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

Submission Title: Frequency band for in-body High Data Rate communication

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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 In-body High-data-rate standardization.

Requirement of HDR in-body WBAN

- Need for HDR (High Data Rate) in-body communication
  - Send high resolution images (minimum 10 Mbps)
  - Communication from the implanted device in the human body to the device on or around the human body for medical applications
- Usage for 10Mbps data rate
  - Transmission of non-compressive images
    - Data rate : determined by resolution, colors, frame rate
      - [640X640, 12bits, 4fps: 19.7Mbps], [800X800, 12bits, 2fps : 15.4Mbps], [640X640, 12bits, 2fps : 9.83Mbps]

Application for HDR in-body communication

- Present capsule endoscope systems
  - Image resolution : 320X320 pixels
  - Frame rate : 2-3 frame/sec

Product	**PillCam (SB/ESO/Colon)**	**EndoCapsule**	**MIRO**
Company	Given Imaging	Olympus	KIST
Frame rate	2/14/4 fps	2 fps	3 fps
Throughput	2.7 Mbps	not published	3.7 Mbps
Image Resolution	CMOS (256X256X20)	CCD	CMOS (320X320X12)

- Requirement for high resolution images
  - Modern wired endoscopes are equipped with HD CCD cameras, providing up to 30 fps at 1920X1080 pixels per frame
  - Require the zoomed image for the inspection of the suspicious area inside the human body

Considerations of frequency band for high-data-rate in-body WBAN (1)

- MICS (402~405 MHz)
  - Cannot support high data rate communication due to the BW (300 kHz/ch)
- ISM for North America (902~928 MHz)
  - 26 MHz for full bandwidth usage
  - Only for North America / Not available for Korea, Japan
  - Difficult to apply implant device due to the in-body path loss
- ISM for Worldwide (2400~2483 MHz)
  - Too large path loss due to the human body which is greater than 100 dB

Considerations of frequency band for high-data-rate in-body WBAN (2)

- Frequency band in March proposal : 270-310 MHz
  - Not available for the proposed band due to the restricted band
- Regulations for low-power, non-licensed band

	Frequency (MHz)	Electric field strength (uV/m)	Measuring distance (m)	EIRP (dBm)
Korea	~322MHz	500	3	-41.25
FCC	216~960MHz	200	3	-49.2

  - Restricted bands for the spurious emission only by FCC
    - 240~ 285 MHz, 322 ~ 335.4 MHz
  - Modified proposed frequency band for in-body high-data-rate communication
    - **285 ~ 322 MHz**

Link analysis for proposed band

- Max. Rx power (P_r)

$$P_r = P_t + G_t + G_r + PL = -109.8 \text{ dBm}$$

  - Transmit Power (Pt) : -49.2 dBm (EIRP of FCC)
  - Antenna Gain (G_t, G_r) : G_t = -10 dBi, G_r = 0 dBi
  - Path Loss (PL) : 50.5 (6 cm, CM2 Deep tissue)

- Receiver sensitivity (P_{min}) :

$$P_{\min} = N + NF + SNR + IL = -91 \text{ dBm} + SNR$$

  - Noise Floor (N) : -174+10log(10MHz)= -104 dBm
  - Noise Figure (NF) : 10 dB is achievable
  - Implementation Loss (IL) : 3 dB is normal

- Link margin(LM) : $LM = P_r - P_{\min} = -18.8 \text{ dBm} - SNR$

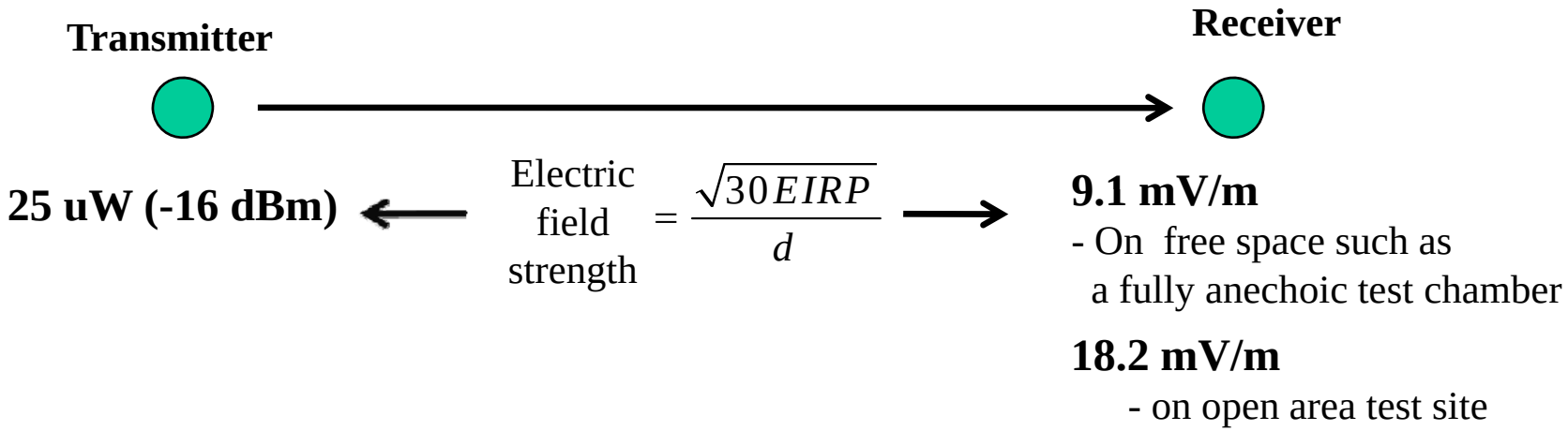
=> No link margin !!!

