Wireless power transmission and Biomedical applications

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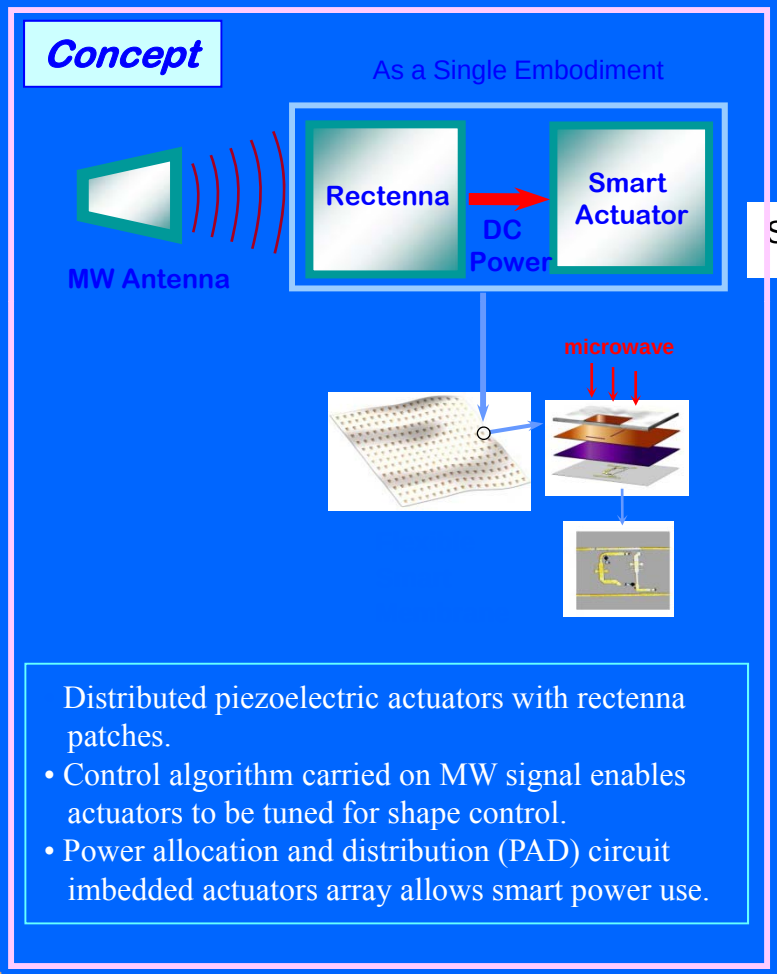
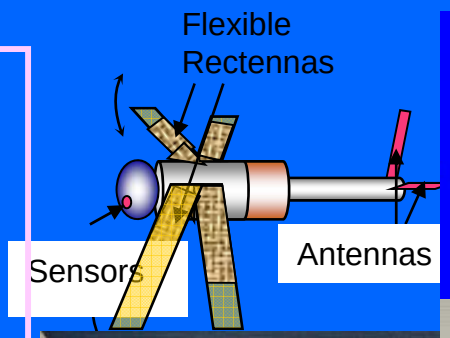
June, 2010

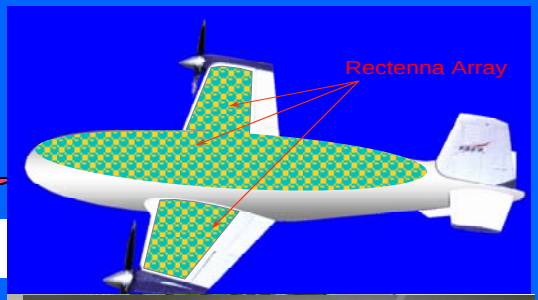
Status of Microwave Power Transmission

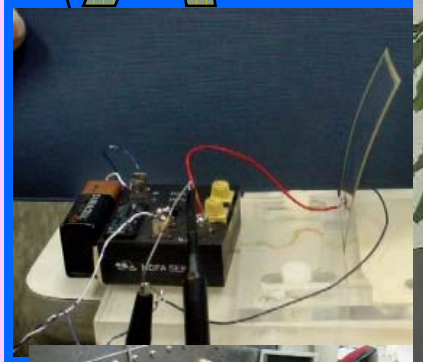


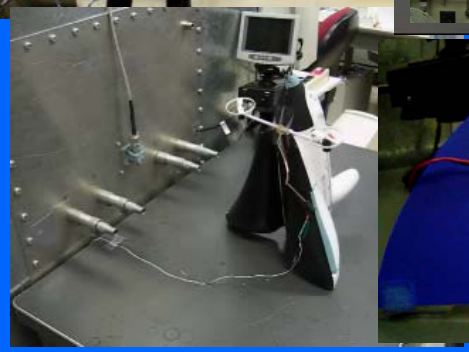
Distributed piezoelectric actuators with rectenna patches.

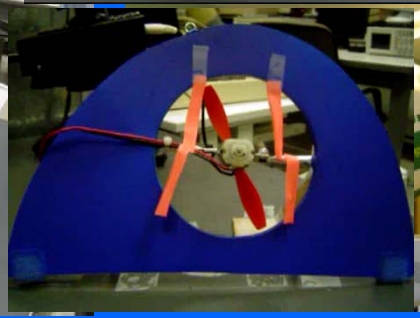
- Control algorithm carried on MW signal enables actuators to be tuned for shape control.
- Power allocation and distribution (PAD) circuit imbedded actuators array allows smart power use.



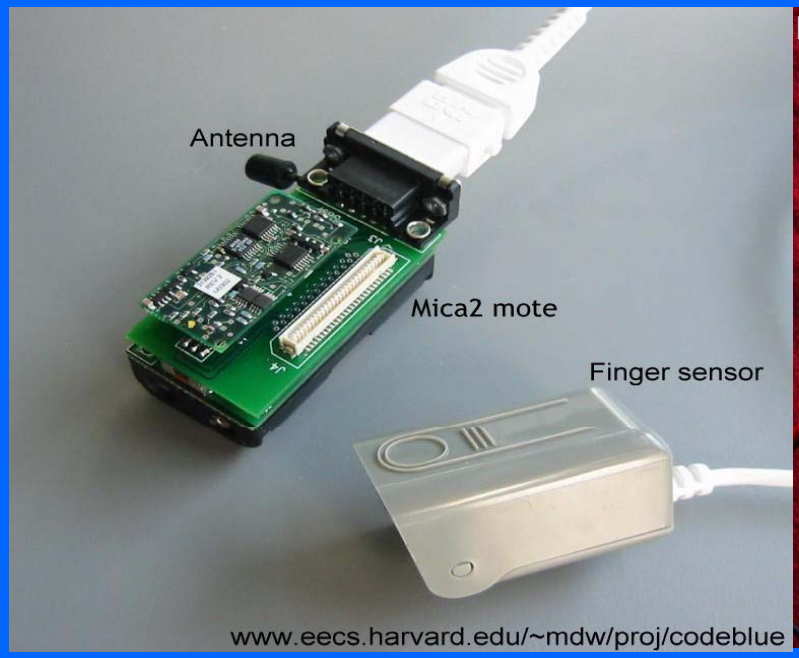








Medical Applications ?



