Medical Applications of MHz to Sub-THz Waves

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Healthcare-Future

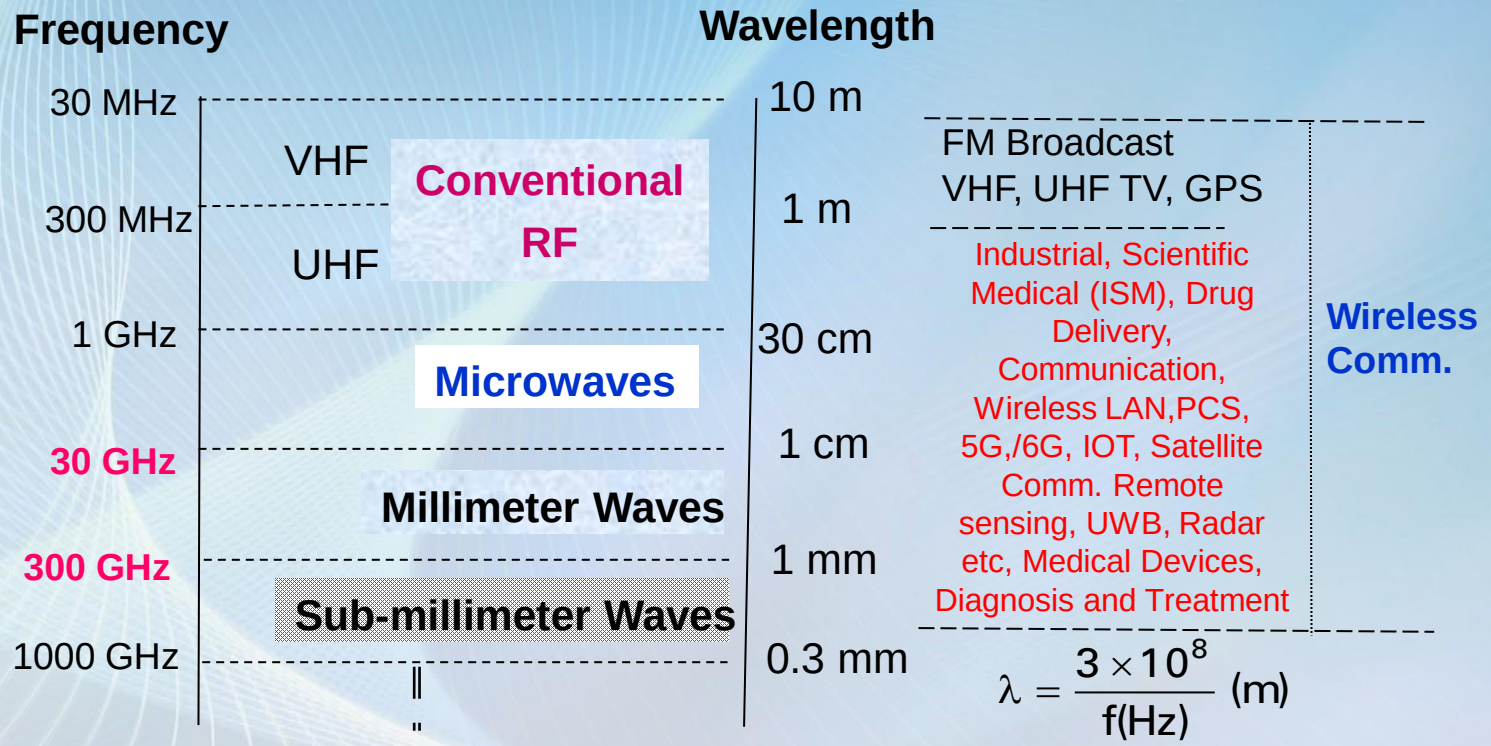
Wealth is not Health

Health is Wealth

- More Stressful Lifestyle
- Extremely Large Number of Patients
- Need to learn from New Medical Threats
- Non-invasive Diagnostic procedures Required
- Targeted Drug Delivery Systems Required
- Need for Remote/Self Medical Assistance
- Reduction in medical costs

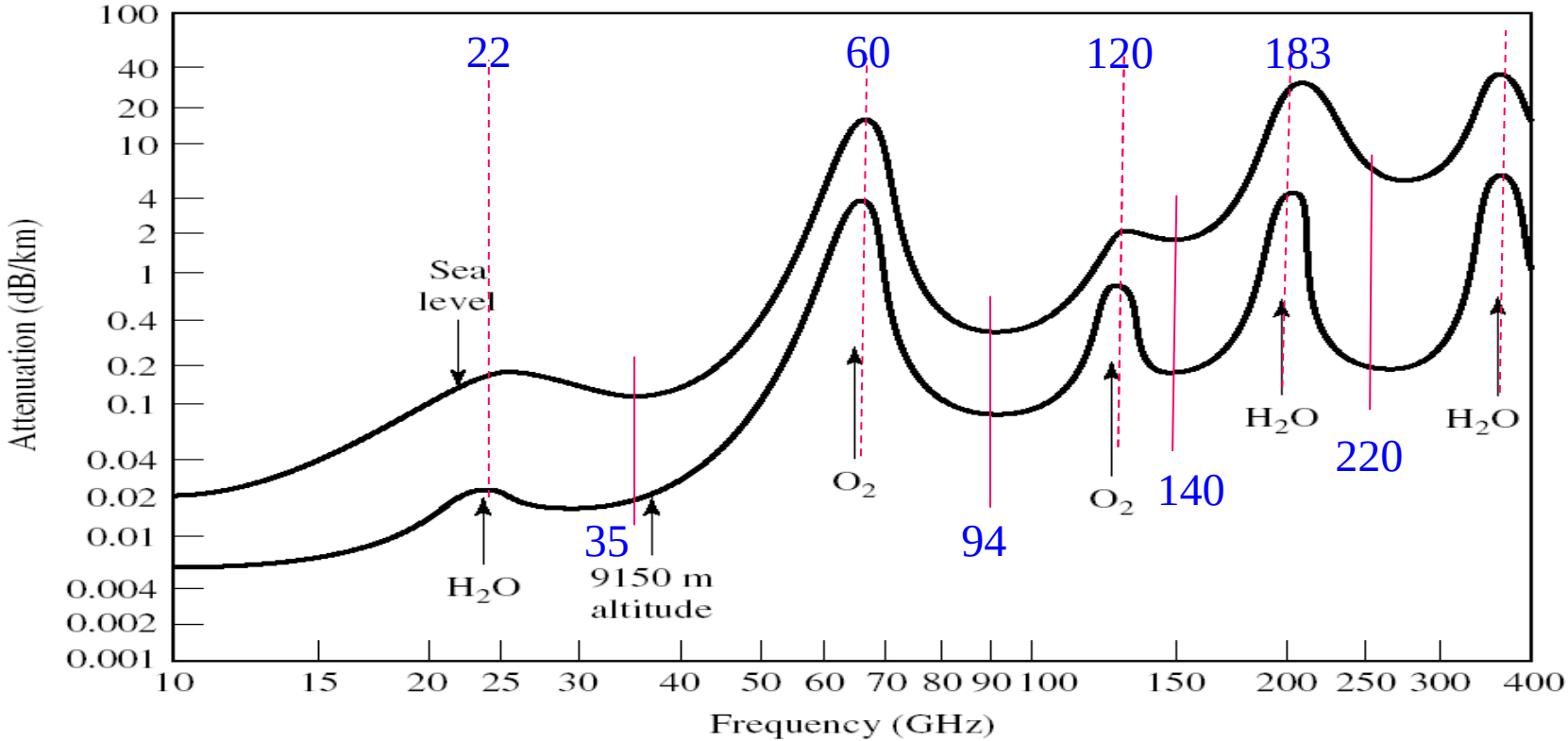
Enablers: MHz to THz Technologies, AI, ML, Cloud Computing, Smart Sensors, 3D printing Technology

What are MHz to Sub-THz Electromagnetic Waves?



Millimeter Waves and Sub-Terahertz Occupy Frequency Spectrum from 30-300 GHz

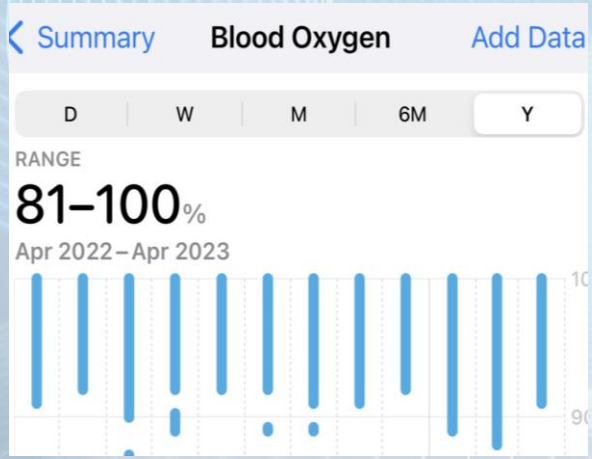
Why Millimeter and Sub-THz Waves?

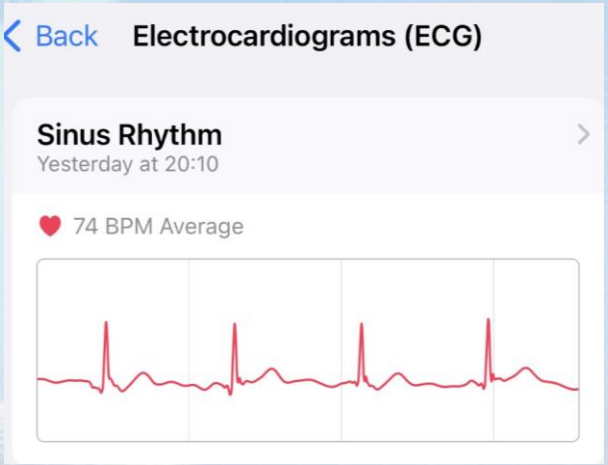


Wearable Non-invasive Sensor Based System

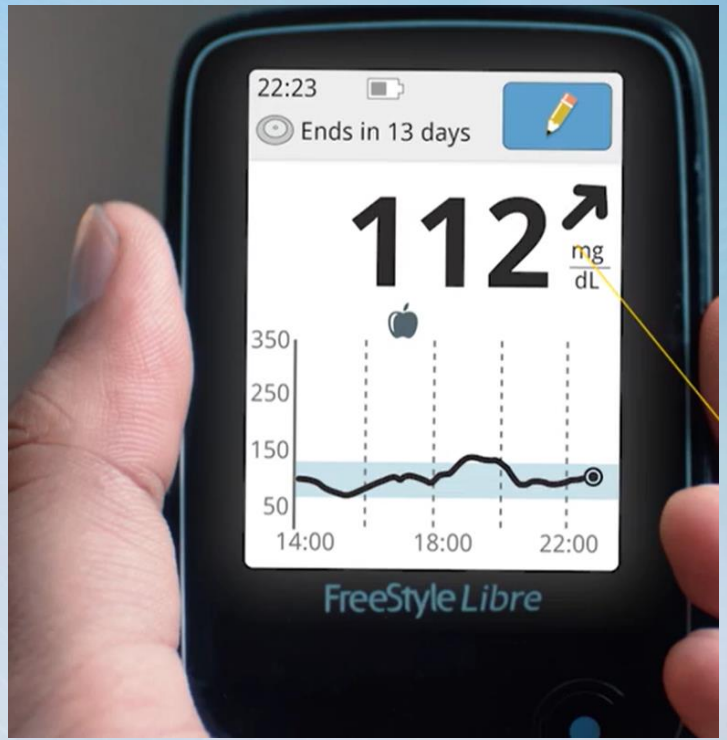
Uses Photodetectors at the back for O2 sensing, Crown to monitor heart beats (ECG) and distance covered for Cardio Fitness

