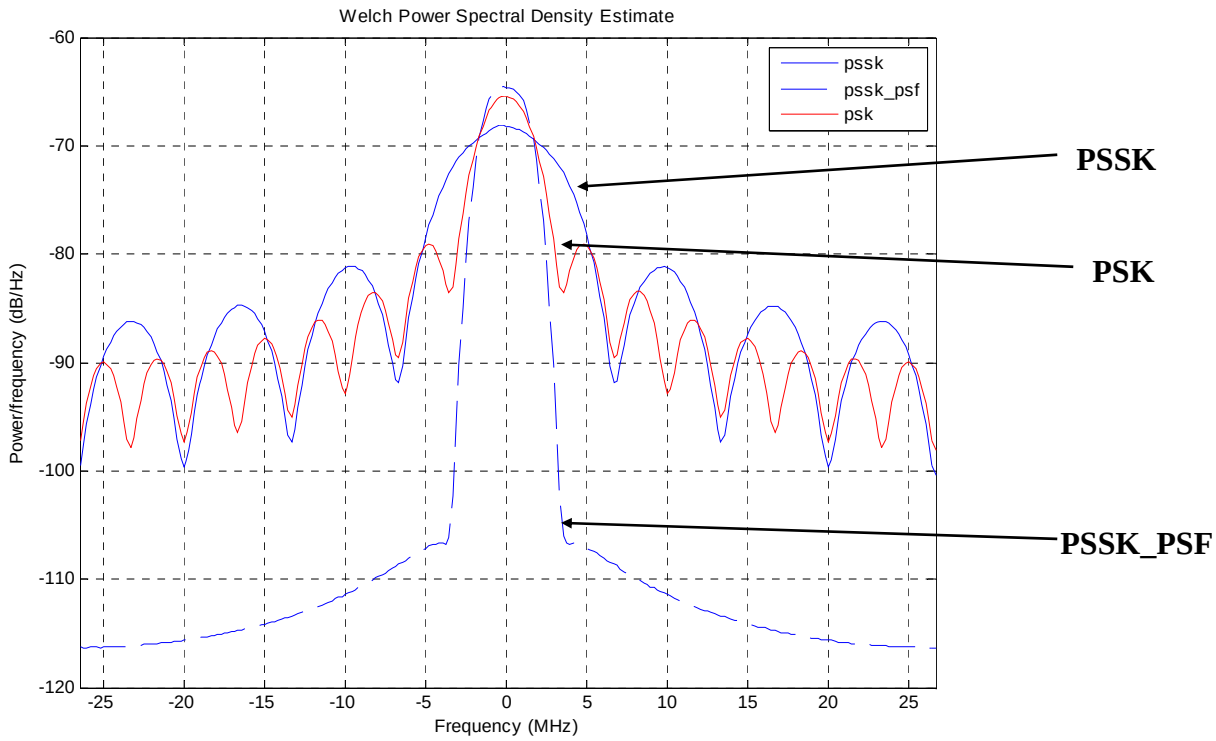
- 20 Mbps mode (8-ary PSSK)
  - 3 dB Bandwidth: 11.6 MHz / 5.8 MHz (without / with pulse-shaping)



