IEEE MTT-S International Microwave Biomedical Conference, September 11th - 13th, 2023, KULEUVEN

Norwegian University of Science and Technology

Oslo University Hospital

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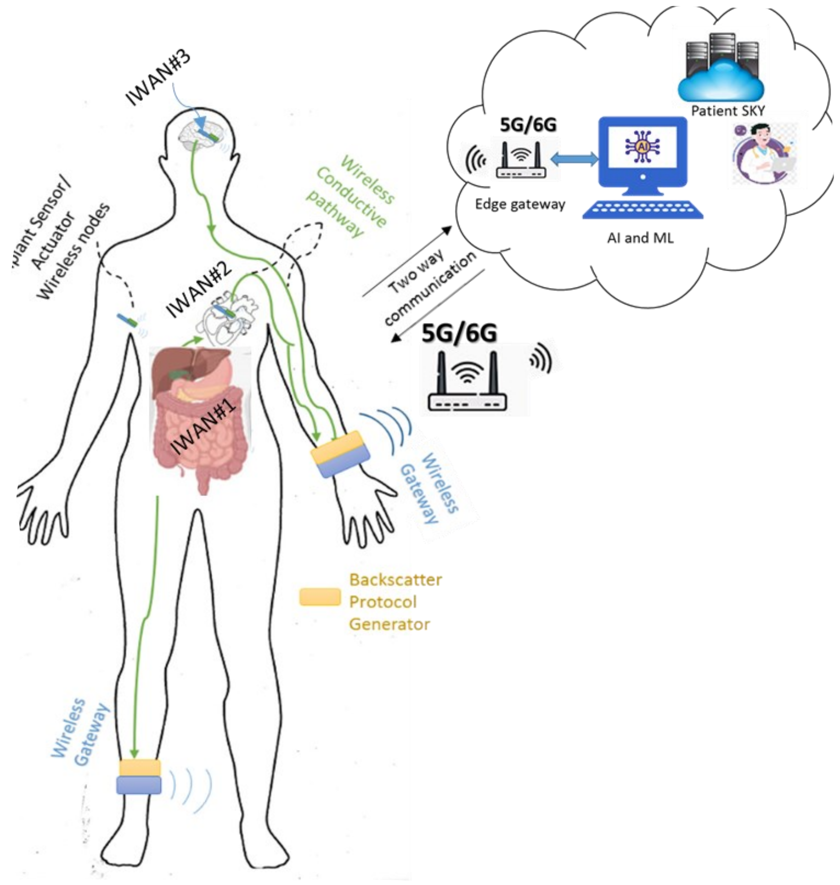
Design and Implementation of a Hybrid Wireless Power and Communication System for Medical Implants

Ali Khaleghi,

Ali.khaleghi@ntnu.no

Wireless Healthcare Devices



- **Wearables:**
  - Continuous health monitoring.
  - Remote patient monitoring.
  - Personalized healthcare insights.
- **Implants:**
  - Constant data collection from within the body.
  - Chronic disease management.
  - Timely interventions and emergency alerts.
- **Advantages:**
  - Seamless connectivity for data transmission.
  - Enhanced patient experience and compliance.
  - Remote accessibility for healthcare providers.
- **Future Trends:**
  - Integration with IoT and AI.
  - Identifying patterns and predicting health risks.
  - Harnessing the power of 5G and beyond.
  - Advancements in nanotechnology for innovative implants.

Toward Human Digital Twin in Healthcare

Human Interface Technologies:
Focus on designing user-friendly interfaces for efficient human-machine interaction

IoT and Wearables:
IoT devices, wearables, and implant sensors provide real-time health data, optimizing personalized care.

Virtual Reality (VR):
VR applications enhance medical training and patient education, transforming the healthcare experience.

Telemedicine Revolution:
High bandwidth and low latency empower telemedicine for remote consultations and monitoring.

AI and Machine Learning:
AI-driven algorithms assist in diagnostics and treatment planning.

Advanced Healthcare Ecosystem:
Integration of 5G, 6G enables seamless connectivity between humans and machines in healthcare.