Uses RF Links to Transmit Data to Mobile devices

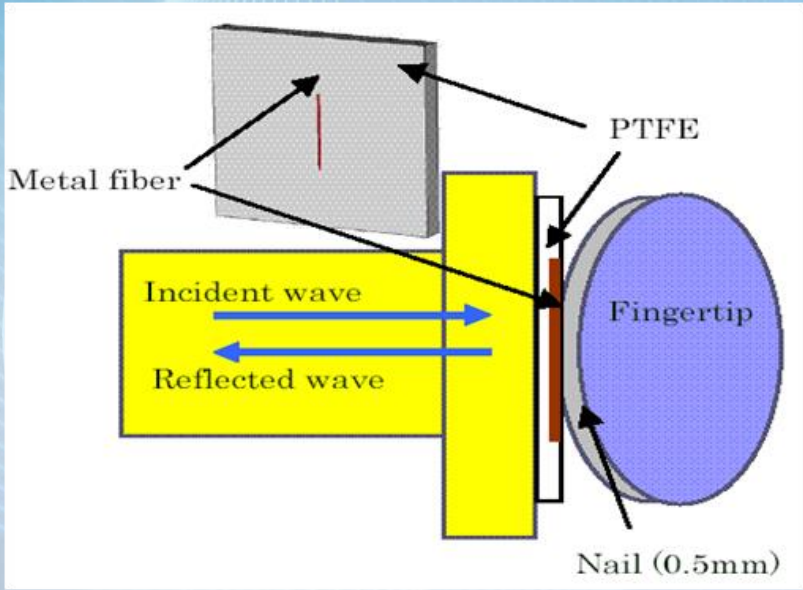




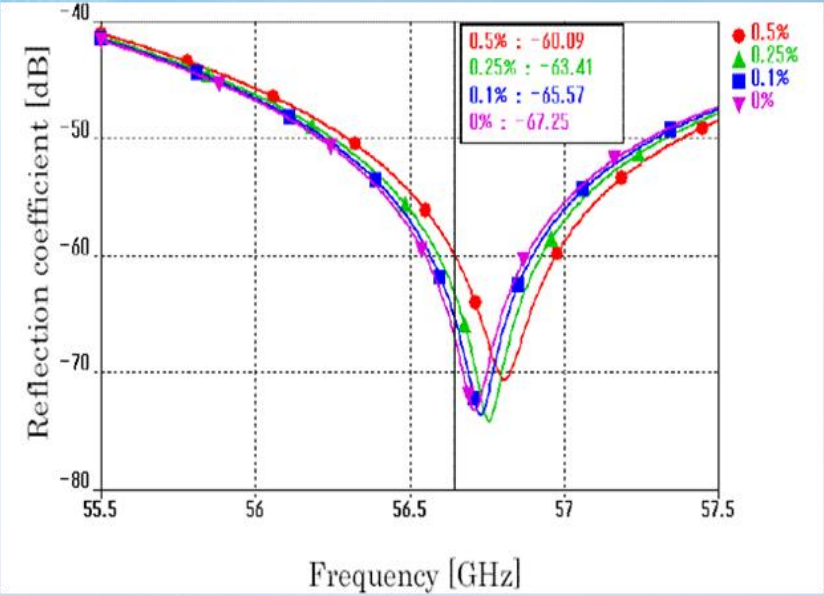
Wearable Sensor based Continuous Glucose Monitor



Millimeter Wave Non-Invasive Glucose Monitoring



60 GHz cavity system to measure blood sugar



Cavity resonant frequency changes depending on the blood glucose level

Device has huge Potential for Commercialization

Source: Yoshio Nikawa, APMC 2007

Sub-THz Sensor Developmental

Development of Dielectric characterization Method

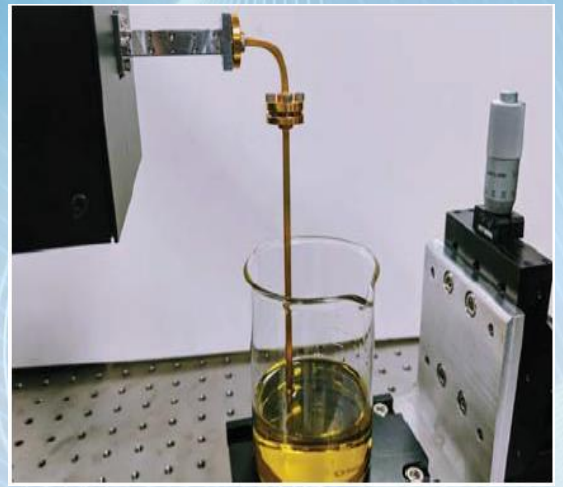
- Designing and testing of liquid and semi-solid material dielectric characterization method in the selected frequency regime.

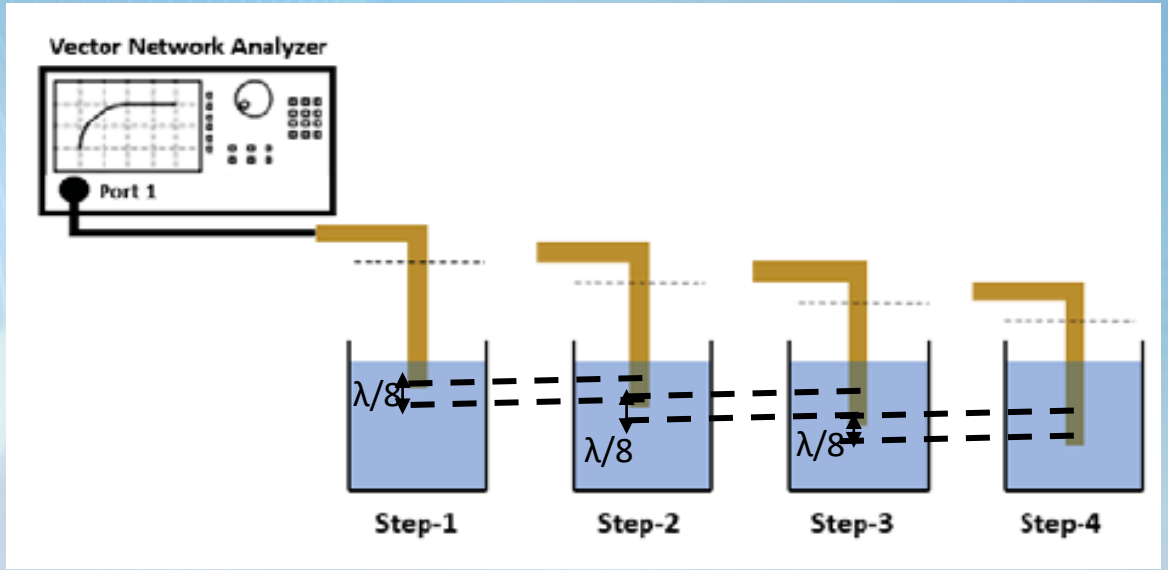
Development and characterization of Tissue Mimicking Models

- Development of phantoms resembling electrical properties of Skin with blood vessels in the selected frequency regime.

Data acquisition and Output Results setup

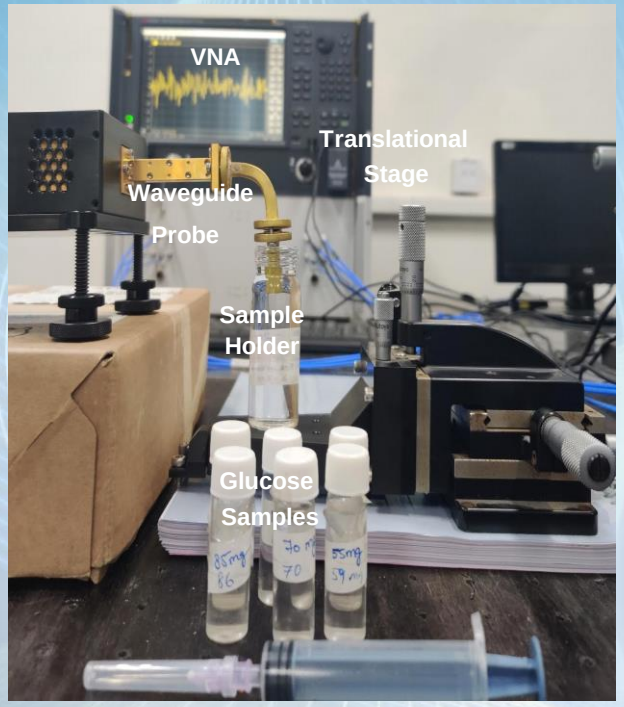
LIQUID DIELECTRIC CHARACTERIZATION ABOVE 100 GHz

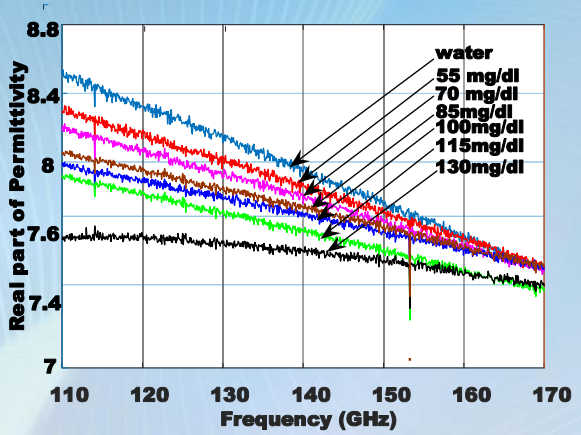


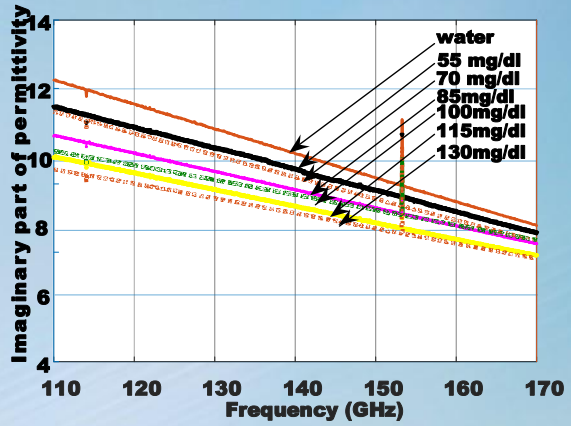


Source: S. Sahin, N. K. Nahar and K. Sertel, "Waveguide Probe Calibration Method for Permittivity and Loss Characterization of Viscous Materials," *2020 94th ARFTG Microwave Measurement Symposium (ARFTG)*, San Antonio, TX, USA, 2020, pp. 1-3, doi: 10.1109/ARFTG47584.2020.9071773.

DIELECTRIC CHARACTERIZATION OF VISCOUS LIQUIDS



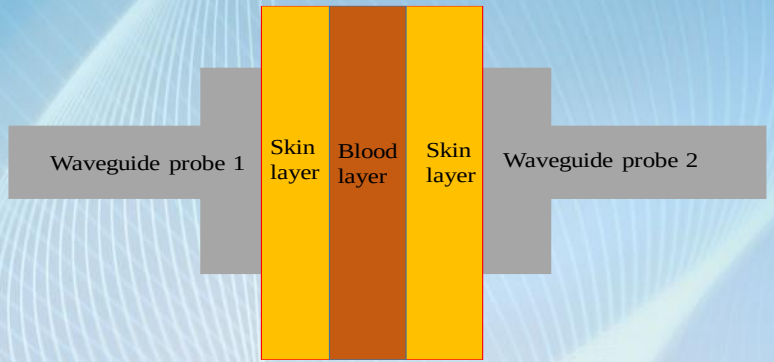


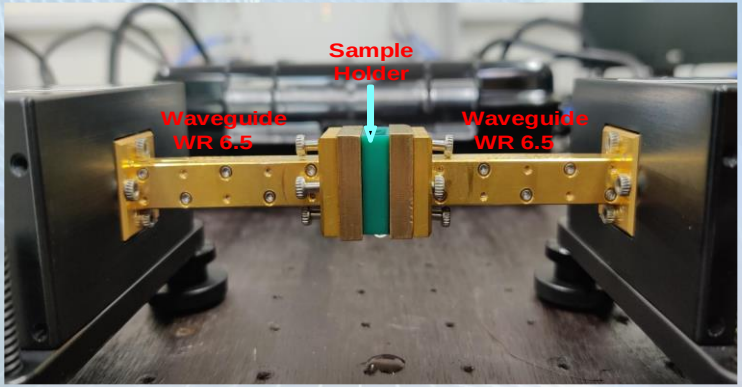


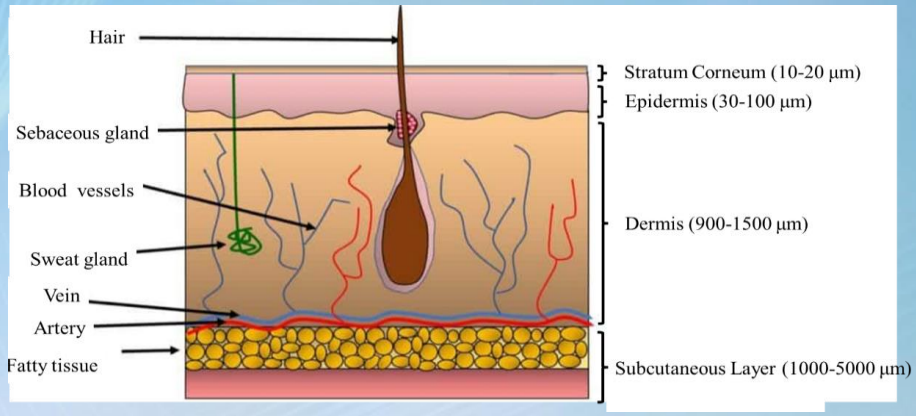
- Obtain complex dielectric constants for different glucose-water mixture concentrations.
- These glucose solutions are used for developing phantoms replicating blood glucose levels.