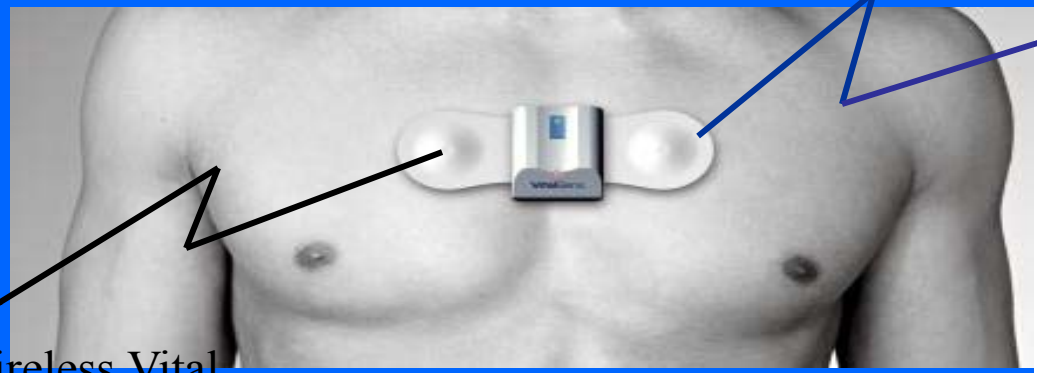
Wireless Pulse Oximeter Sensor

Uva/AID-N Wireless two-lead EKG Sensor

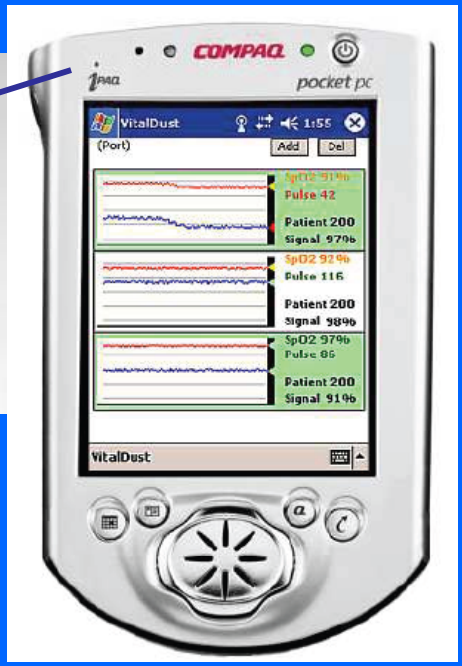
Source: WWW.eecs.harvard.edu/~mdw/pro/codeblue

Commercial Products

(an example)



Wireless Vital
Signs Monitoring

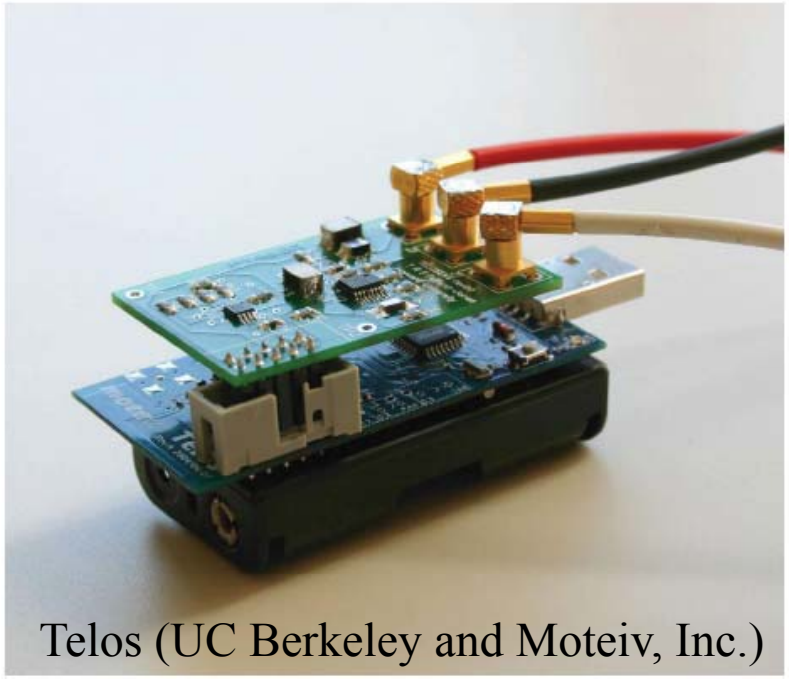


Monitoring Vital Signs such as respiration, oxygen in the blood, temperature and ECG

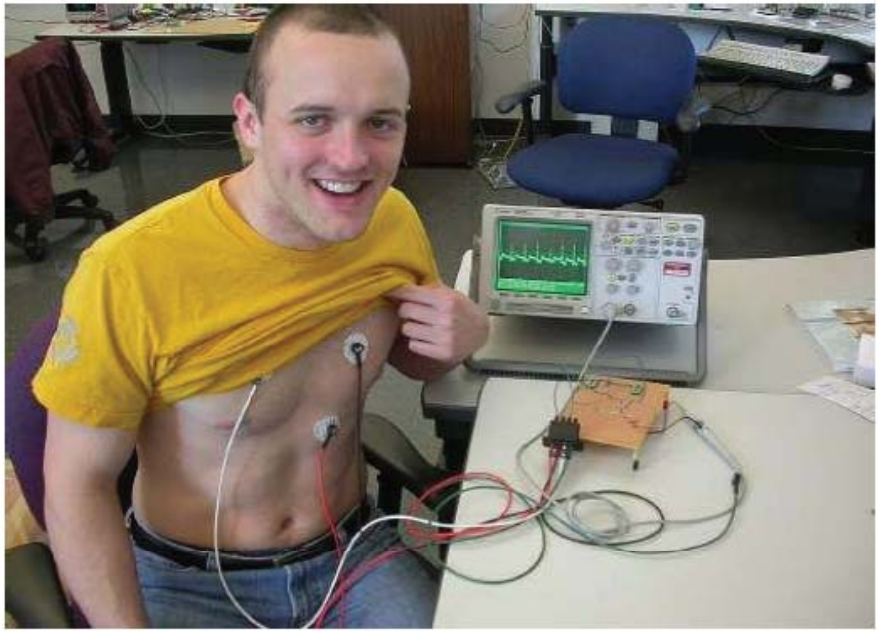
" The elements provided included:
Long battery life, ….."

Source; http://www.std-ltd.com/

EKG Monitoring



Telos (UC Berkeley and Moteiv, Inc.)



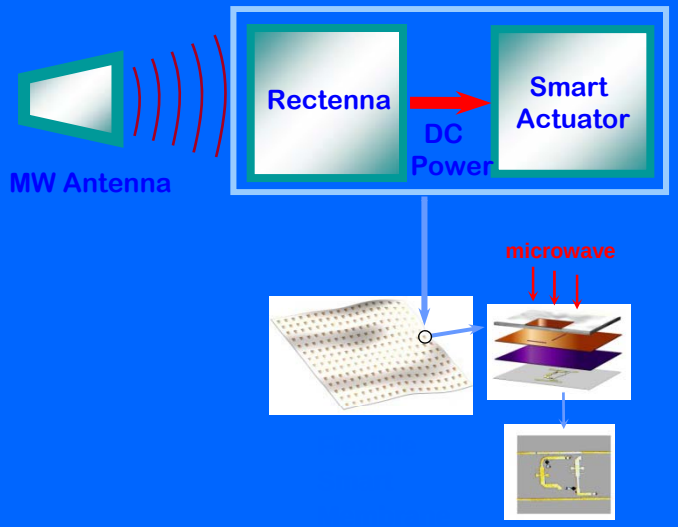
By Matt Welsh
Harvard University

Other Medical Applications ?

Microwave-driven Membrane Actuator Technology

Concept

As a Single Embodiment



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- Control algorithm carried on MW signal enables actuators to be tuned for shape control.
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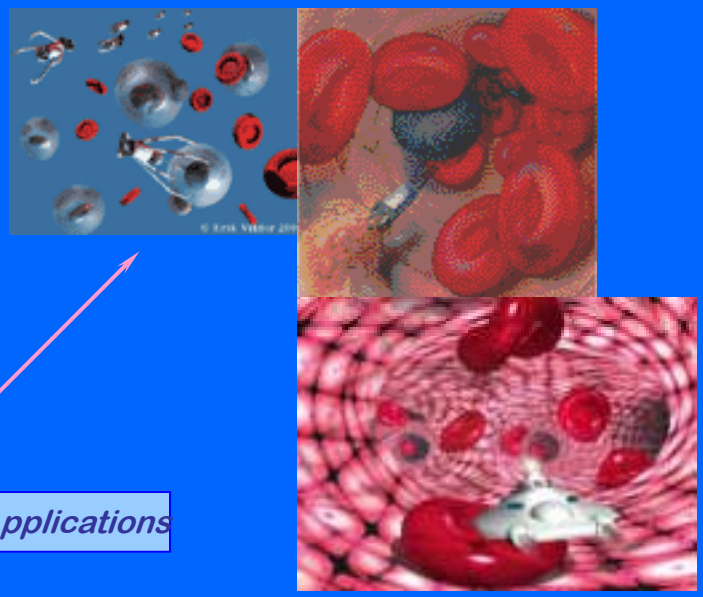
Applications