Application of Implantable Sensor-actuation Technology

CARDIAC
PACEMAKERS, IMPLANT ECGS, ACCELEROMETER, ICDS

NEURAL
NEUROSTIMULATORS FOR PAIN, BRAIN SENSING, BMI

MUSCULOSKELETAL
ORTHOPEDIC IMPLANTS AND SENSORS

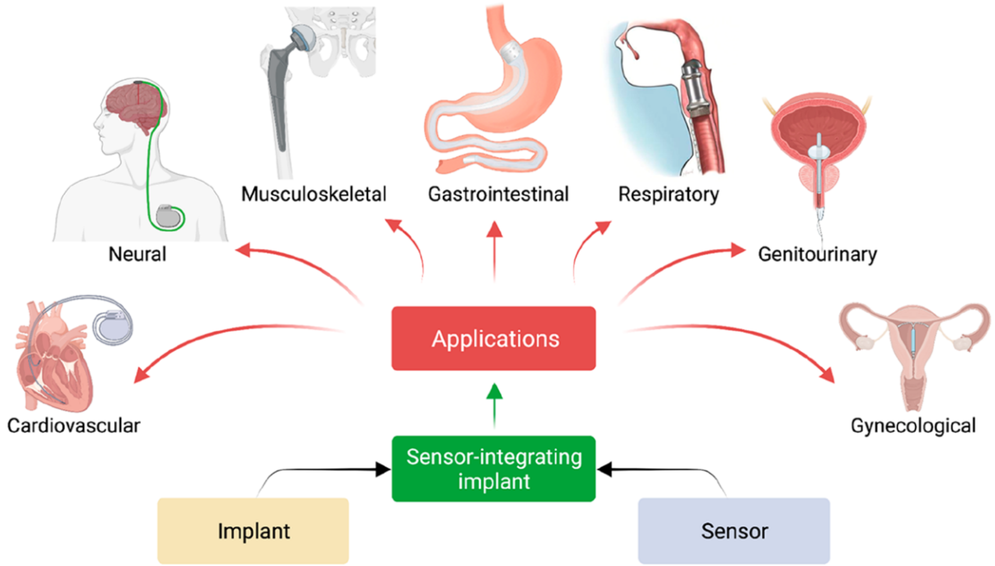
GASTRIC
BLEEDING SENSORS, IMAGING,

HEARING AID
COCHLEAR IMPLANTS

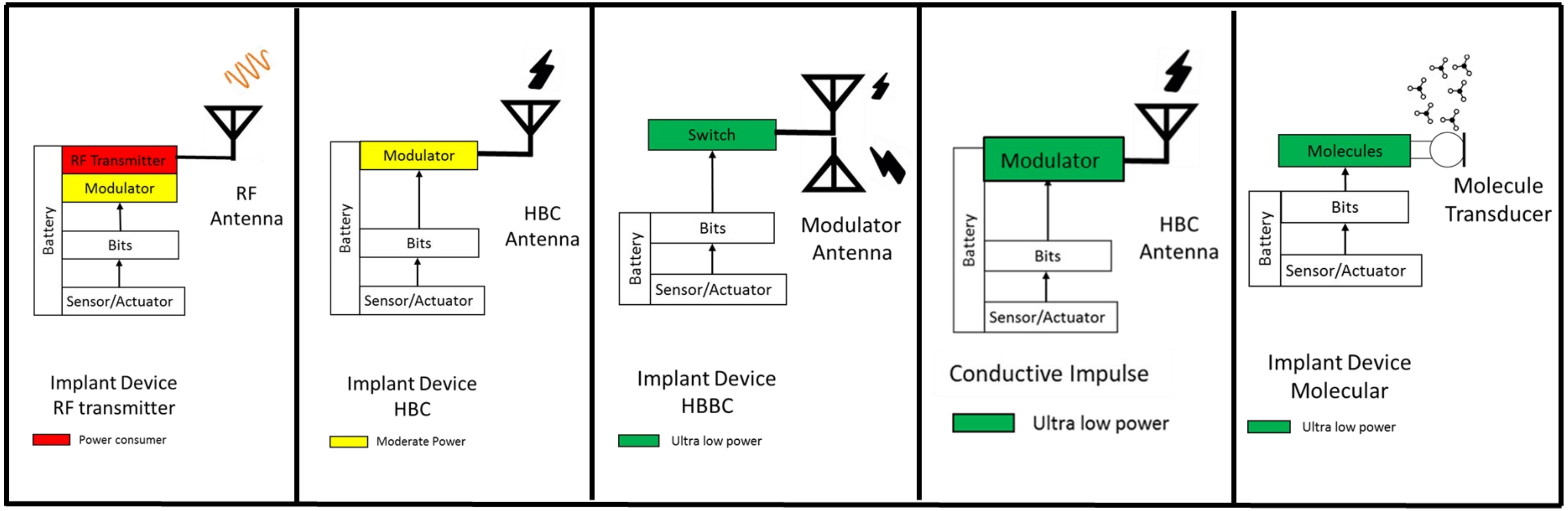
VISUAL
RETINAL IMPLANTS

DRUG DELIVERY:
DRUG PUMPS TARGETED DRUG DELIVERY, GLUCOSE SENSORS

PRESSURE:
IMPLANTABLE BLADDER CONTROL, INTRACRANIAL PRESSURE FOR BRAIN INJURIES



Realizing Battery-Free Intra-body, and Implant to On-body Systems

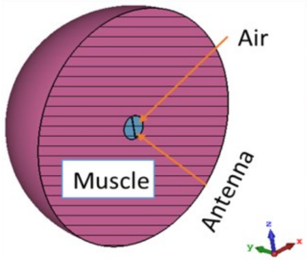


Merge <u>Radio-Frequency, Wireless backscatter, and Conductive Impulse</u> as a hybrid system for battery-free communication and sensing

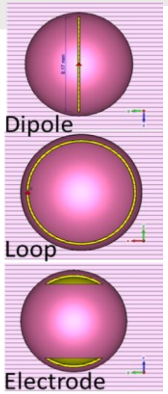
Antenna forms in Tissues for RF range

Muscle embedded antenna

- Dipole
- Loop
- Electrode with a capacitive gap

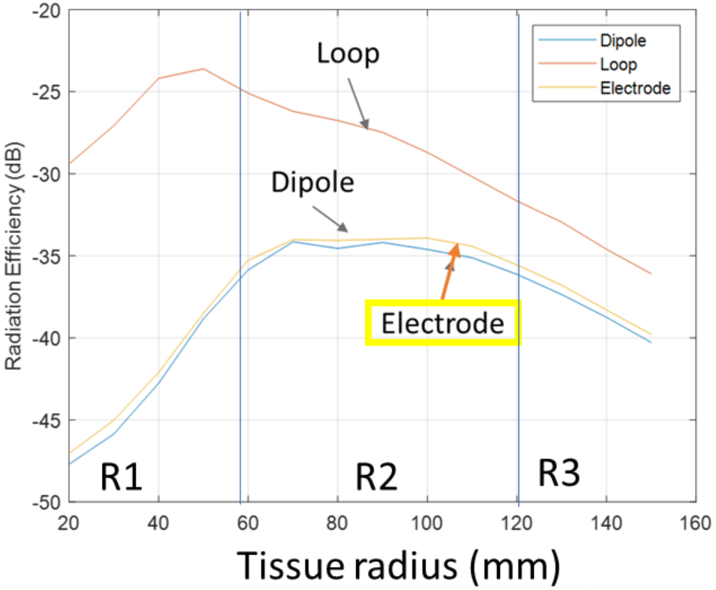


Gap to the muscle 0.5 mm (all scenarios)
Material: Lossy Al wire σ=3.56×10^{7}
Wire diameter: 0.2 mm



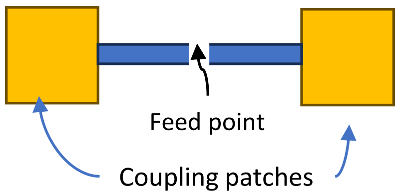
Antenna	Z (Ω)	eff. (dB), 403MHz	SAR (10g) W/Kg	Q-factor	10 dB BW (MHz)
Dipole (air)	**0.057-j 8296**	**-3.37**	-	-	-
Dipole (Muscle)	9.9- j7609	-34.8	26.6	806	0.35 MHZ
Loop (air)	0.34+j60	-28	-	-	-
Loop (Muscle)	0.85+j 60	-28.6	7	72	3.5 MHz
CCEA	30+j0	-34.5	47.5	1.3	100 MHz

For any given size of implant and depth, an optimum frequency governs maximum power efficiency.