Source: P. Kaurav, S. K. Koul and A. Basu, "Non-Invasive Glucose Measurement Using Sub-Terahertz Sensor, Time Domain Processing, and Neural Network," in *IEEE Sensors Journal*, vol. 21, no. 18, pp. 20002-20009, 15 Sept.15, 2021.

Sub-THz Non-Invasive Glucose Monitoring



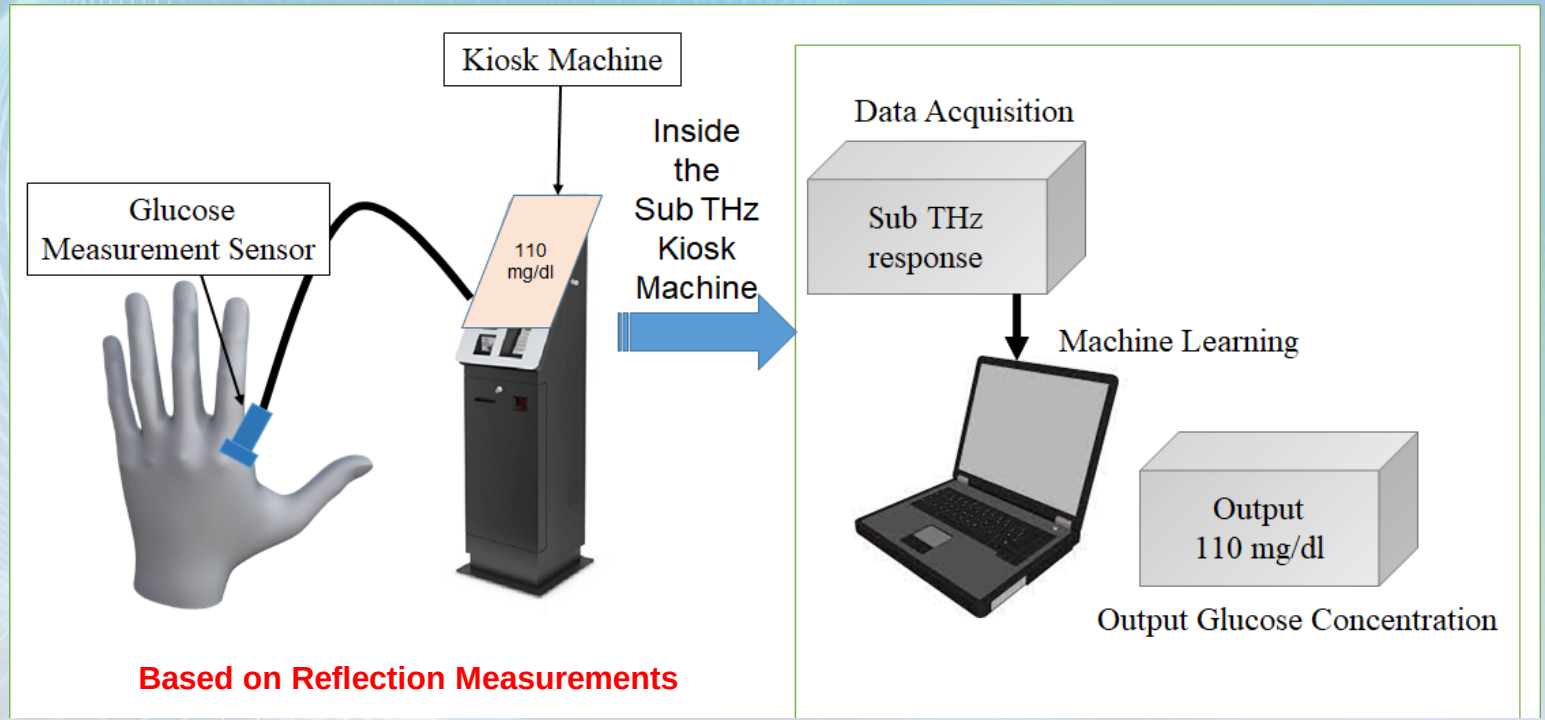




- **Electromagnetic Sensor used is WR 6.5 Waveguide Probe**
- **Phantom to mimic skin area between thumb and index figure (Thumb- index Web Space) is used in this study.**
- **Both Transmission or Reflection of sub-THz wave can be used**

Source: Shiban K Koul and P. Kaurav, Sub THz Sensing Technology for Biomedical Applications, Springer 2022

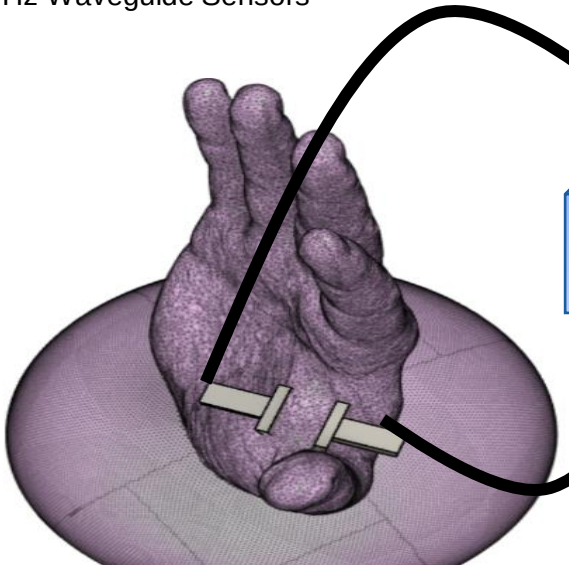
Sub-THz Non-Invasive Glucose Monitoring



Source: P. Kaurav, Shiban K Koul and Ananjan Basu, IEEE Sensor Journal, Sept 2021

Sub-THz Non-Invasive Glucose Monitoring

1. Sub THz Waveguide Sensors



2. Data Acquisition

[S21 S11]

3. Time Domain Processing & Neural N/W

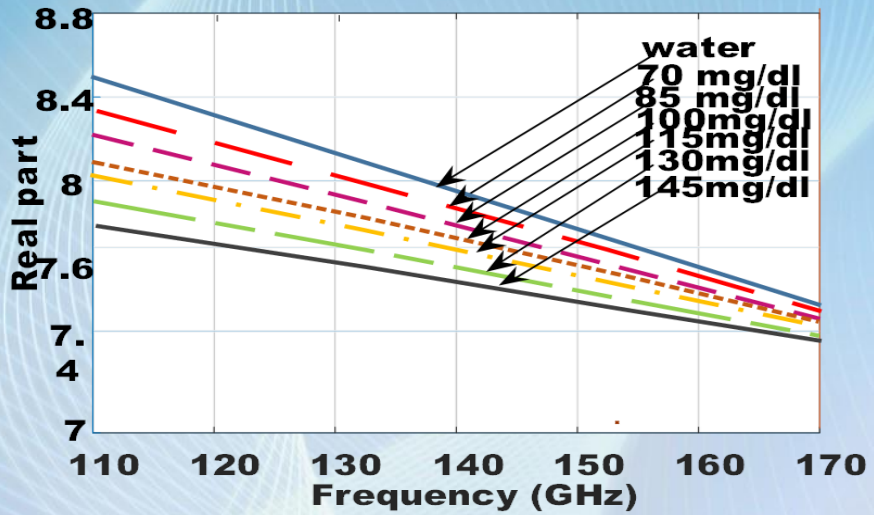
Output
110 mg/dl

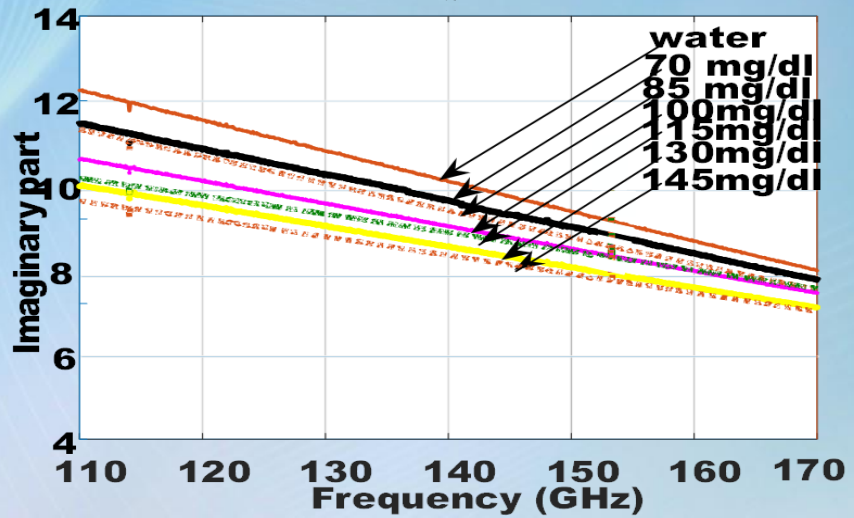
Based on Transmission and Reflection Measurements

4. Output Glucose Concentration

Source: P. Kaurav, Shiban K Koul and Ananjan Basu, IEEE Sensor Journal, Sept 2021

Sub-THz Non-Invasive Glucose Monitoring

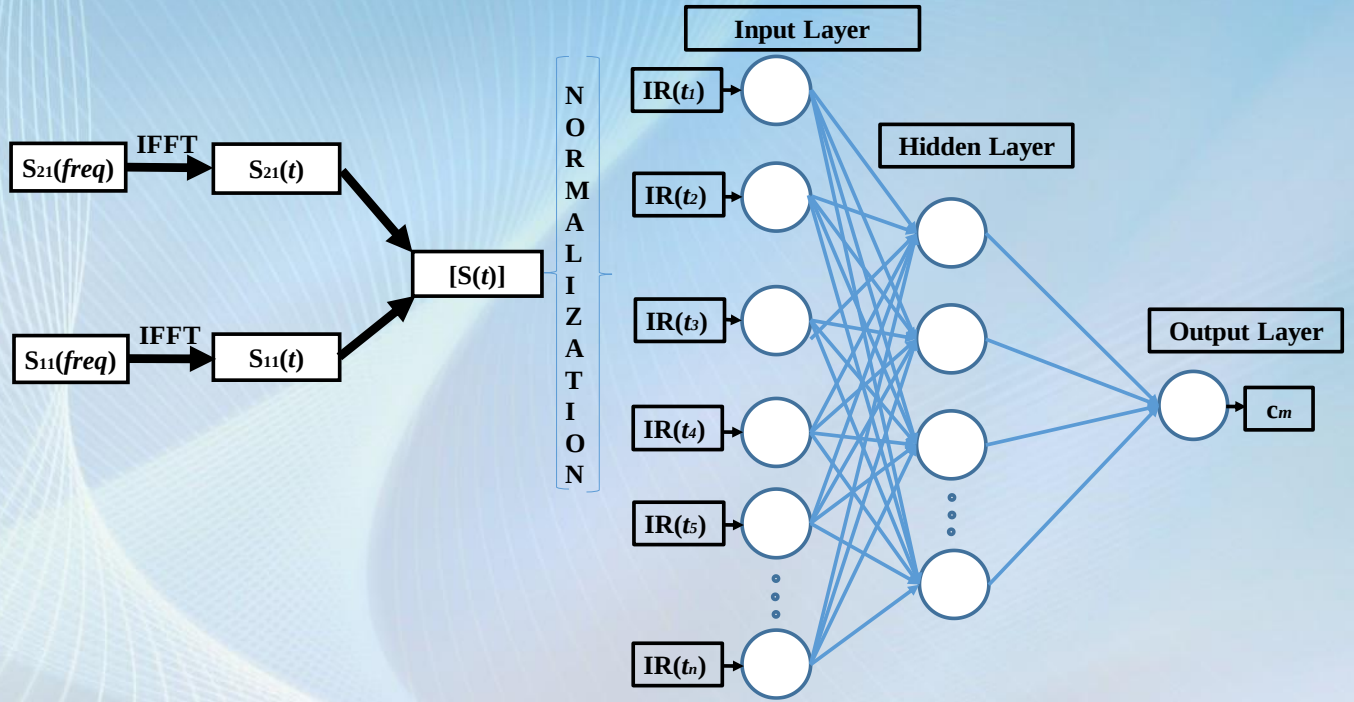




Real and Imaginary Parts of dielectric constant as a function of frequency for various concentrations of Glucose