FCC rule for MICS (1)

- Maximum EIRP for MICS transmitter

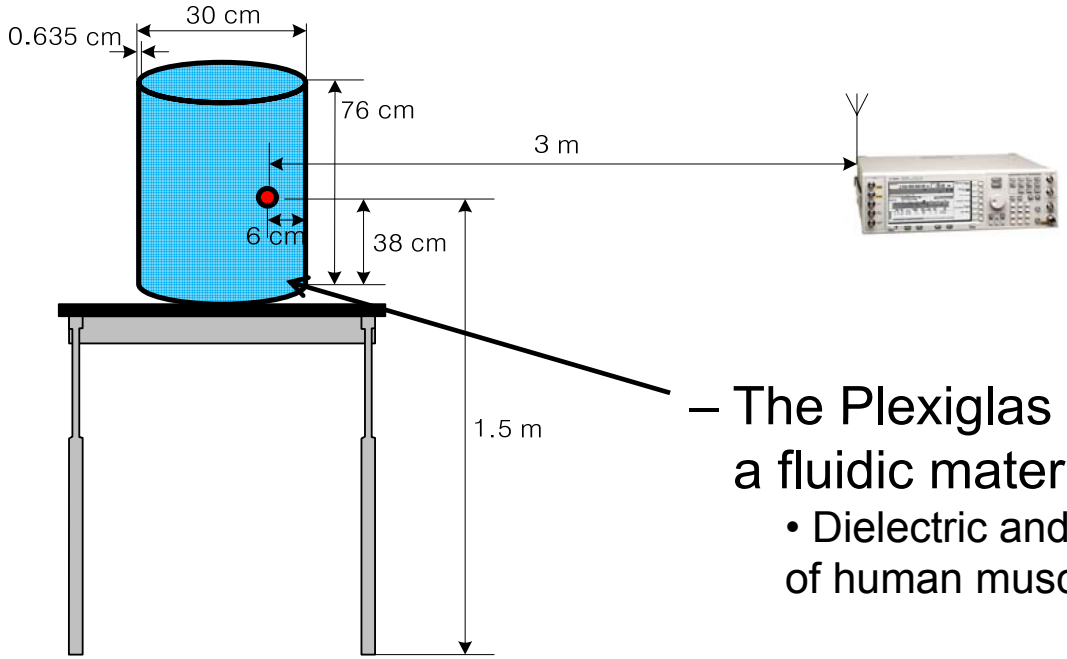
FCC Rule 95.639 (f)

Compliance of any MICS transmitter with the 25 microwatts EIRP limit may be determined by measuring the radiated field from the equipment under test at 3 meters and calculating the EIRP



FCC rule for MICS (2)

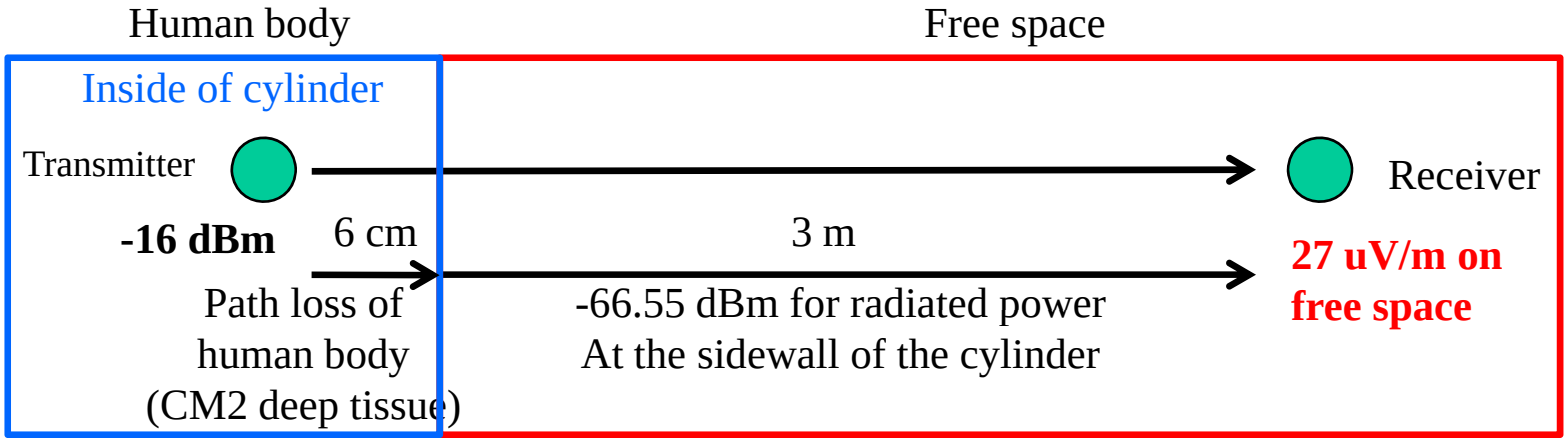
- Test fixture for implant devices (FCC Rule 95.639(f))
  - Consider environment of a human body
  - Use to simulate operation of the implant under actual operating conditions