20Mbps mode

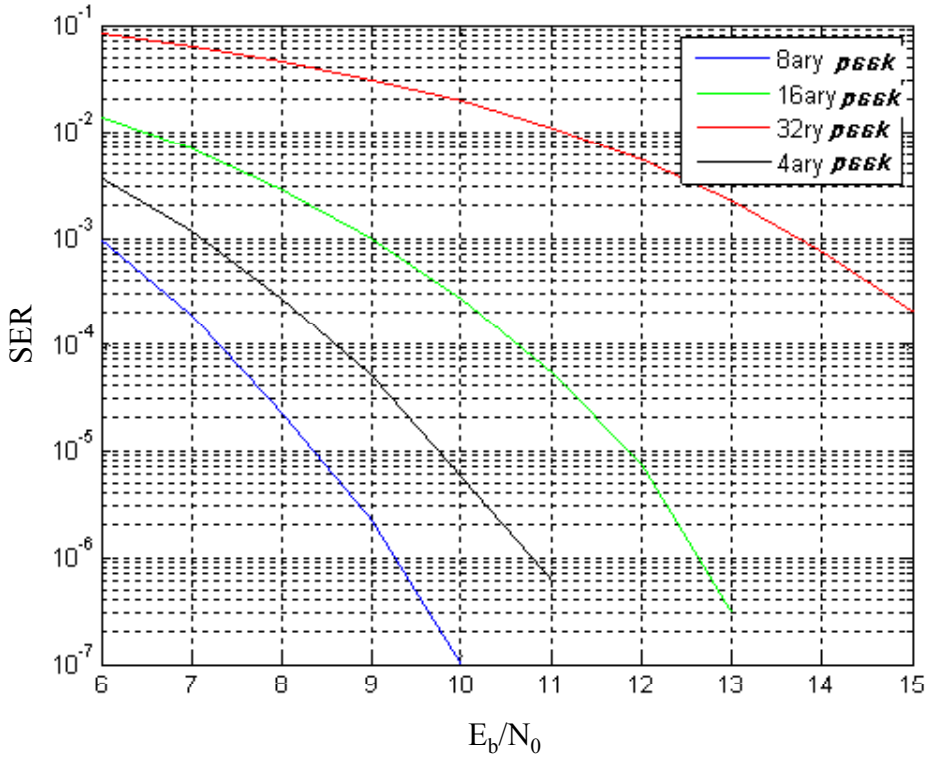
Mode of Data-rate and Spectrum

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



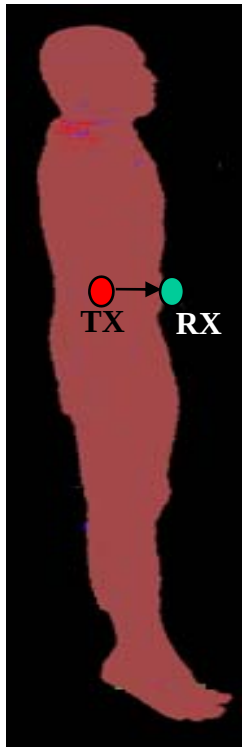
Reliability

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



Link Budget

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

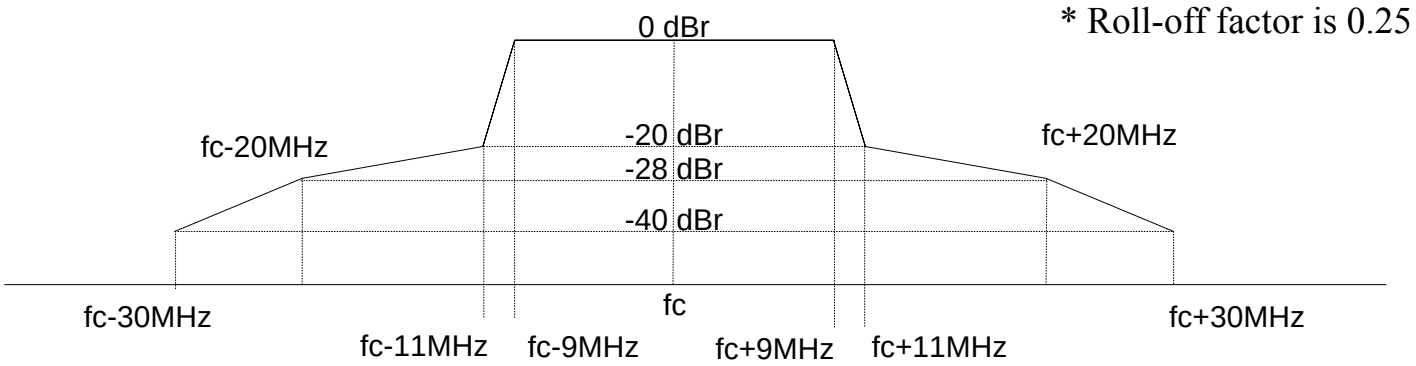


TX-to-RX Distance: 20 cm

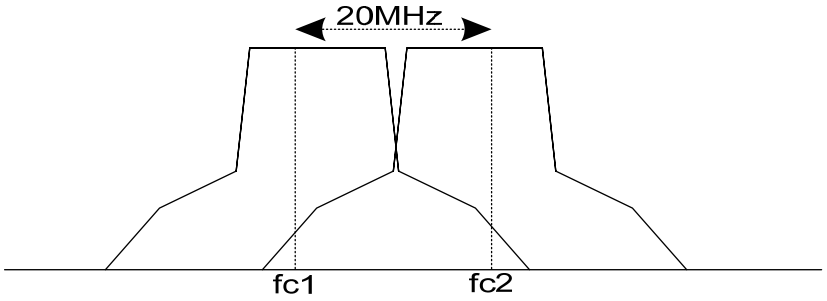
Parameters	Values (20Mbps)	Values (10Mbps)	Unit
Transmit Power	0	0	dBm
TX Antenna Gain	−10	−10	dBi
Body Attenuation	−65	−65	dB
RX Antenna Gain	0	0	dBi
Noise Figure	−5	−5	dB
Implementation Loss	−3	−3	dB
kTB noise	−106	−110	dB
SNR	23	27	
Link Margin	9	13	dB

Spectral Mask and Channelization

- Spectral mask



- Bandwidth per channel



Conclusion

- PSSK was proposed for high-data-rate WBAN PHY.
- PSSK Proposal summary
  - Data rate
  - Channel
  - Bandwidth
  - Link margin