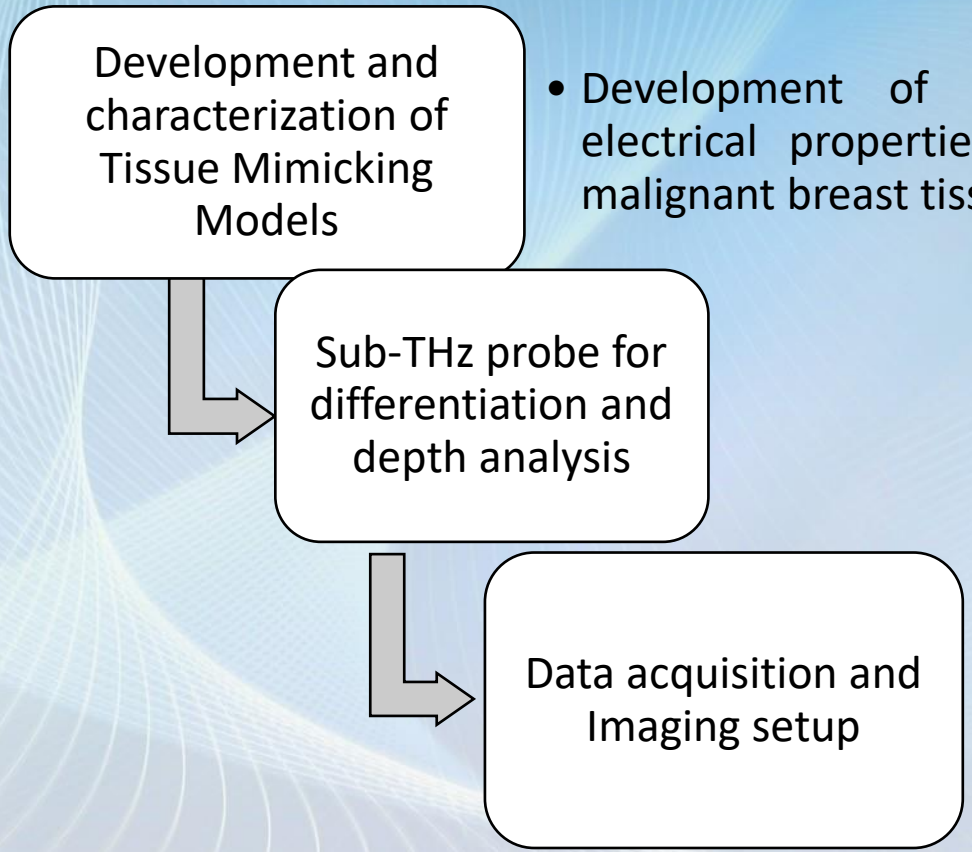
Source: Shiban K Koul and P. Kaurav, Sub THz Sensing Technology for Biomedical Applications, Springer 2022

CONVERSION OF S-PARAMETERS TO GLUCOSE CONCENTRATION



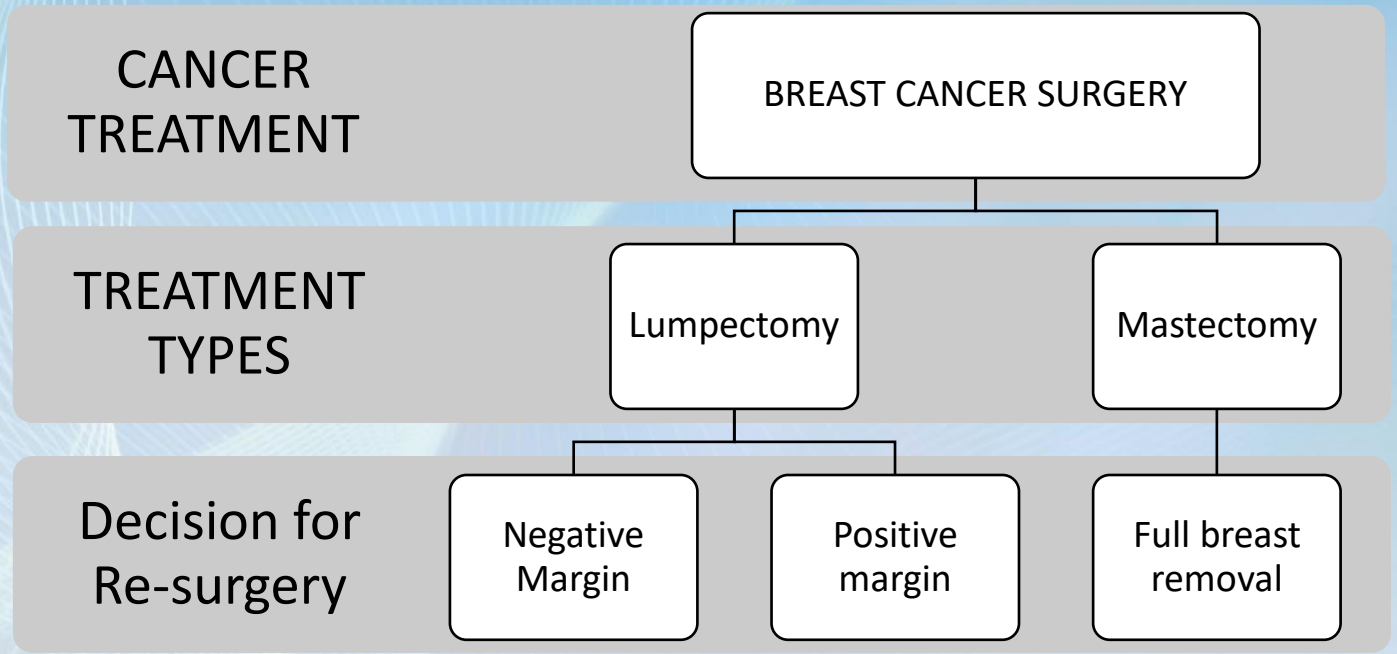
Obtaining glucose levels from S parameters using Levenberg-Marquardt algorithm based NN model

Tumor Margin Assessment Imaging Technique in Sub-THz Band



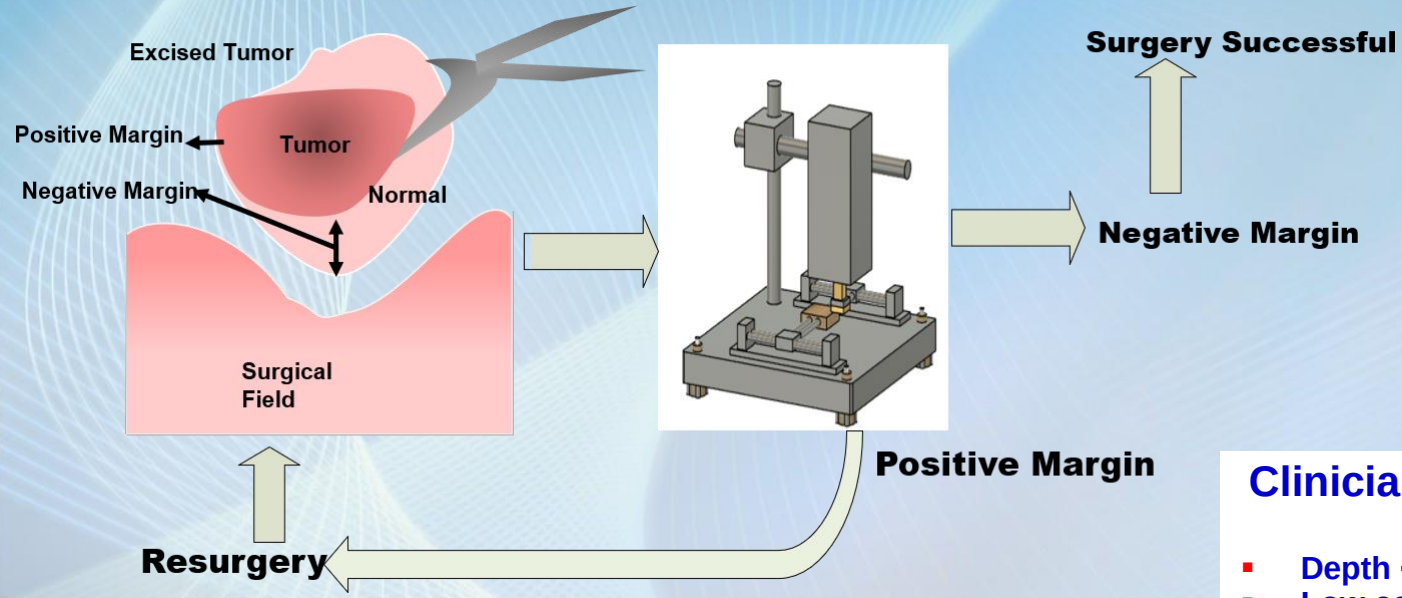
- Development of phantoms resembling electrical properties of fat, fibrous and malignant breast tissues in Sub-THz band

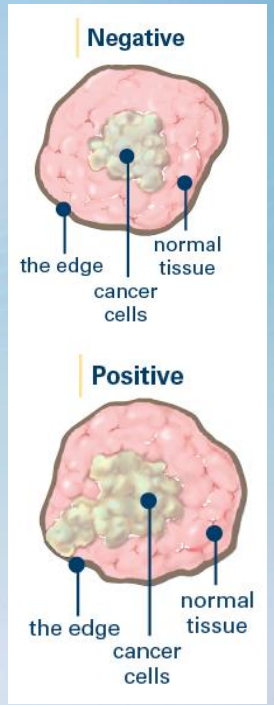
Sub-THz EM Sensor Based Breast Tumor Margin Assessment



Electromagnetic Sensor: WR-65 Waveguide Probe Operating in 110-170 GHz

Sub-THz EM Sensor Based Breast Tumor Margin Assessment





Clinician Needs

- Depth <=1mm
- Low cost
- Time <20 minutes

Source: P. Kaurav, Shiban K Koul and Ananjan Basu, IEEE Journal of Electromagnetics, RF and Microwave in Medicine and Biology, 2021

Water-Agar Based Phantoms for Mimicking Breast Tissues

- Different compositions of water-oil and agar are mixed to develop three different types of breast tissues.
- Malignant tissue: more water concentration
  Fat tissue: least water concentration
- Bruggeman's effective concentration method is used to develop these tissue phantoms to mimic the dielectric properties of real tissues in the selected frequency regime (110-170 GHz)

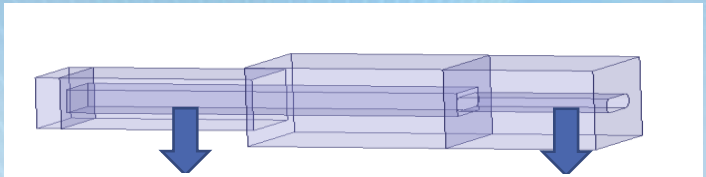
Phantom Type	Mimicking Tissue	Composition of Phantom Constituents			
		Water (ml)	Agar (g)	Oil (ml)	Pectin (g)
Agar5%Oil20%	Malignant	70	4.6	17.5	4.2
Agar5%Oil40%	Fibrous	70	6	46.5	4.2
Agar5%Oil80%	Adipose/fat	70	18.6	280	4.2

Source: P. Kaurav, Shiban K Koul and Ananjan Basu, IEEE Journal of Electromagnetics, RF and Microwave in Medicine and Biology, 2021