- The Plexiglas filled with a fluidic material
  - Dielectric and conductivity properties of human muscle tissue at 403.5 Mhz

Consideration for proposed band

- Test fixture for the proposed band
  - Use the test fixture same as MICS by FCC for implant device
  - Maximum electric field strength at receiver side : 200 uV/m
  - Apply transmit power of MICS for the safety of human body : -16 dBm



- Measurement of the electric field at 3m
  - Satisfy the regulation of 285-322 MHz : < 200 uV/m
  - Not enough receiver sensitivity for signal detection due to excessive path loss
    - The location of the receiver should be on skin for reliable communication

Link budget analysis

- Max. Rx power (P_r)

$$P_r = P_t + G_t + G_r + PL = -76.5 \text{ dBm}$$

  - Transmit Power (P_t) : -16 dBm
    - Antenna Gain (G_t, G_r) : G_t = -10 dBi, G_r = 0 dBi
    - Path Loss (PL) : 50.5 (6 cm, CM2 Deep tissue)
- Receiver sensitivity (P_{min}) :

$$P_{\min} = N + NF + SNR + IL = -82 \text{ dBm}$$

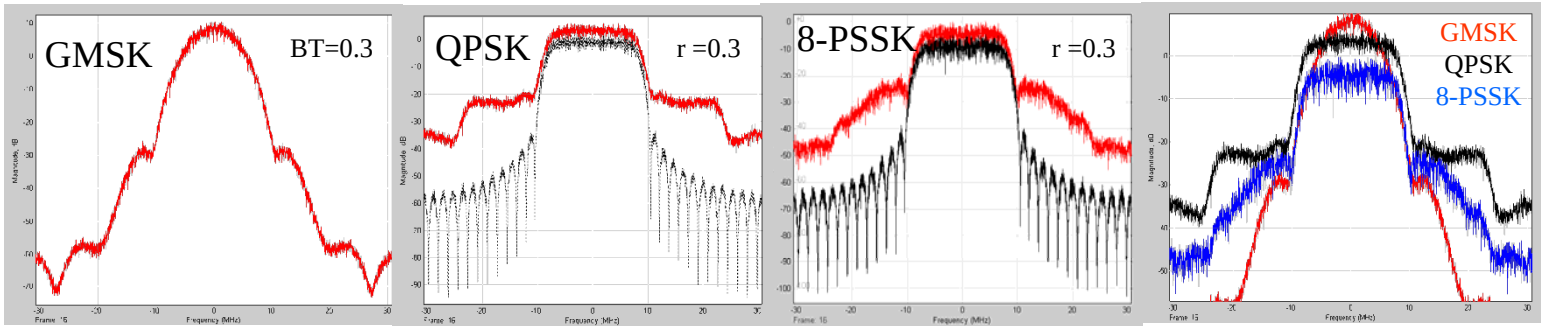
  - Noise Floor (N) : -174+10log(10MHz)= -104 dBm
  - Noise Figure (NF) : 10 dB is achievable
  - Minimum SNR (SNR) : 7.8 dB (BER 10^{-6})
  - Implementation Loss (IL) : 3 dB is nomal
- Link margin(LM) :

$$LM = P_r - P_{\min} = 5.5 \text{ dB}$$

Modulation

- Comparison between 8PSSK and conventional modulations

Modulations	8PSK	QPSK	OQPSK	(G)MSK
Back-off gain (r=0.3)	1.5 dB	1.5 dB	0 dB	-1.5 dB
Power gain	3 dB	3 dB	3 dB	3 dB
Bandwidth gain	-3 dB	-1.25 dB	-1.25 dB	0 dB
Performance gain	5.4 dB	1.5 dB	1.5 dB	1.5 dB
Total gain	6.9 dB	4.75 dB	3.25 dB	3 dB



Conclusions

- Frequency bandwidth allocation
  - 285~322 MHz with 2 channels (18.5MHz/1ch)
  - Test fixture : same condition as MICS
- Suggested modulation
  - Propose 8 PSSK modulation for in-body high data rate communications
  - Apply to in-body communication from device in human body to device on skin to meet sensitivity level