A. Khaleghi and I. Balasingham, "Capacitively Coupled Electrode Antenna: A Practical Solution for Biomedical Implants," 2021 15th European Conference on Antennas and Propagation (EuCAP), Dusseldorf, Germany, 2021, pp. 1-5, doi: 10.23919/EuCAP51087.2021.9411050.

Simulation Model

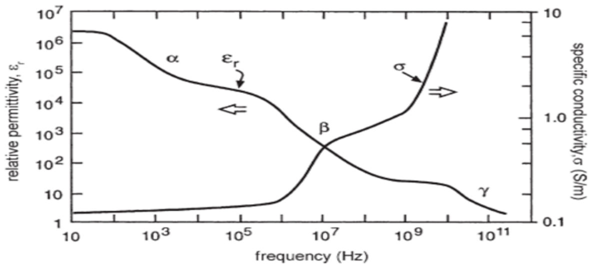


On-body antenna
(Patch loaded dipole)

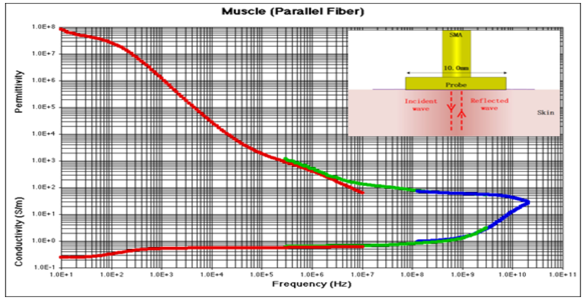
Gap loaded electrodes

Capsule implant

Antenna models



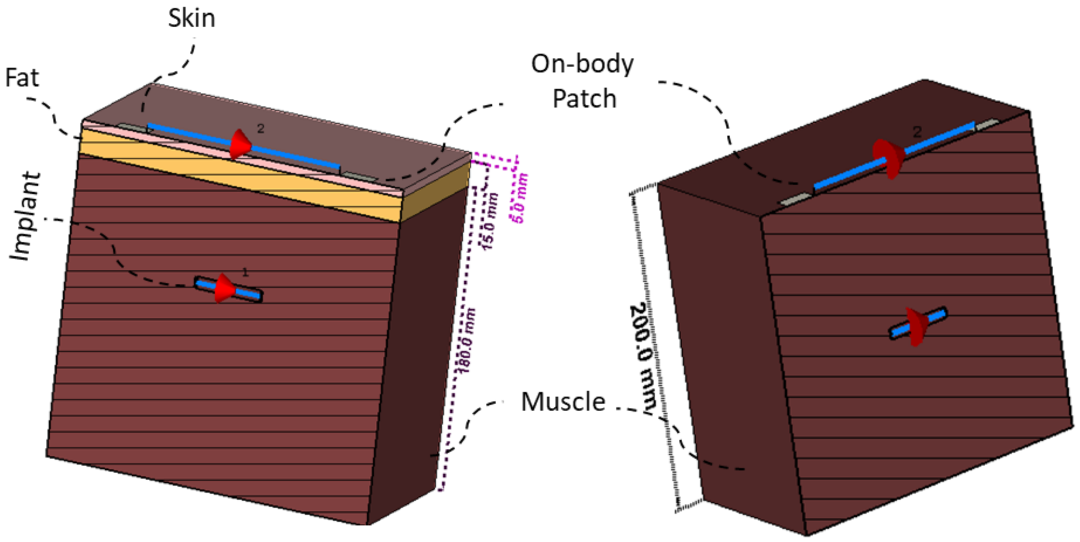
Different dispersions exhibited by biological tissues across a wide range of frequencies



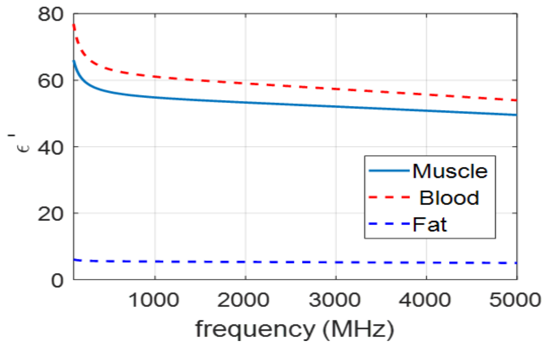
http://niremf.ifac.cnr.it/docs/DIELECTRIC/Report.html

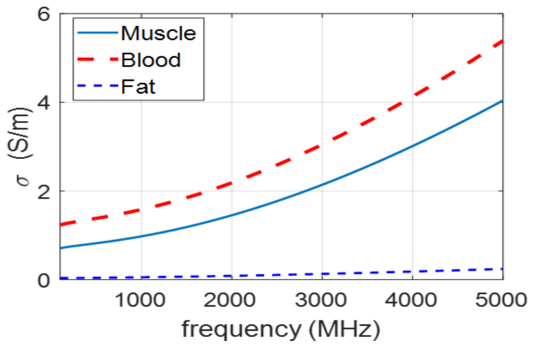
Gabriel *et al 1996, 4-Cole-Cole model*

$$\varepsilon_r(\omega) = \varepsilon_\infty + \sum_{n=1}^{4} \frac{\Delta\varepsilon_n}{1 + (i\omega\tau_n)^{1-\alpha_n}} + \frac{\sigma_i}{i\omega\varepsilon_0}$$