Sub-THz EM Sensor Based Breast Tumor Margin Assessment

Requirements

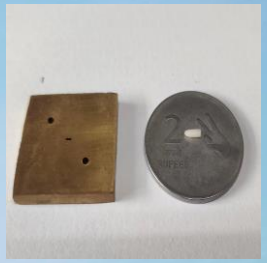
- Development of Low-Cost sub-THz Sensor
- Development of Breast Phantoms
- Manual/Automatized Measurements on Breast Phantoms
- Construction of images for margin assessment



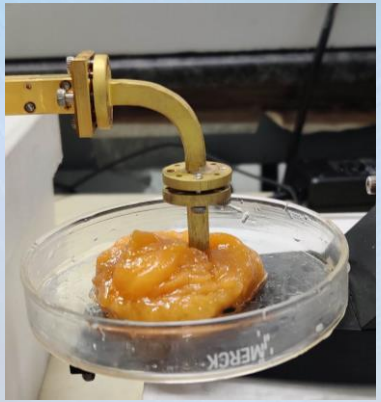
WR -6.5 Waveguide

Waveguide IRIS

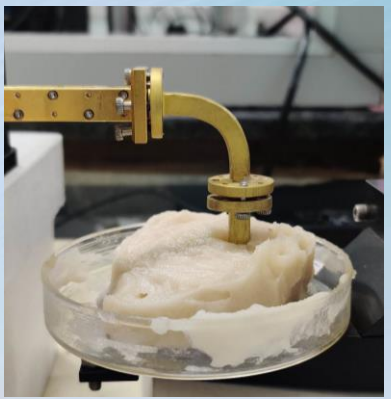
EM Sensor



Tumor & Healthy Breast Tissue Phantoms Using Water, Oil and Agar



Tumor



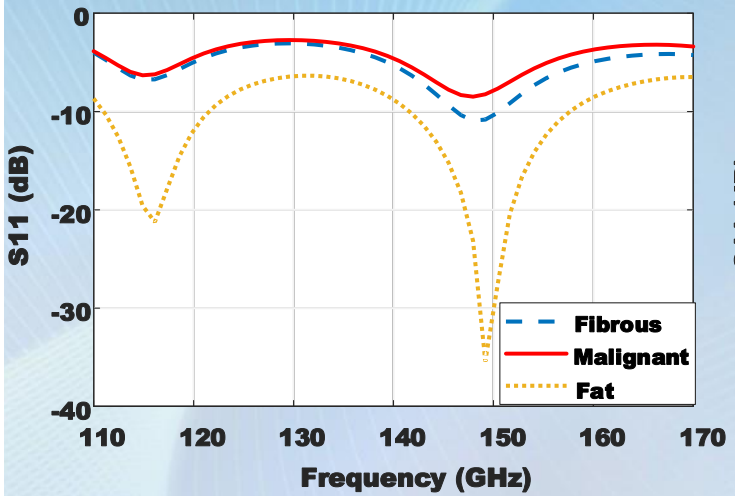
Healthy

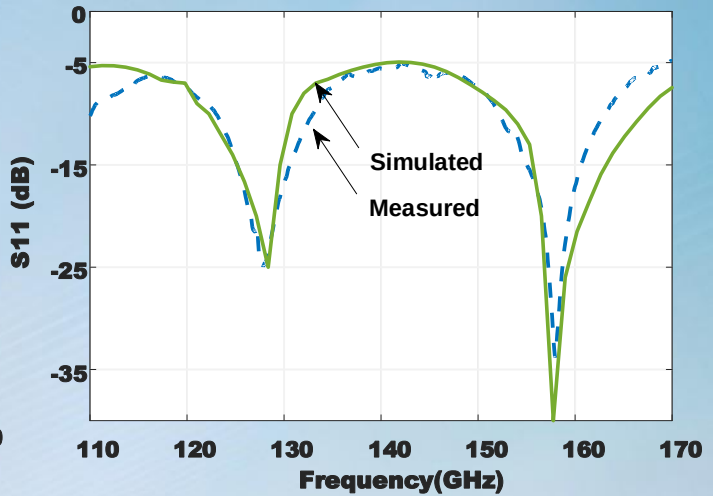
Source: P. Kaurav, Shiban K Koul and Ananjan Basu, IEEE Journal of Electromagnetics, RF and Microwave in Medicine and Biology, 2021

Sub-THz EM Sensor Based Breast Tumor Margin Assessment

Imaging Setup

- Development of Low-Cost sub-THz Sensor
- Development of Breast Phantoms
- Manual/ Automatic Measurements on Breast Phantoms
- Construction of images for margin assessment





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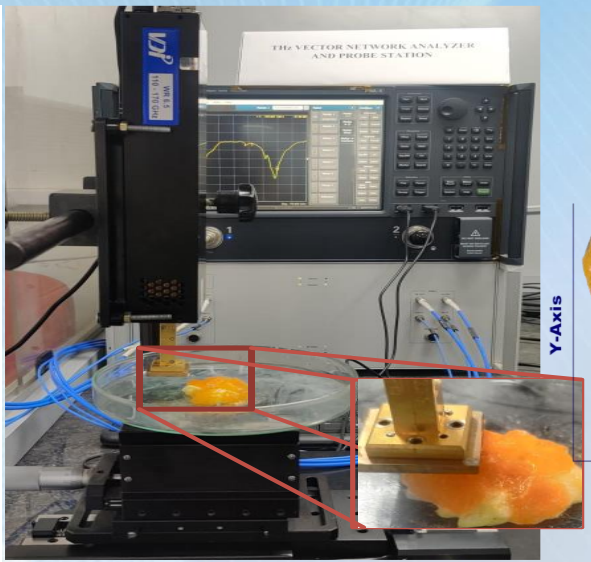
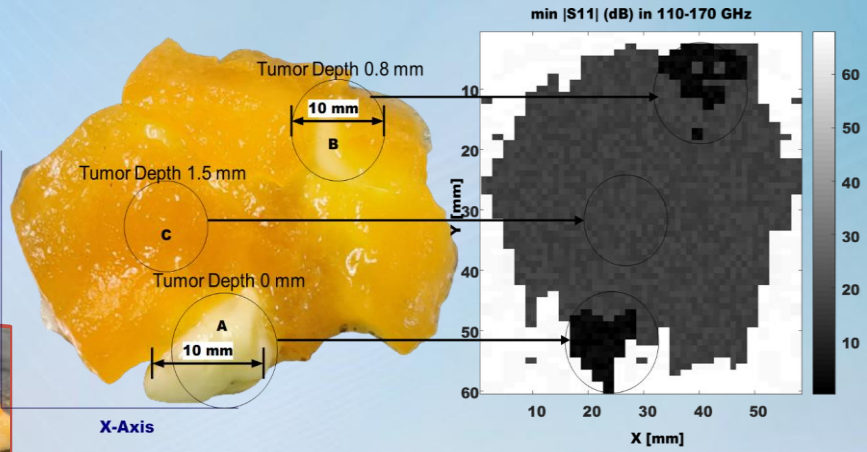
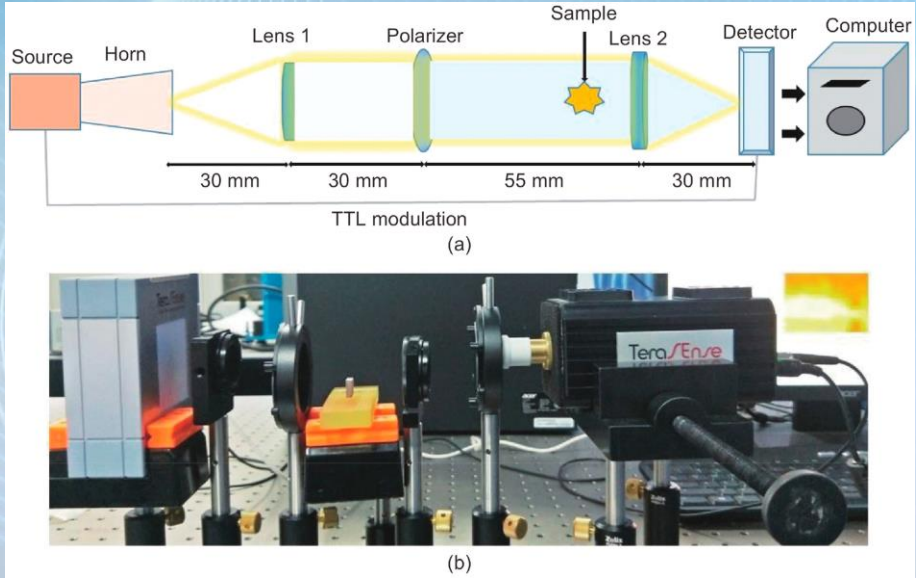
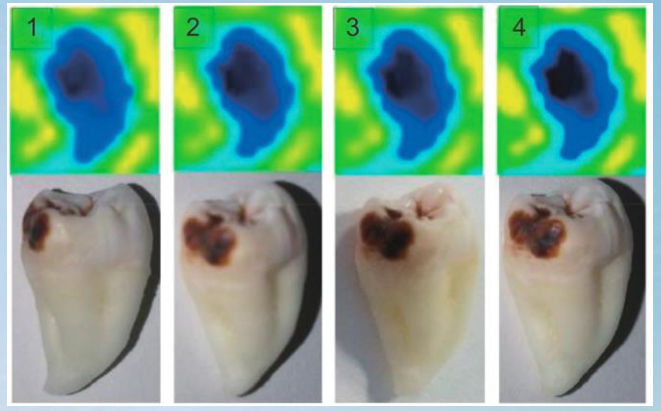




Source: Shiban K Koul and P. Kaurav, Sub THz Sensing Technology for Biomedical Applications, Springer 2022

Dental Diagnosis and Treatment





THz Imaging of Dental Caries

Dental caries are significantly lossy than a sound tooth in millimeter waves. Microwave and millimeter-wave heating for the lossy dental caries can be used as a sterilization treatment.

Source: 1. Yoshi Nikawa et al., IEEE Transactions on MTT, Nov.2000: 2. N. P.Yadav et al., Journal of Electronic Science & Technology, Sept 2021

Millimeter Wave Therapy

- All living Cells generate alternating Electromagnetic fields.
- Cell communication in our body is at 42.5, 53.6 and 61.5 GHz
- Cause of poor health is unbalance in these waves
- Communication with body cells and cell membranes requires low intensity exposure at right place using millimeter waves
- Non-Thermal Exposure using low intensity Millimeter waves is called Millimeter Wave Therapy (MWT)
- Research has shown healing effect for Cardiovascular disorders, diabetes, wound healing, pain relief, gastrointestinal disorders
- Reduction of toxic effects of Chemotherapy in cancer patients

MWT requires light weight affordable millimeter wave sources

Millimeter Wave Applicator

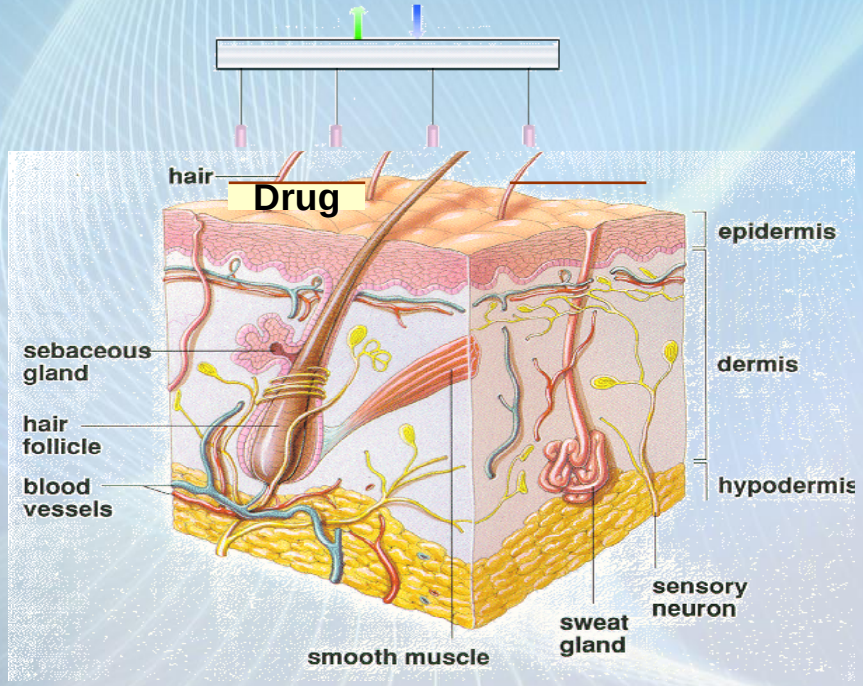
Application Scope

- Cancer
- Tumors
- Diabetes
- Prostrate
- Skin Ulcer
- Cardiovascular Diseases
- Pain Management