J.C. Chiao

Probe-Pin Devices with Wireless Power

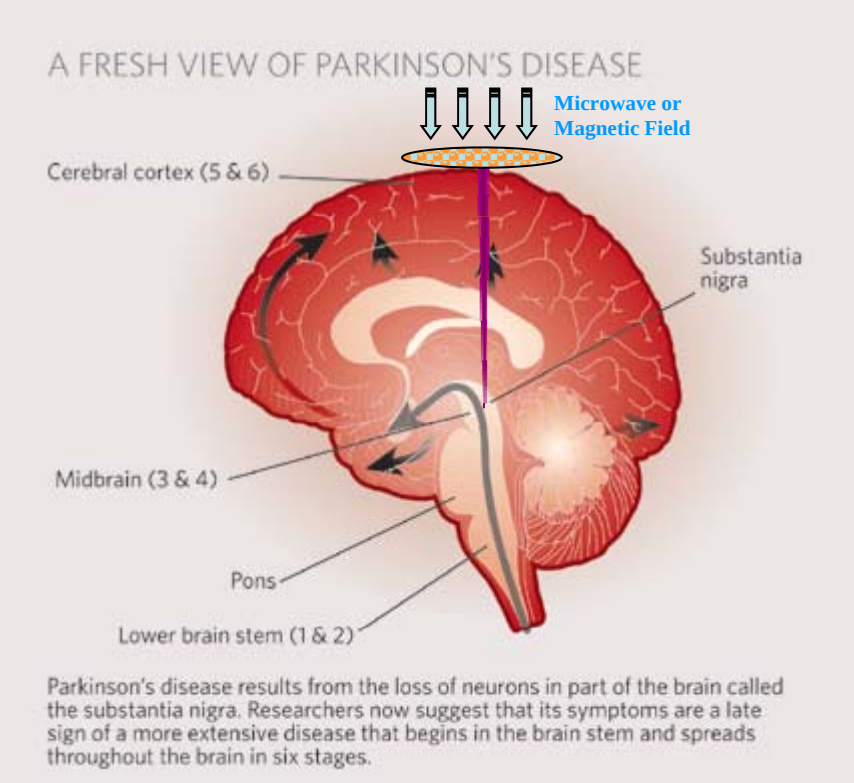


Fig. 1 A wireless power receiver with a probe-pin device (PPD) is implanted for deep brain stimulation (DBS). The wireless power receiver couples with incident microwave (Fig. 2) or with rotating magnetic field (Fig. 3)

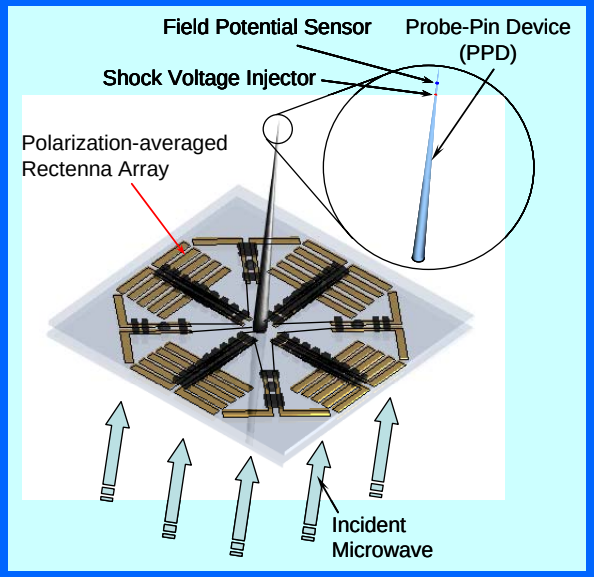


Fig. 2 An array of dipole rectennas with a probe-pin device (PPD) couples with microwave to generate DC power for DBS.

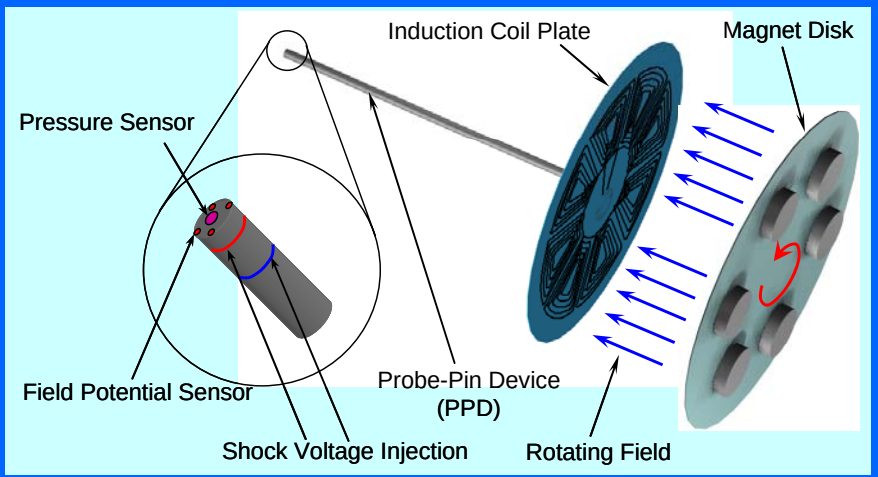
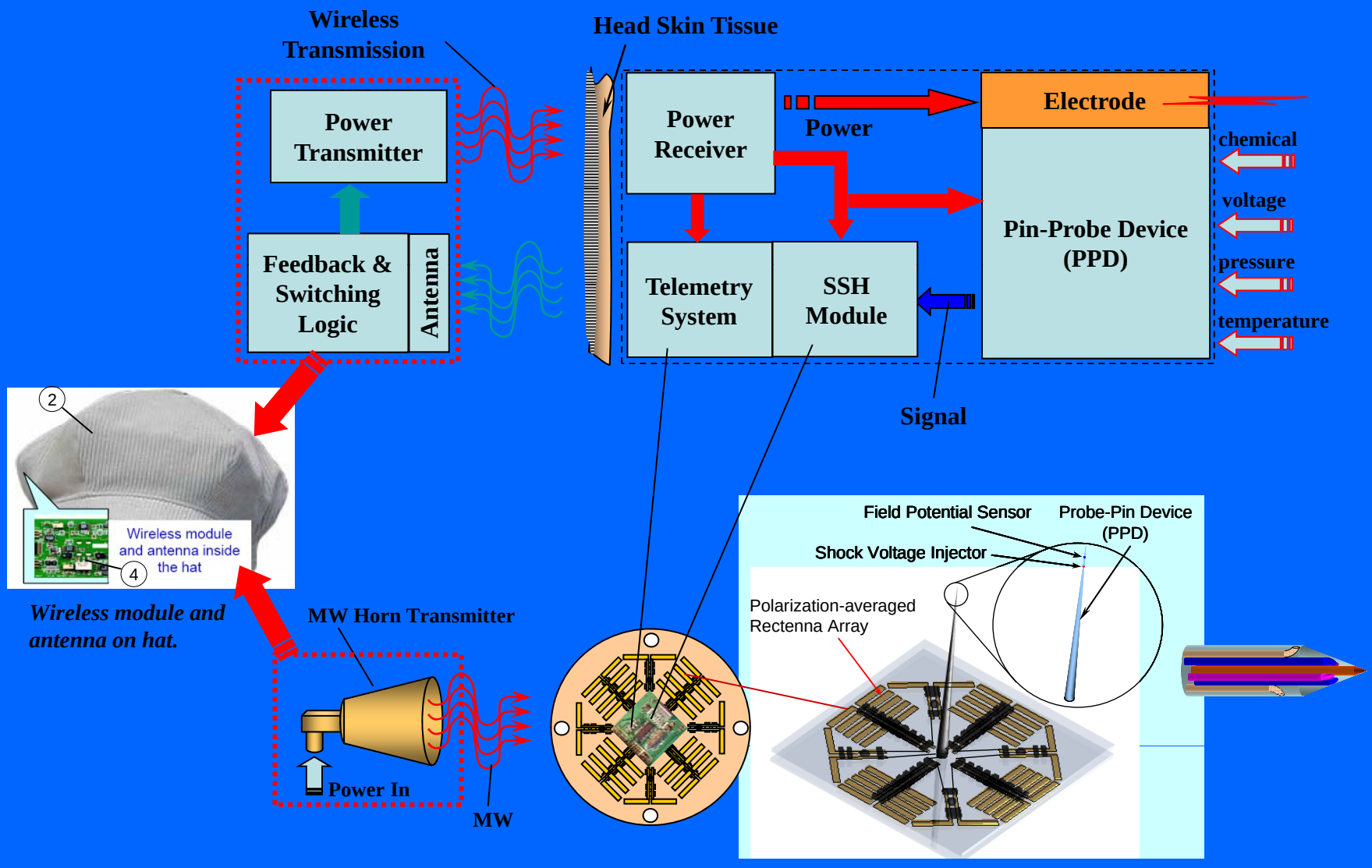
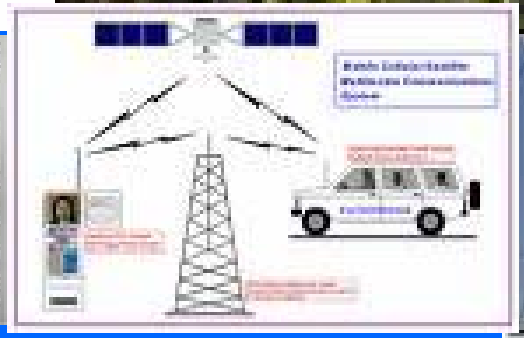