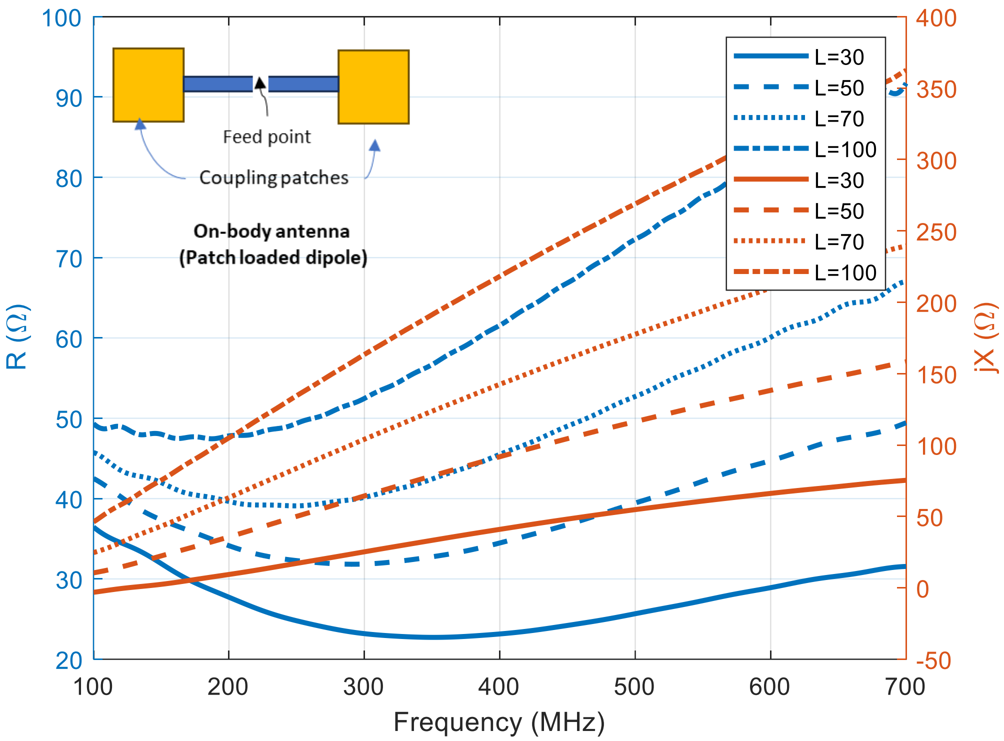
RF link modeling



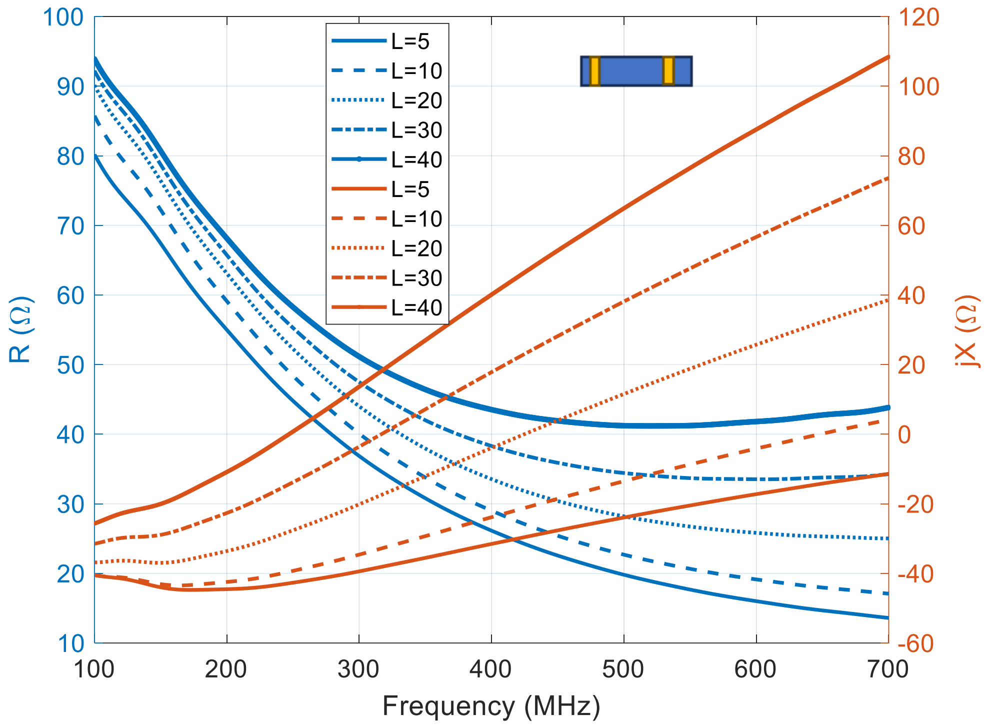


Tissue properties modeling

Impedance of Implant and Wearable Antennas

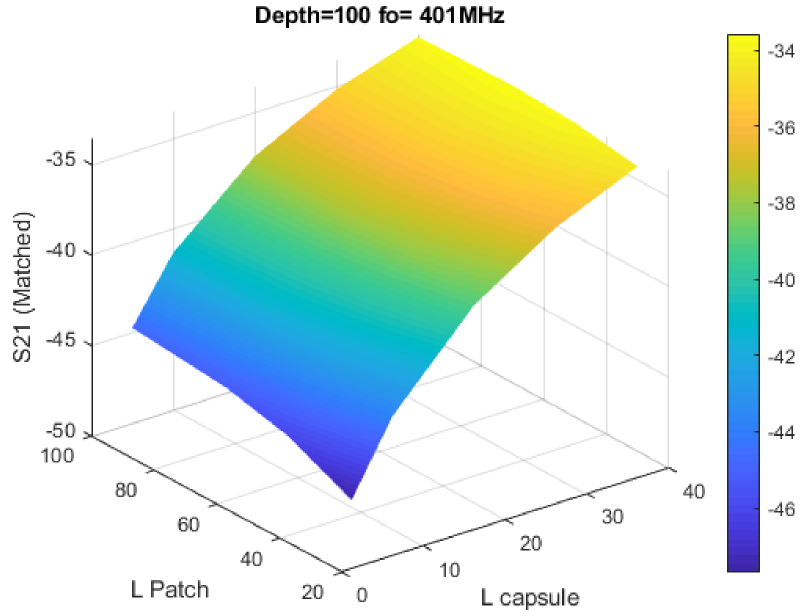


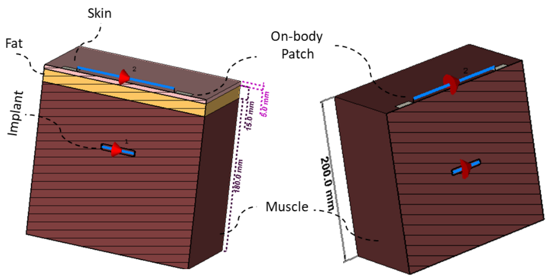
Impedance of on-body patch in contact with muscle tissue versus frequency for different patch sizes