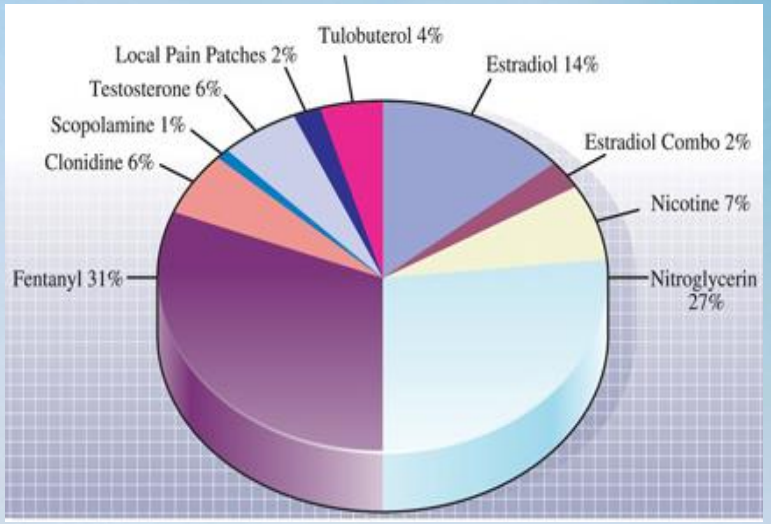
Source: Hubei-YJT Technology Co. Ltd

Radio Frequency Assisted Drug Delivery

RF Energy



Global TDD Sales: Low Molecular Weight Drugs

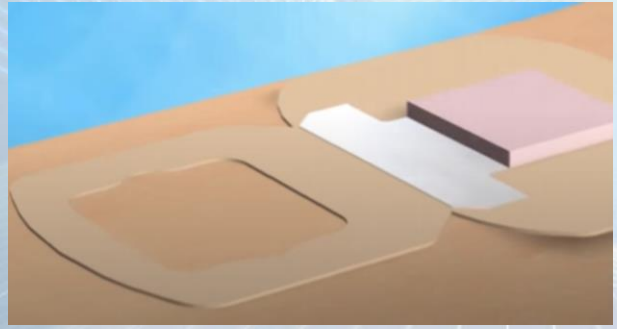


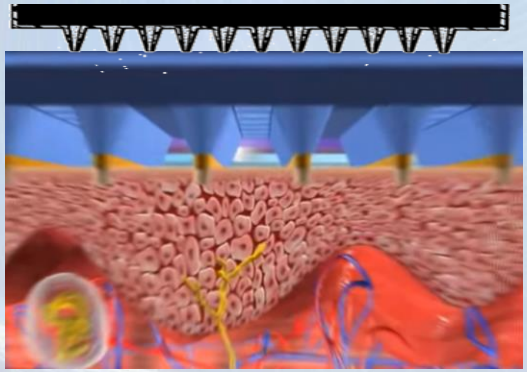
Source: PhD Thesis Rachna Prasad, CBME, IIT Delhi 1984

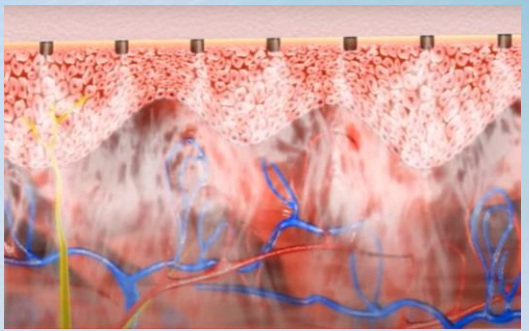
Radio Frequency Assisted Transdermal Drug Delivery

- High Molecular Weight drugs
- Hydrophilic Drugs
- Protein and peptide Drug

Microneedle Array with drug reservoir

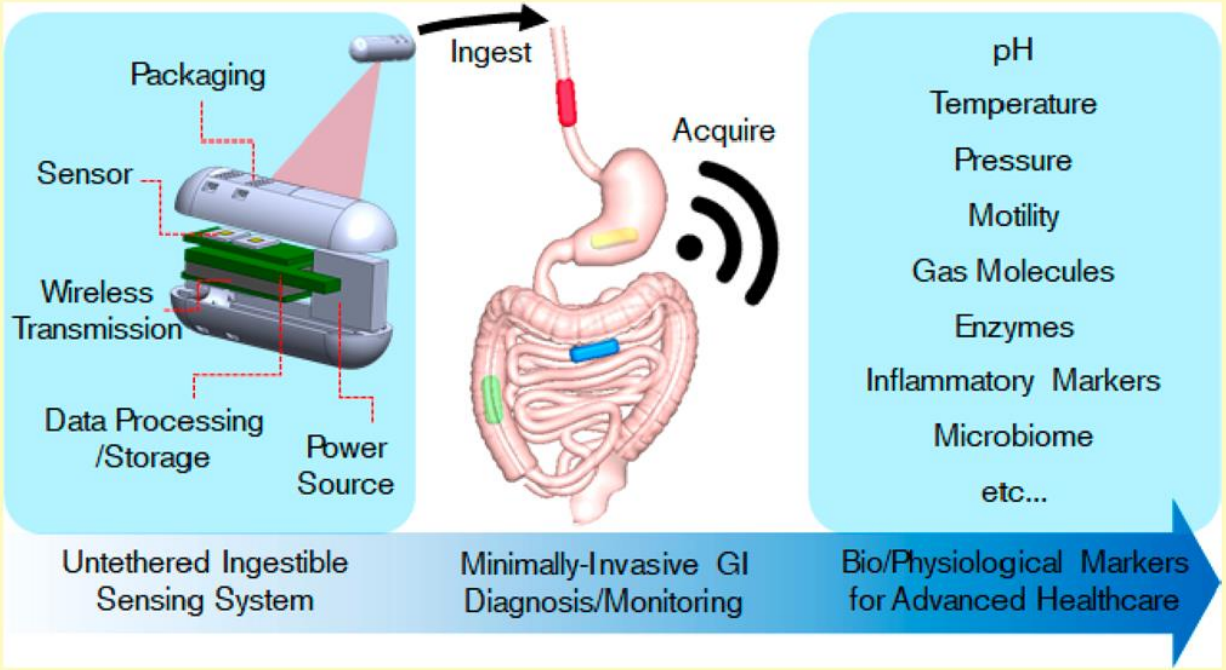






Source: Via Derm

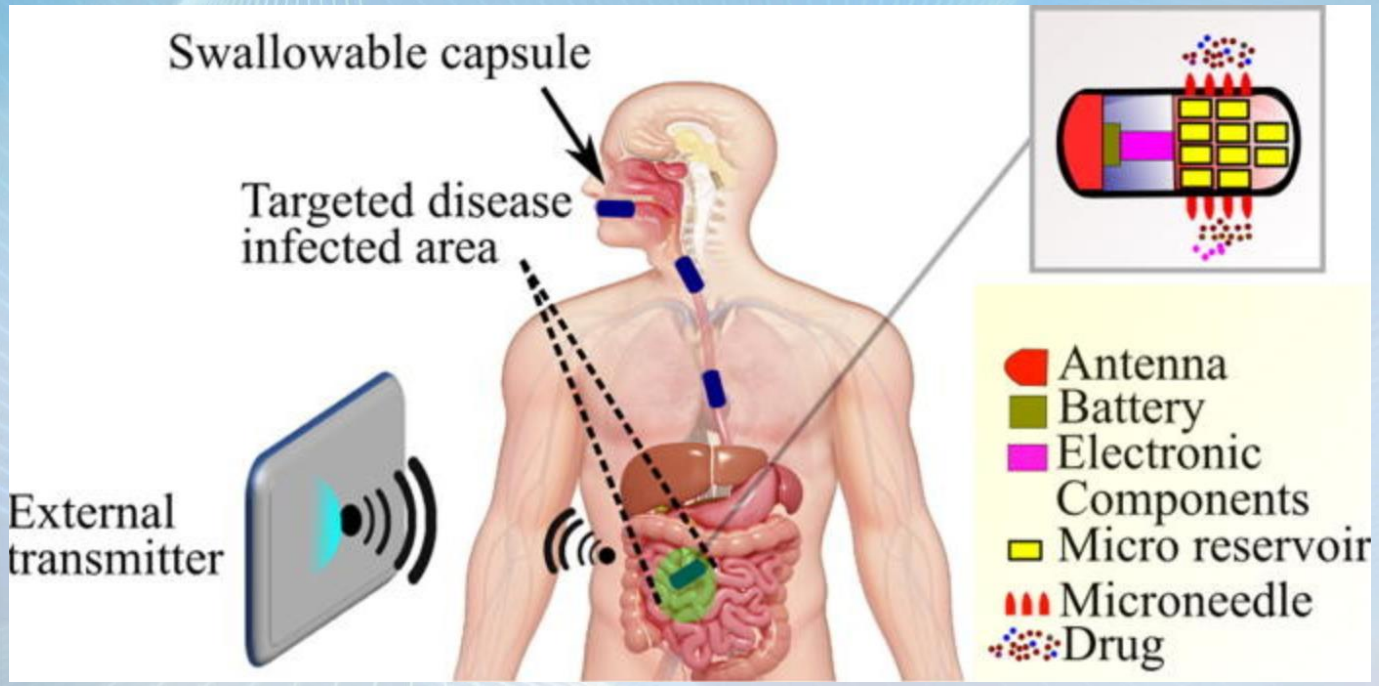
Minimally Invasive Screening-Ingest Capsule

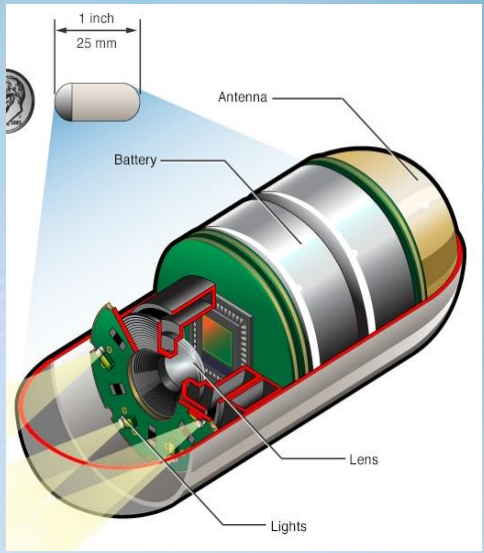


Different pill capsules are available which when digested emit EM signals that are picked by Nursing staff to ensure that the patient has taken medicine

Source: Luke A. Beadslee et al., ACS Sensors 2020

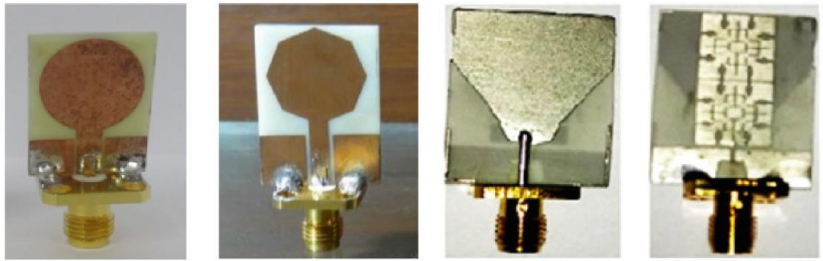
Controlled Drug Delivery System- Endoscope Capsule