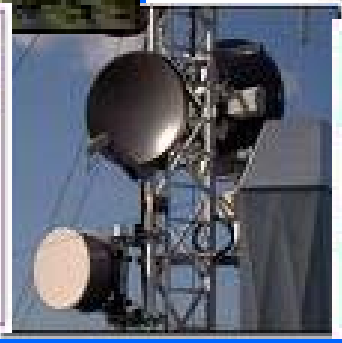
Fig. 3 A magnetic induction coils with a probe-pin device (PPD) couples with a rotating magnetic field for DC power for DBS.

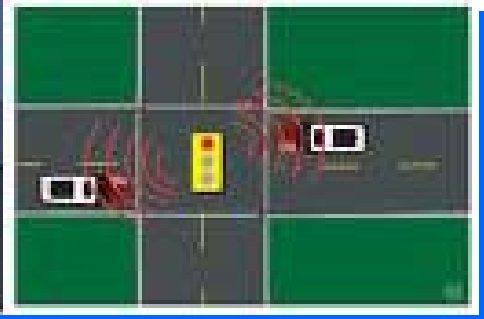
Master Logic dependent PPD



Microwave Exposure on Human Body?







Cellar Phone Interference in a class room

In social reasons, the cellular phones are required to be off when they are in places such as class room, libraries, law courts, churches, concert halls and theaters.

- In safety and security reasons, the cellular phones should be off where they are in hospital, petrol stations and especially to ensure that explosive bombs are not detonated remotely by a cellular phone.

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Jamming Device

- The radio waves emitted by an intentional jamming device may cut off the calls of cellular phones in a specified area.

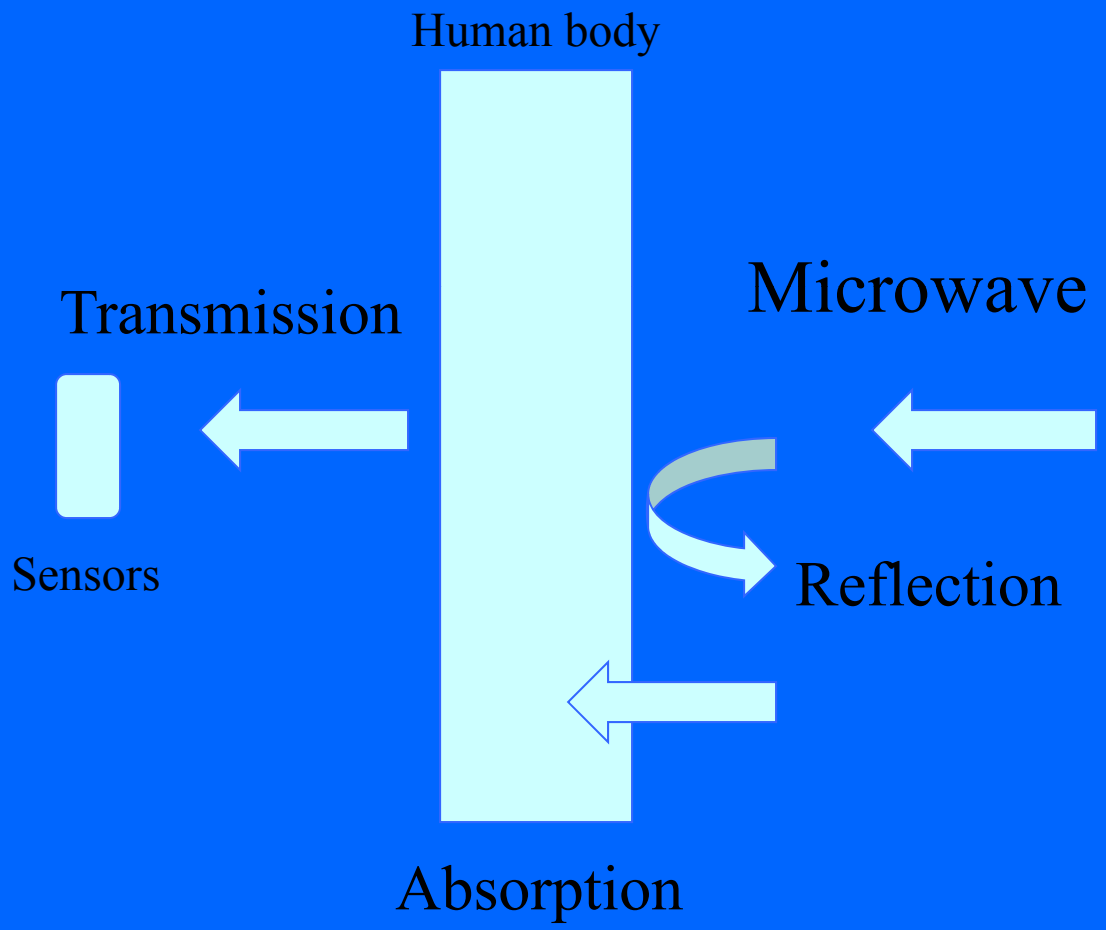
Legal Issues

- In the United States, cell-phone jamming is covered under the Communication Act of 1934, which prohibits people from willfully or maliciously interfering with the radio communications of any station licensed or authorized to operate.