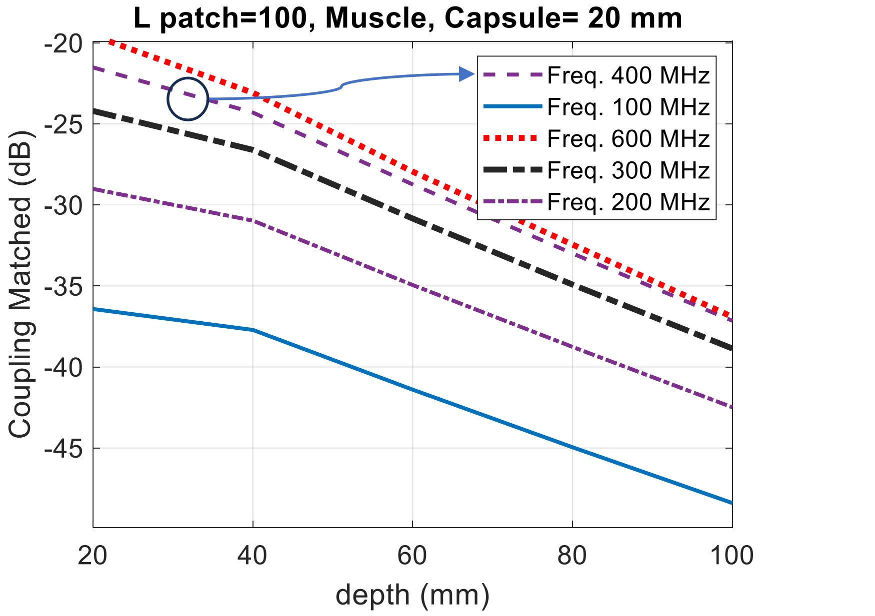


Calculated implant antenna impedance in muscle tissue for different implant lengths, L=5, 10, 20, 30, 40 mm

Power Coupling Between Wearable and Implant Antenna in Muscle Tissue





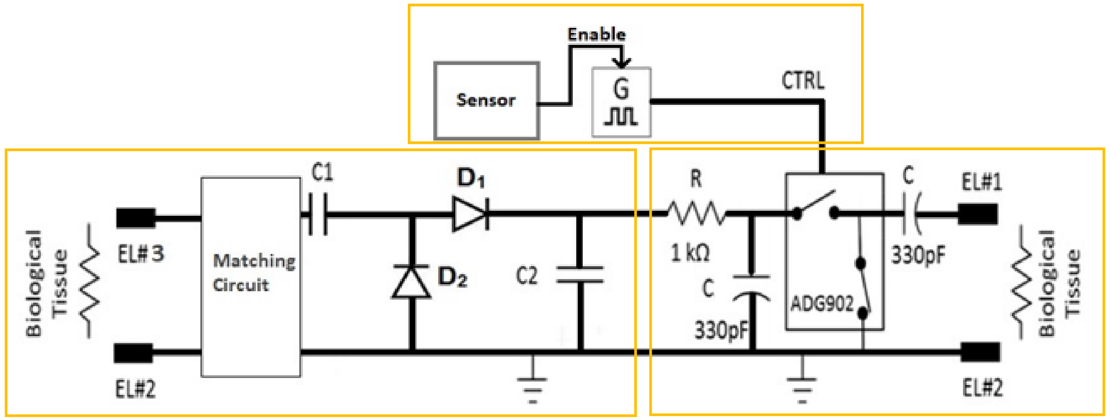


Coupling factor at depth 100 mm versus capsule size and on-body size

Coupling factor between on-body (**Length=100 mm**) and implant (**capsule size 20 mm**) depth and frequency