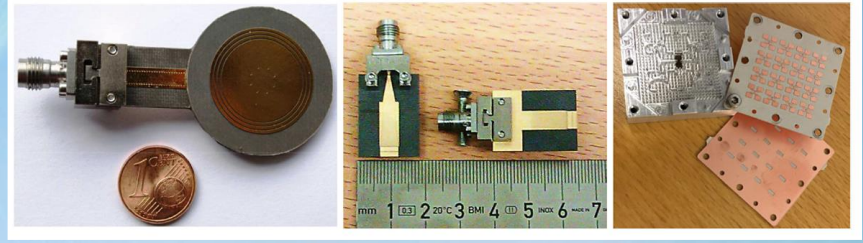


Source: Open Literature

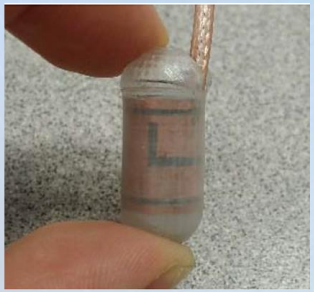
Types of Antennas for Healthcare Applications



UWB Antennas



MM-wave Antennas at 60 GHz

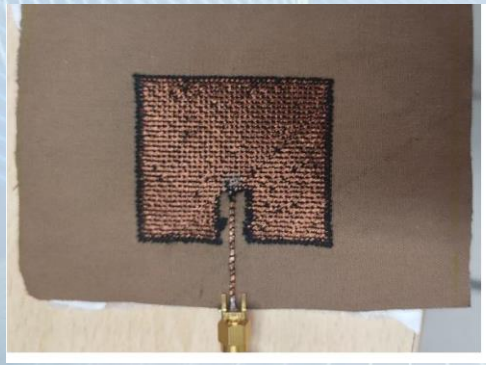


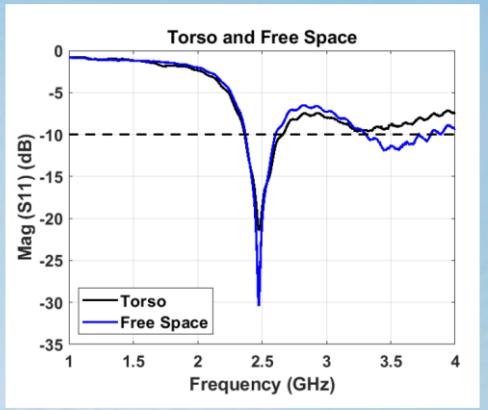
Capsule Antenna

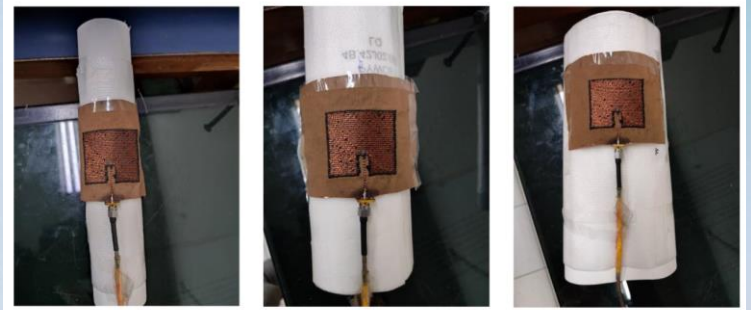
Smart Tattoo Antenna

Source: Shiban Koul and Richa Bhardwaj, Wearable Antennas and Body Centric Communication, Springer 2021

Flexible Antennas for Healthcare Monitoring and Rehabilitation







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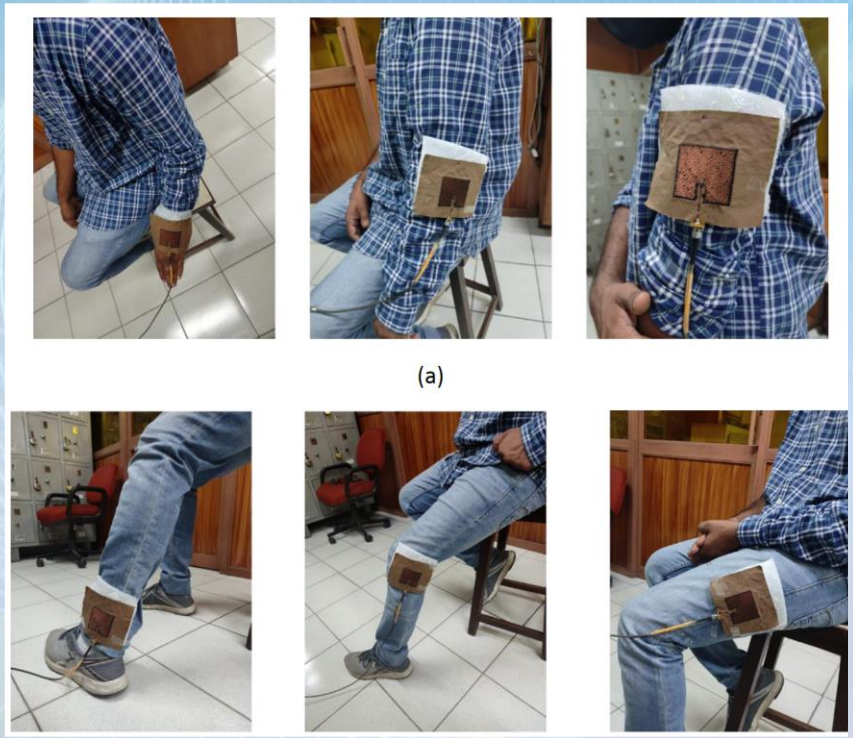
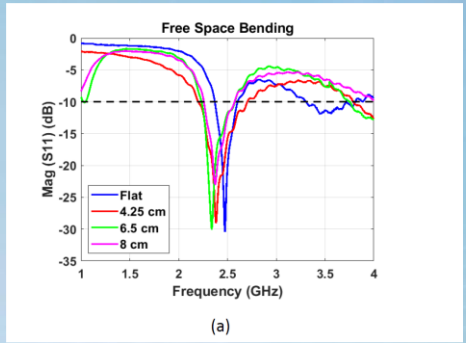
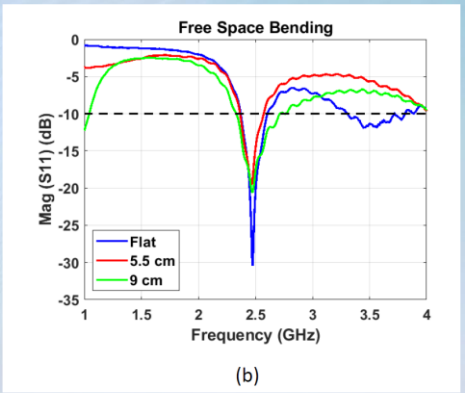
Flexible Antennas for Healthcare Monitoring and Rehabilitation

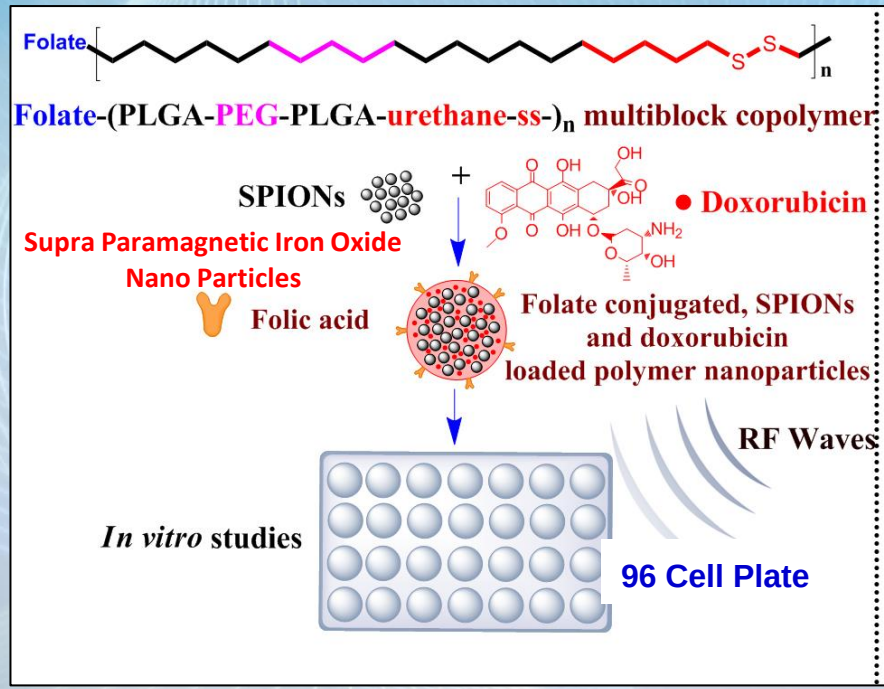


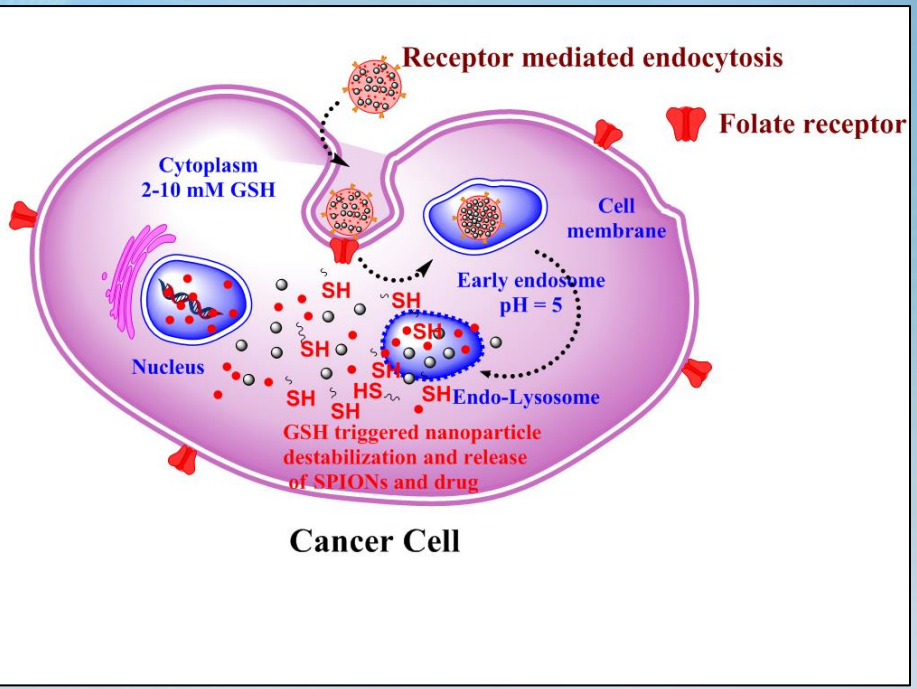




Source: Shiban Koul and Richa Bhardwaj, Wearable Antennas and Body Centric Communication, Springer 2021

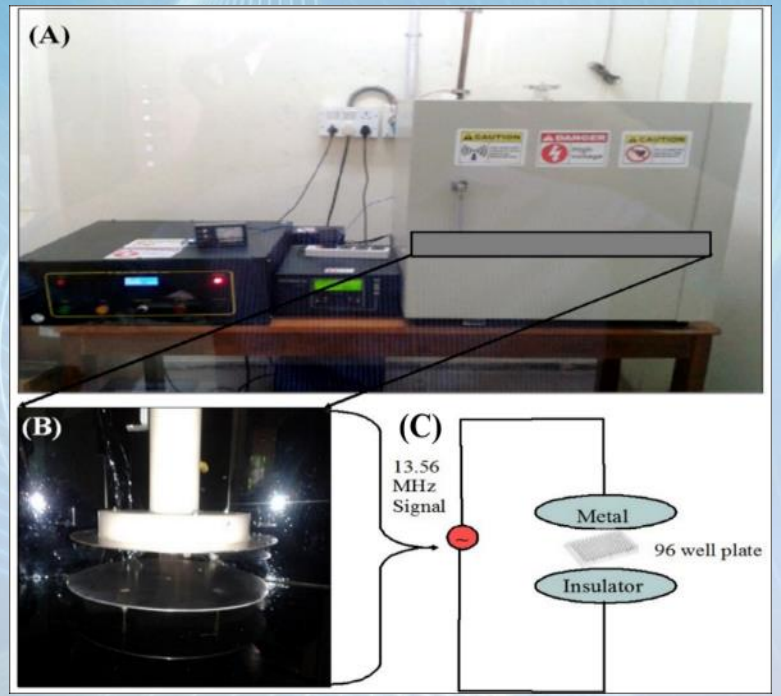
RF Assisted Hyperthermia for Enhanced Pharmacological Effect at Lower Doses of Chemotherapy- In Vitro studies