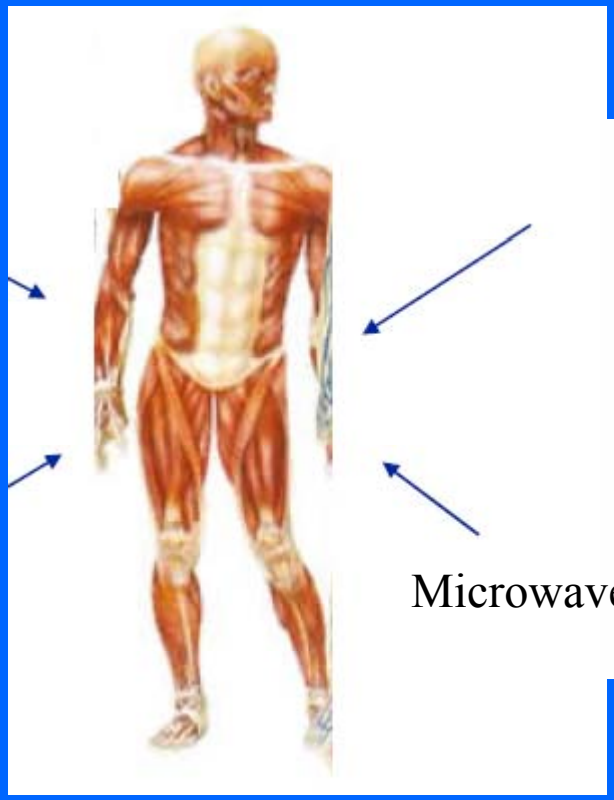
The mysterious deaths of the honeybees

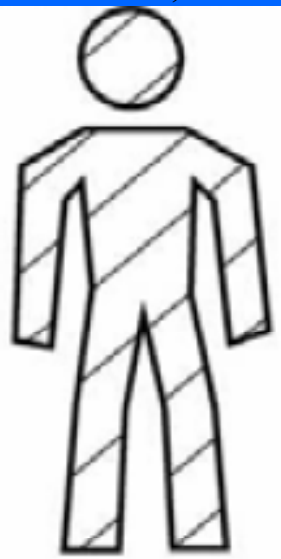
- **Honeybee colony collapse drives price of honey higher and threatens fruit and vegetable production.**
- Beekeepers throughout the United States have been losing between 50 and 90 percent of their honeybees over the past six months, perplexing scientists, driving honey prices higher and threatening fruit and vegetable production.
- but does not explain the reason. Primary reasons suggested, and sometimes in the past confirmed, include parasitic mites and consequent viruses.
- **However, the electromagnetic environment is also crucially influential on honeybees, and is undergoing rapid and enormous change from human communications systems.**

Major Concerning

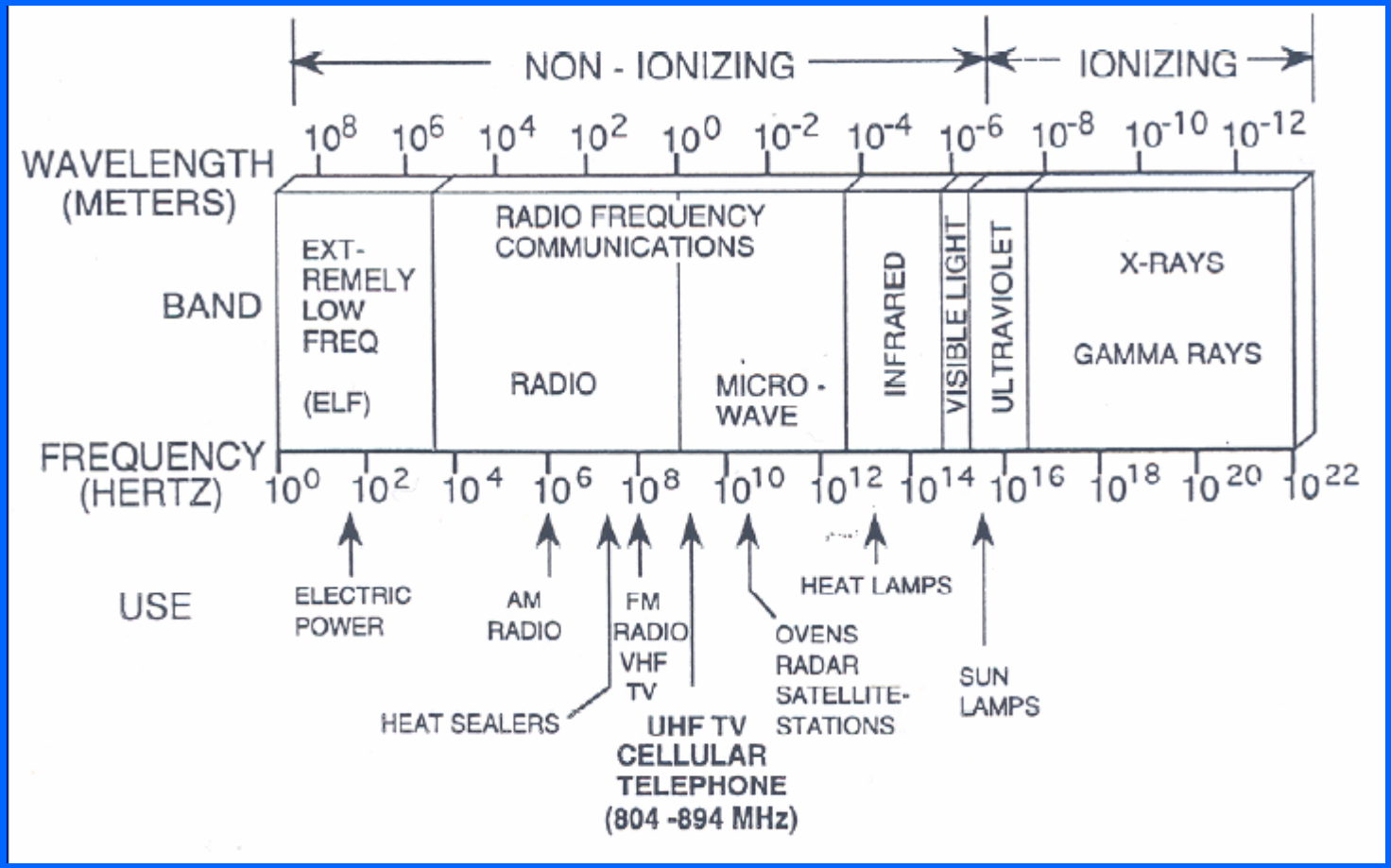


Microwave Exposure on human body –Safety ?



Low Frequency (< 30 MHz)	Medium Frequency (30-300 MHz)	High Frequency (>300 MHz)
		
Low average SAR Uniform Distribution	High SAR Uniform Distribution	Low SAR Surface absorption

Safety (Electromagnetic Spectrum)



From: Rothman; Epidemiology (1996)

The electromagnetic spectrum:
wavelength, frequency, and energy

Nonionizing ← ← ← | → Ionizing

Am Radio 100 kHz	FM/TV 100 MHz	Microwaves 100 GHz	IR Heating 10^{13} Hz	Visible 10^{15} Hz	Medical X-Rays 10^{18} Hz
3 km 0.4 neV	3 m 0.4 μeV	3 mm 0.4 meV	30 μm 0.04 eV	300 nm 4 eV	0.3 nm 4 keV

Cell Phones:
1 ~2 GHz

Human body heat

Vision

Induced Currents

Vibrate molecules

Photo-chemistry

Molecular, DNA damage

Typical E & M energies

Radiation	Energy	Actions
Soft x-ray	4 keV	Ionize molecules
Visible light	1 to 3 eV	Bend molecules
Thermal energy (IR)	0.03 eV	Dis-aggregate molecular clusters
Microwave	0.0004 eV	Vibrate molecules
2 GHz Cellular Phone	0.00001 eV	?

Source strengths

• Cellular Phone	~0.5 Watt
• Single light bulb	100 Watts
• Single ham-radio antenna	1 kW
• Array of Cellular phone base-station antennas	1.2 kW
• Typical AM Radio Station transmitter	50kW
• Typical FM radio station transmitter	100kW
• Typical UHF TV transmitter	1 MW

Irradiances

- Sunlight (1 solar Constant); 137.2 W/cm^2
- Microwave oven leakage standard (in-home use): 5 mW/cm^2
- Cellular Phone (2 GHz) whole-body public guideline: 1 mW/cm^2

SAR

- SAR is proportional to the square of the internal electric field strength.

$$SAR = \frac{\sigma \left| E^2 \right|}{\rho}$$

Where, σ = Conductivity of the tissue (S/m)

ρ = mass density of the tissue (kg/m^3)

E= rms electric field strength in tissue (V/m)

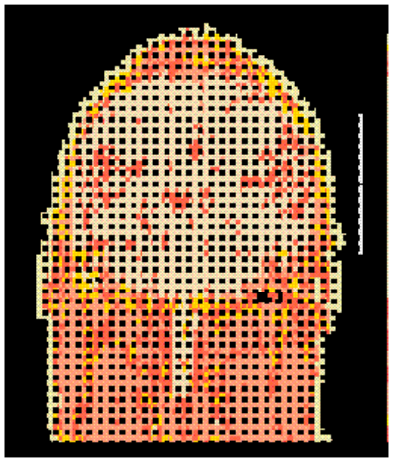
Radiation Standards ?