Wireless Powering Circuit with RF

Data source



RF energy harvesting
And backscatter load
modulation

Conductive impulse

Implant electronics

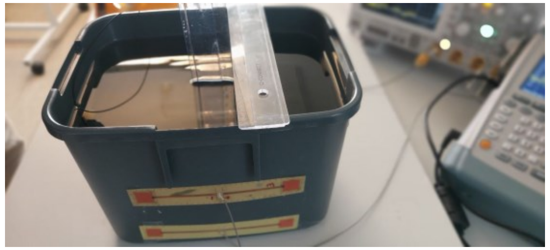
Osciloscope

Specrum analyzer

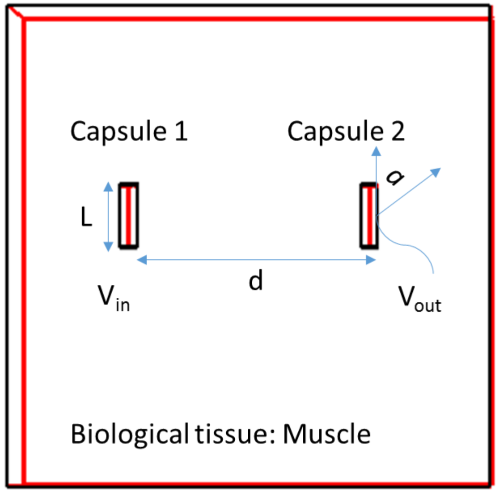
RF generator

Main hub capsule

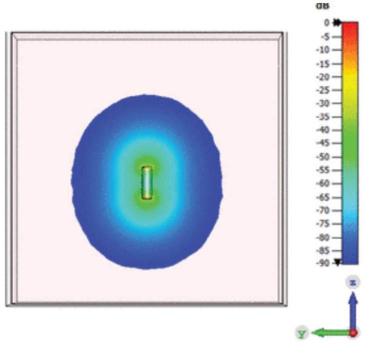
Secondary
galvanic implant

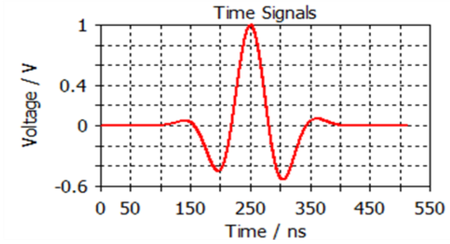


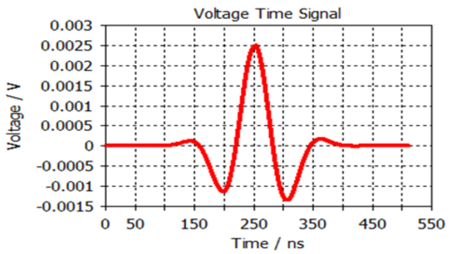
Conductive Impulse Connectivity

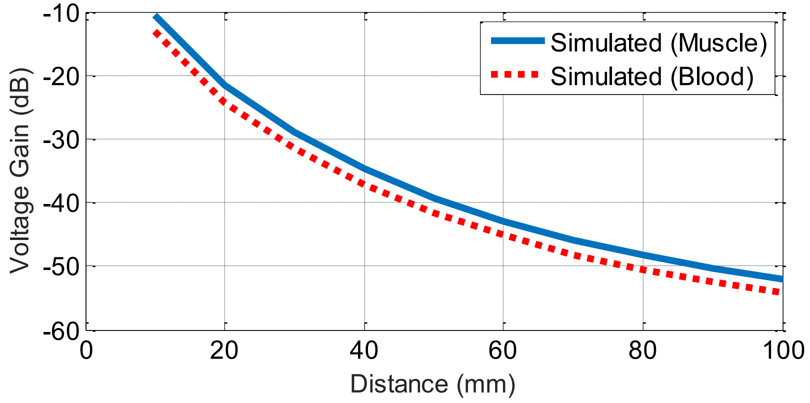


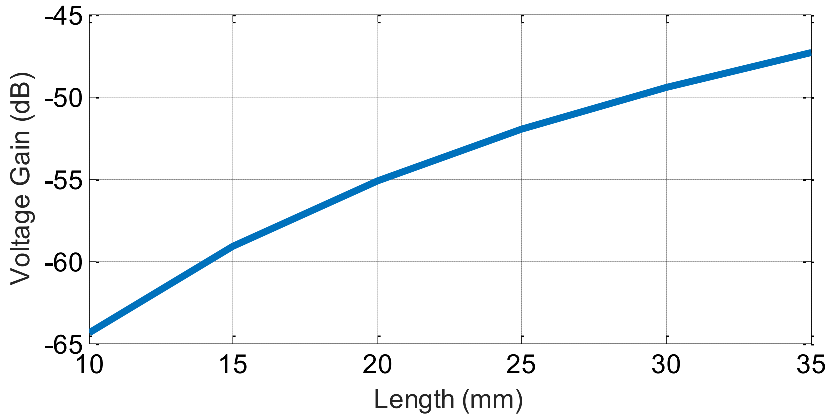
Conductive link modeling in homogenous muscle model



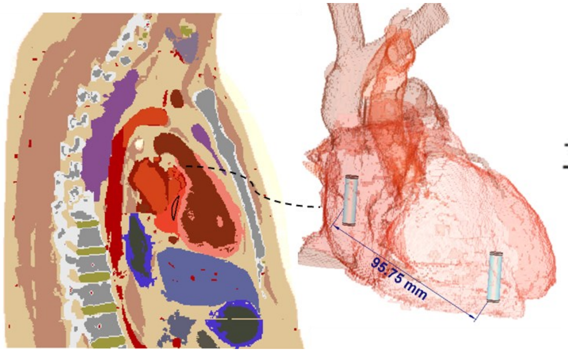


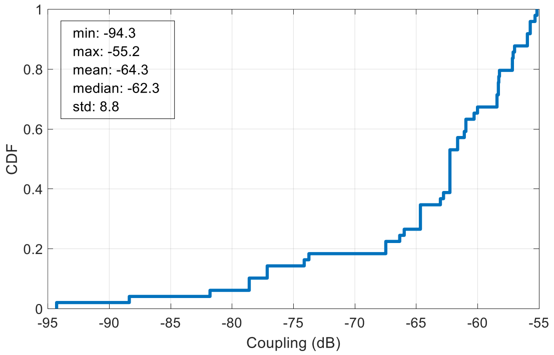


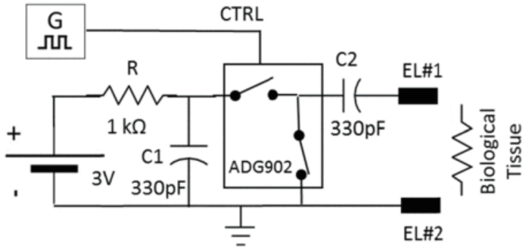




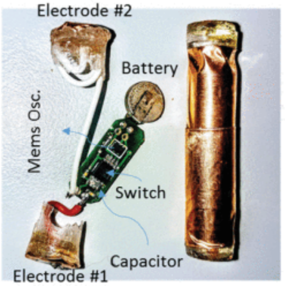
Measurement and Modeling of Conductive Impulse



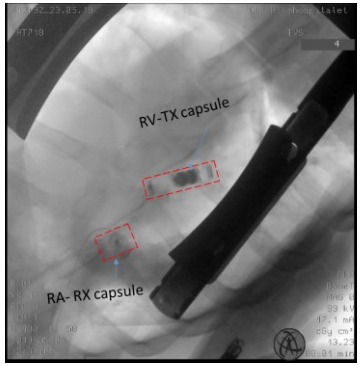


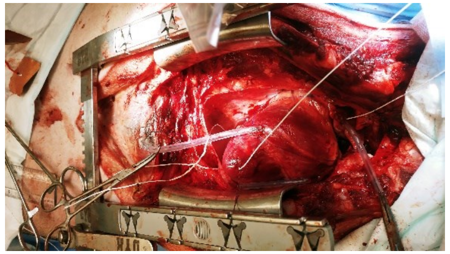


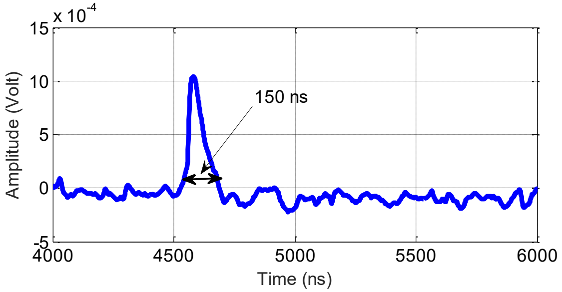
(a)



(b)