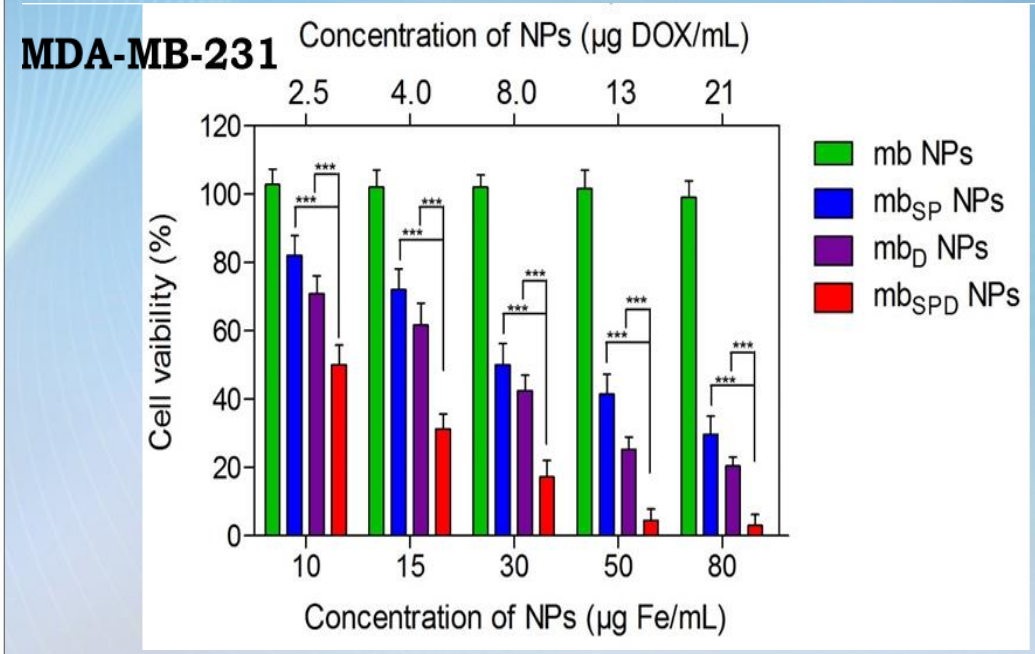




Source: C.Nehate, M. Alex, A. Kumar and Veena Koul, Material Science and Engineering C:Materials for Biological Applications, June 2017

RF Hyperthermia Treatment

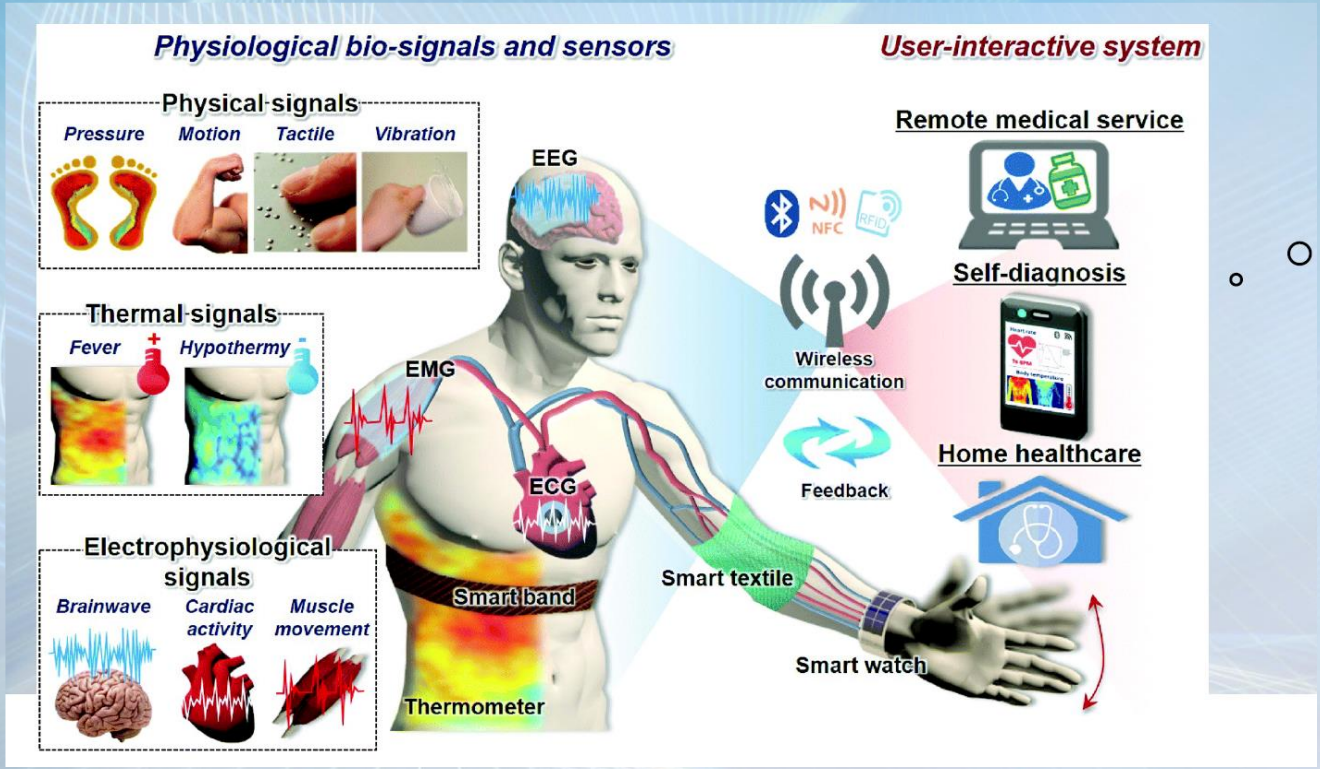




RF Exposure for 10 minutes at 50 Watts

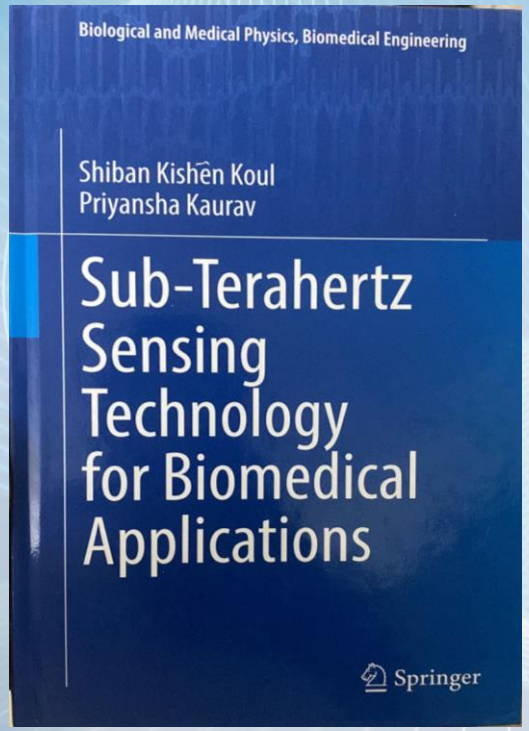
Source: C.Nehate, M. Alex, A. Kumar and Veena Koul, Material Science and Engineering C:Materials for Biological Applications, June 2017

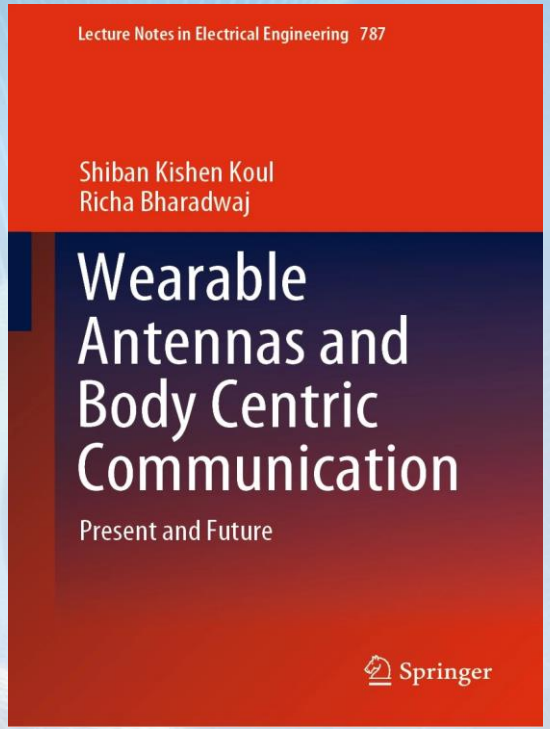
Wearable Sensor Based System

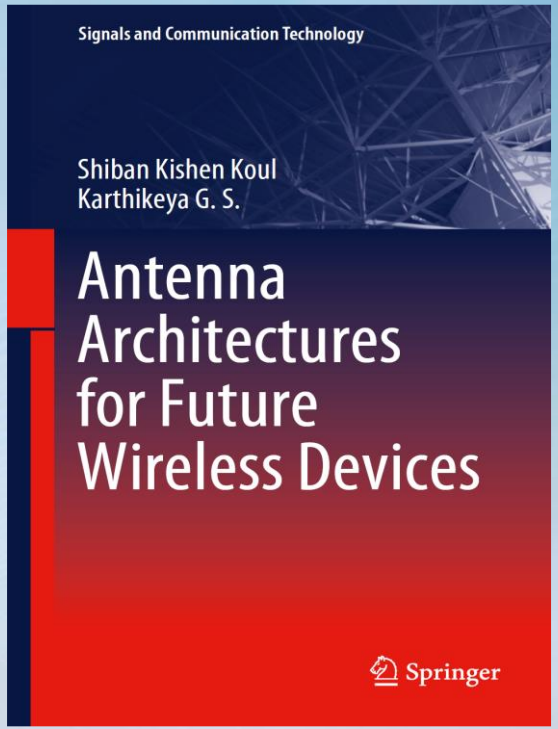


Source: M. Bozzi, 1st DML Talk 2022

Recent Books







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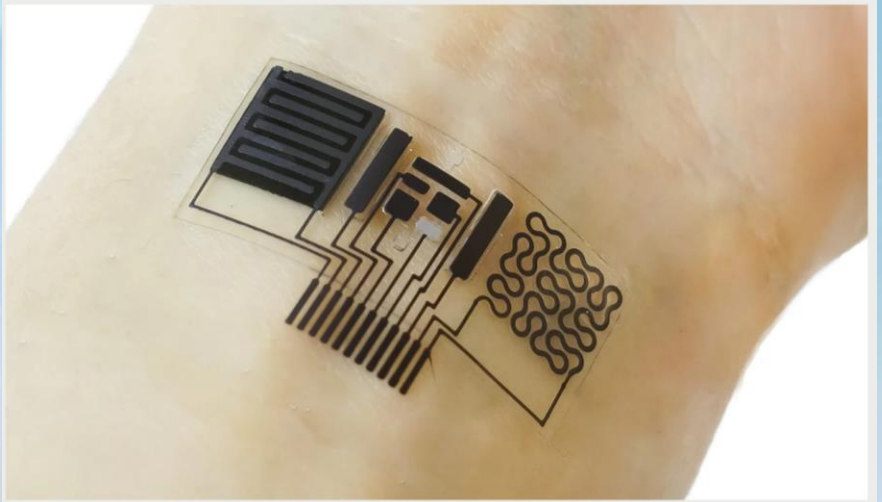
IEEE Computer Society 2023 Technical Predictions

Remote (Wireless) and Wearable Technologies for Healthcare



Caltech's team has experimented with different forms of energy to harvest for powering its e-skin, including human sweat and friction of materials during movement. WEI GAO/CALTECH

Source IEEE Spectrum 01 Nov.2023

Conclusions and Recommendations

- Whether we like it or not- RF is there everywhere.
- Need to join AP or MTT-S Society and learn MHz to THz Technologies.
- Require multiple skills such as knowledge of Basic Electromagnetics, Antenna Engineering, Microelectronics, Computer Science (AI,ML, Cloud Computing), Mechanical Engineering, Material Science and Bio-medical Engineering.
- Need to Collaborate with Medical doctors as well as Engineering Professions.
- Together we need to Serve Humanity
- Future will demand low-cost wearable and wireless devices

Thank You for Your Kind Attention

Any Question ???