Exposure Limits

(0.3 – 100,000 MHz)

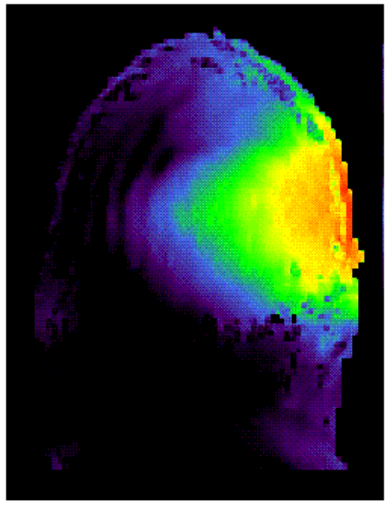
- Whole-body exposure (FCC) :
  - Controlled/Occupational exposure:
    - 4 W/kg 0.4 W/kg
  - Uncontrolled/Public exposure
    - 4W/kg 0.08 W/kg (divided by 50)

- Partial-body(local) exposure:
  - 1.6 W/kg for public/uncontrolled exposure



Voxel size = 1.0x1.0x1.0 mm

Tissues: muscle & high water content tissue-light red, fat and bone-dark yellow, blood-dark red, brain -light yellow, skin-ligh yellow



Radiated power from antenna = 125 mW

0 db = 9.50 W/kg

SAR distribution in phantom human Head model exposed 1.9 GHz dipole Antenna.

Calculated specific absorbed radiation (SAR) distribution in an anatomical model of head next to a 125 mW dipole antenna. Peak SAR is 9.5 W/kg averaged over a 1 mg cube. **(*USAF/AFRL*).**

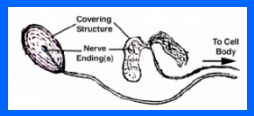
Actions on fixed or free charges

- Microwave fields applied to tissue will cause force on
  - Free charges: current may flow
  - Fixed charges: dipole may vibrate
- These established Microwave interactions may
  - Lead to temperature changes
  - Re-orient proteins
  - Distort proteins
  - Cause membrane breakdown

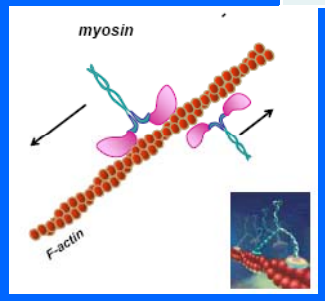
Can these actions on electric charges affect biology?

- Possibly, Yes.,
  - Charged ions, molecules, structures are present
  - At molecular level, interactions are electrical in nature; human body is electrical charged
- But, maybe Not,
  - Can forces caused by microwave be heard in the noise of natural cells
  - How do microwave effects link to disease or malfunction?

Biological force generator



Force Transducer	Measured force
Hair cell activation in inner ear	1 pN
Single kinesin (protein dimer) molecule	3 pN
Single actin molecule	4 pN
Mechano-receptive ion channel	12 pN
Stretch DNA molecule 10%	20 pN
DNA strand-to-strand binding	70 pN
Stall force of flagellar motor	100 pN



What force can E-fields from microwave exert on charged biological molecules?

- Use ICNIRP guideline for maximum allowable SAR (2 W/kg); the associated electric field strength in tissue is about 45 V/m at 1 GHz.
- Then, the force on a cell-membrane protein (Using Coulomb's law) with 100 unbalanced charges is ~ 0.001 pN.

After Peter Valberg, 2005

- However, the dipole moment of water molecule due to microwave can not be neglected.

International Commission on Non-Ionizing Radiation Protection (*ICNIRP*).

Thermodynamic Facts about organisms at 310K

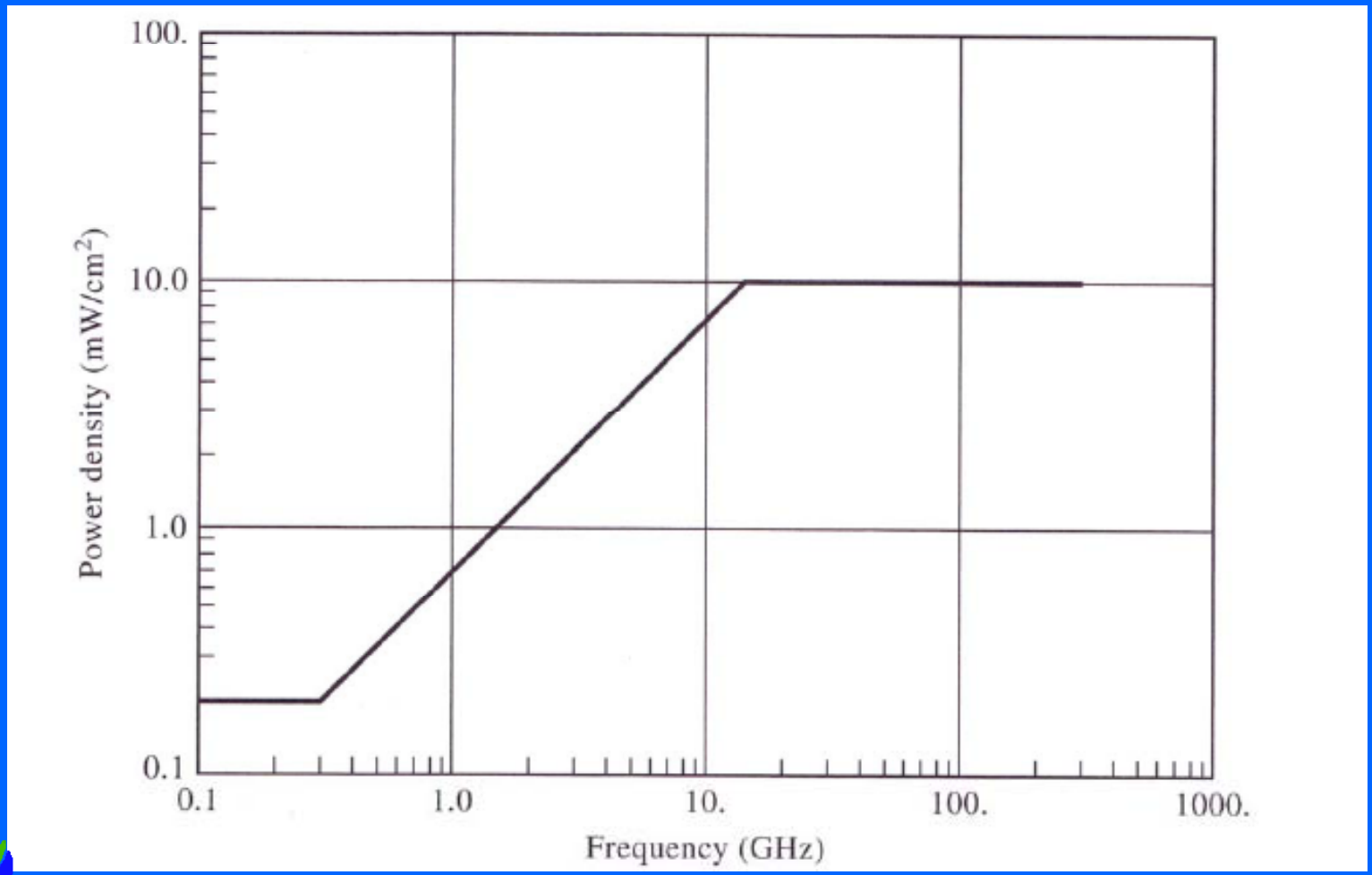
- Peak E & M emission are at a wavelength Of ~ 10μm
- Based on Blackbody radiation at 310K is ~ 2 mW/cm^2 (Stefan-Boltzmann's Law)