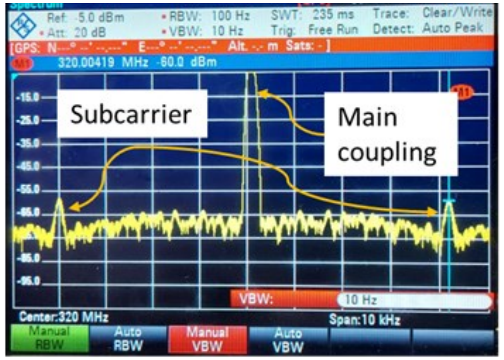


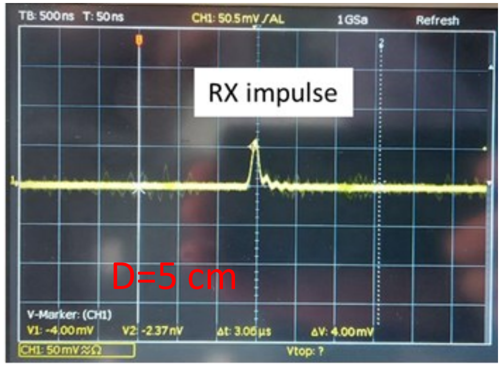


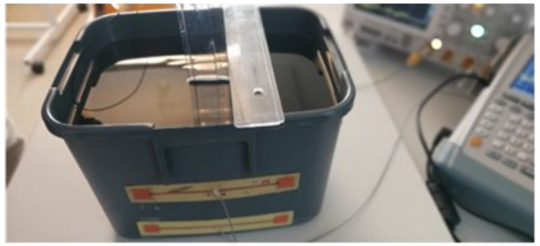
Measured pulse shape at d=7cm of the transmitter inside cardiac RV

A. Khaleghi, R. Noormohammadi and I. Balasingham, "Conductive Impulse for Wireless Communication in Dual-Chamber Leadless Pacemakers," in IEEE Transactions on Microwave Theory and Techniques, vol. 69, no. 1, pp. 443-451, Jan. 2021, doi: 10.1109/TMTT.2020.3038782.

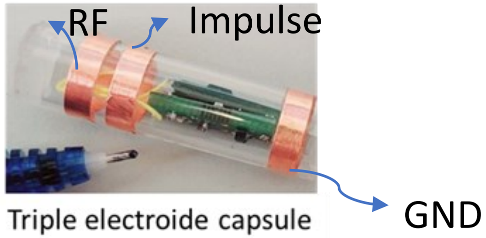
Modulated Backscatter with RF and Impulse Intra body Connectivity





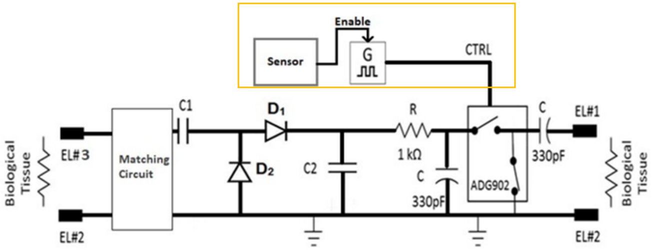


Bi-static radar antennas and test phantom

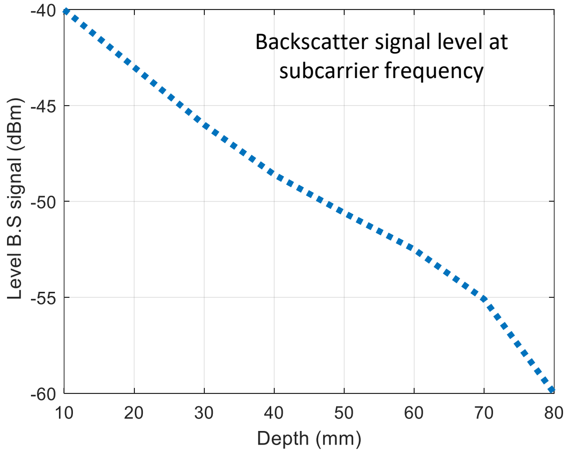


Triple electroide capsule

Data source

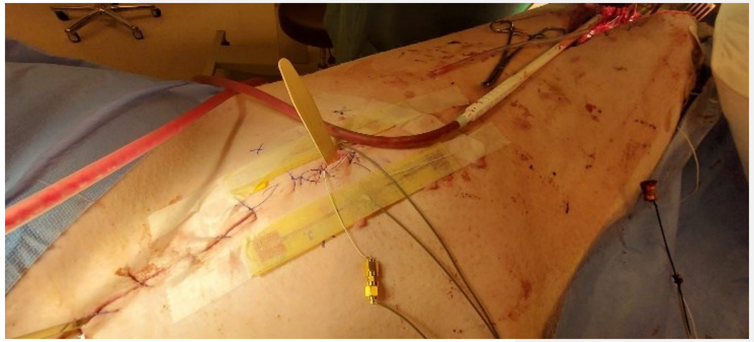


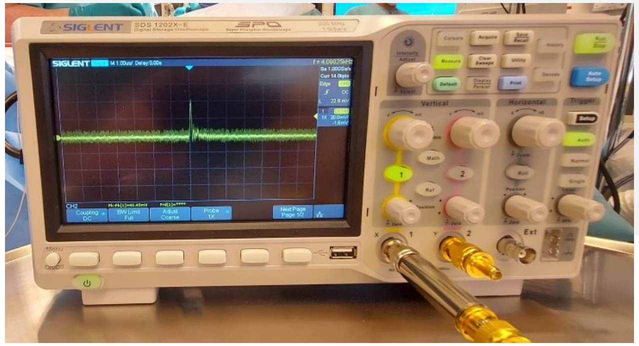
RF backscatter load modulation



Measured Backscatter RF signal level for P_{TX}=25 dBm P_{RX}= -10 dBm (100 micro watts, d=80mm)

Animal Experiment: Hybrid WPT, Backscatter and Impulse Connectivity





Impulse transfer between two implants (intra body link) powered by RF

RF Backscatter detected on the body

Depth: 8 cm

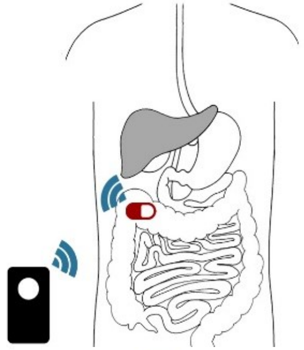
Battery-free Implants empowered by Wireless Communications