E & M Irradiance in mW/cm^2

- Noonday sunlight at the earth's surface 140
- Heat loss from 37 C body (radiation) 2
- 3 feet from a 100-watt light bulb 1
- RF guideline, for 850 MHz, Occupational 3

- RF guideline, for 1.9 GHz Occupational 5

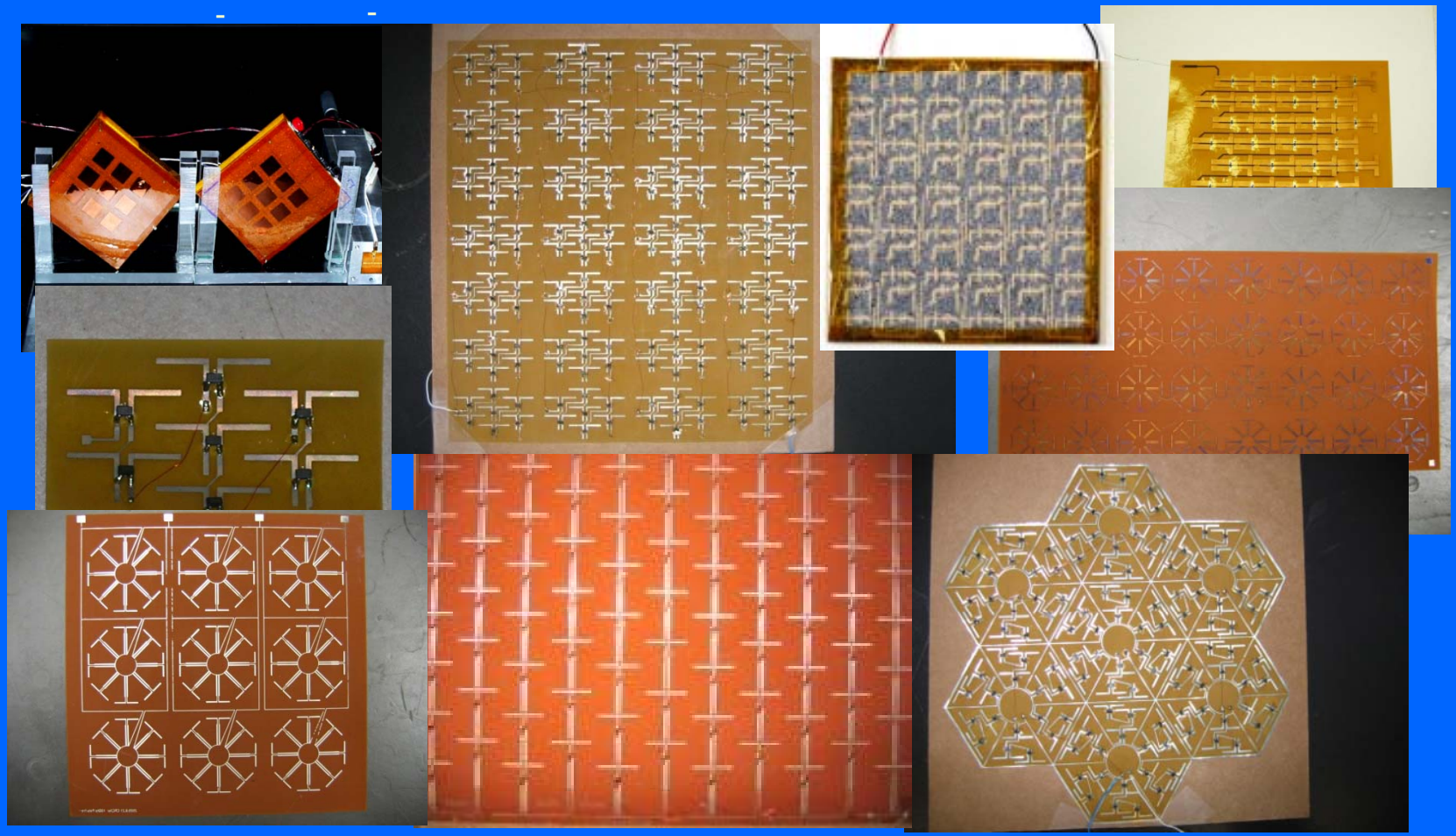
Recommended power density limits



Energy Weapon ?

- Active Denial System (ADS)
  - May be deployed in Iraq in " months, to reduce causalities", USA today, July 2005.
- But, Limited knowledge of Potential effects
  - "The long-term physiological effects of the microwave received by an individual are still being studied. …." Non-Lethal Weapons and Future Peace Enforcement Operations, NATO RTO Technical Report, 2004.