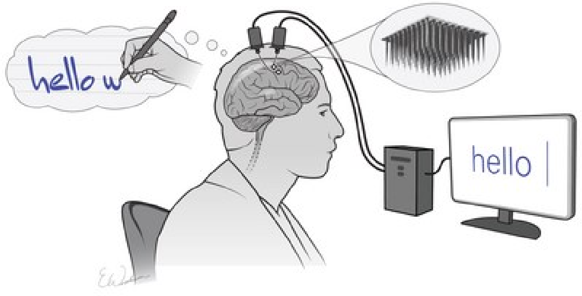
High data rate sensors

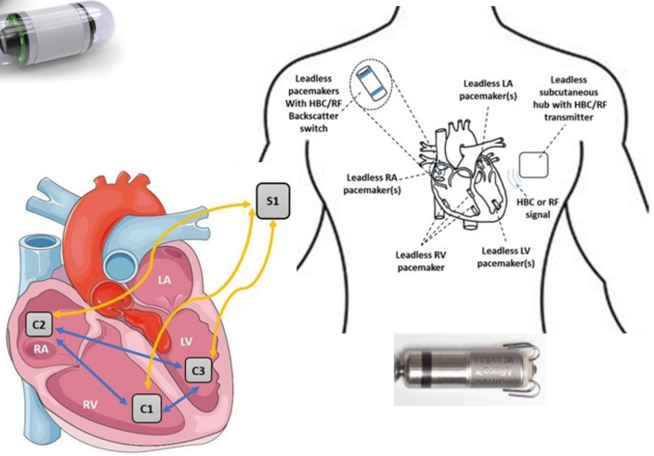
- Wireless video capsule endoscopy (WCE)
- Wireless Brain-machine Interface (BMI)

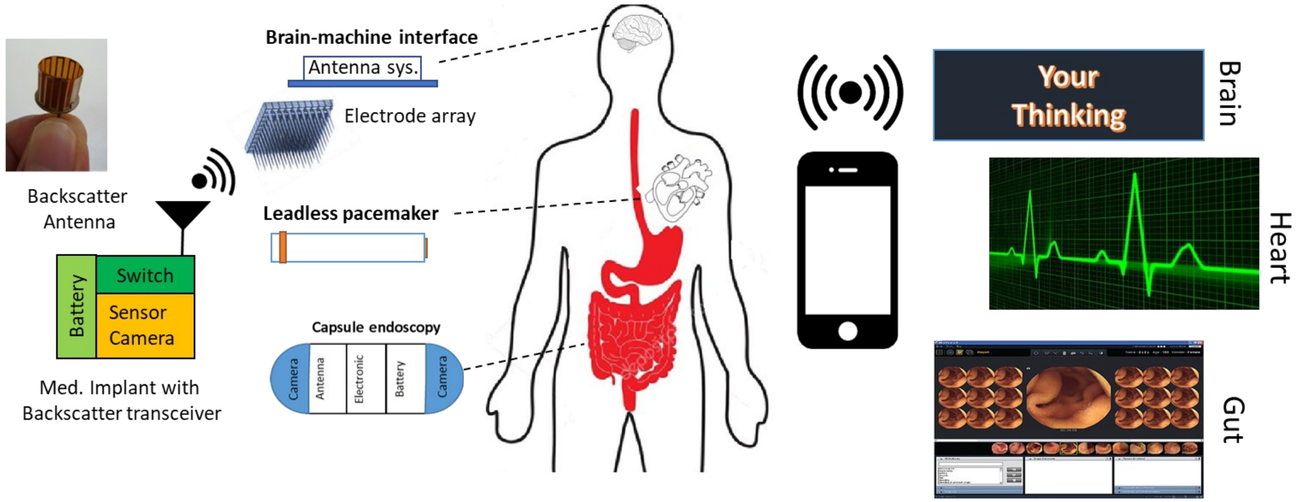
Low to moderate rate sensors

- Multi-chamber cardiac pacemaker capsules
- Biological chemical sensors









Battery-less Communication Solutions for Medical Implants

Conclusion

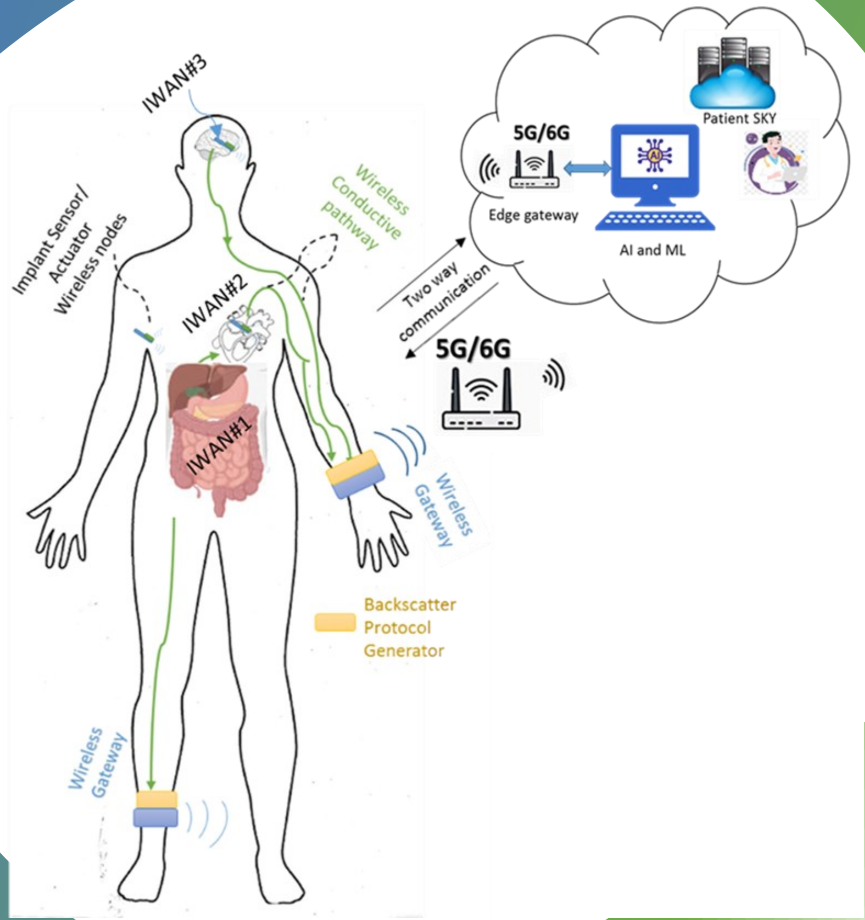
Dual Channels: Uses RF backscatter and galvanic links for diverse communication.

Efficiency & Depth: Operates at 401 MHz, effective up to 8.5 cm inside the body.

Compact Design: Utilizes small antennas optimized for efficiency.

Battery-Free: Operates without an implant battery, using near-zero power.

Scalability: Supports multi-node implant connectivity.



Thanks for Your Attention