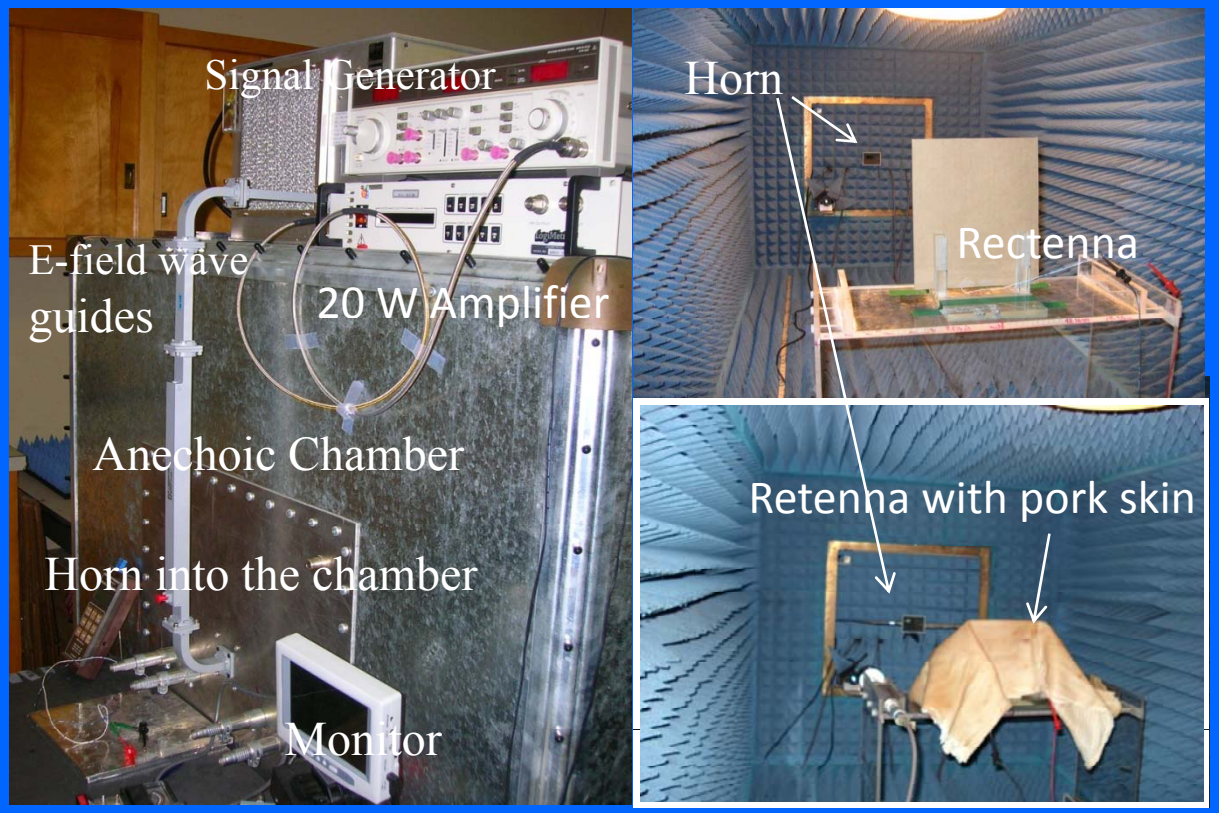
Various Rectennas Developed

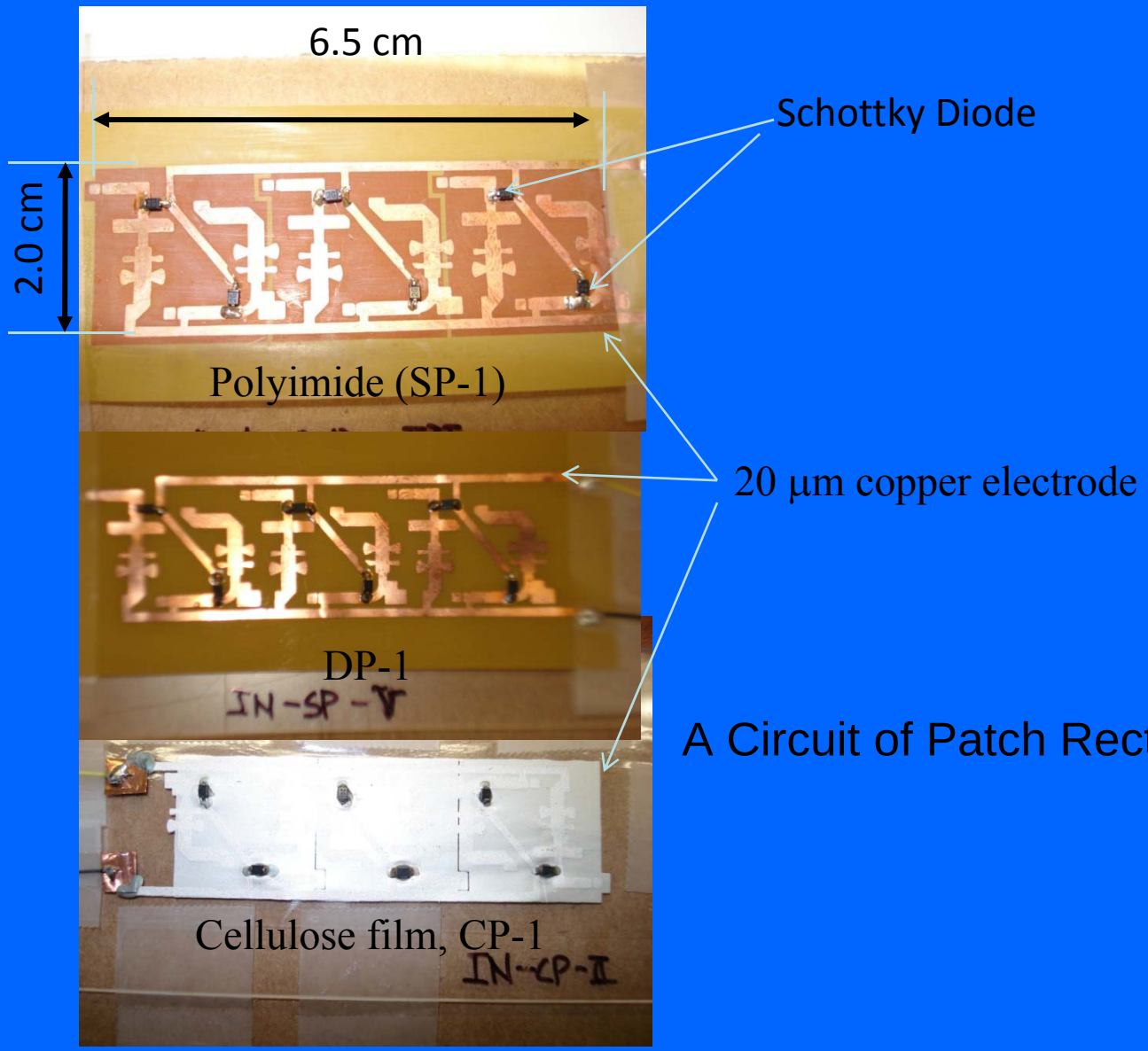


Performance of rectennas developed

Model	# of Rectennas	**Output Voltages (V)**	**Output Current (mA)**	**Circuitry**	**Remarks**
DR-10-P4-S6	24	50	20	P/S	**14 X 9.5 cm**
DR-10-P10-S9	95	2	100	P/S	**20 x 20 cm (Thinner R.)**
DR-10PF0-S1	8	2	25		**Round Array**
DR-10PFO-P9-S9	72	12	30-40	P/S	
DR-0507	105	20	340	P/S	**20 x 20 cm (Thinner R.)**
DR-PF-10-S3-P42	196	15	260	P/S	**16 x 20 cm**
Polyimide Rectenna	2	10	2.5	P/S	**2 X 6.5 cm**
Cellulose Rectenna	2	11	2.5	P/S	**2 x 6.5 cm**

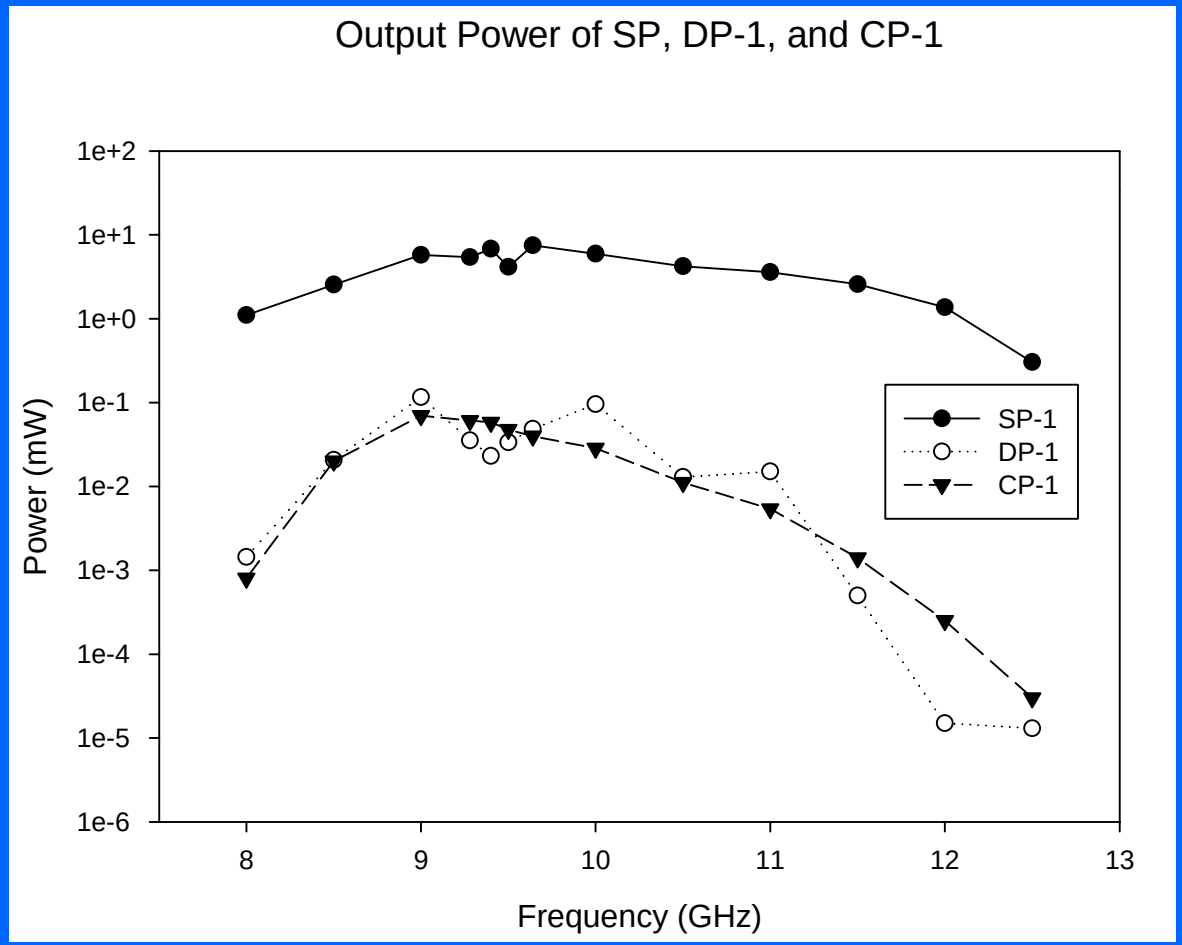
Experimental Set up for rectenna performance measurement for polyurethanes and pork skin



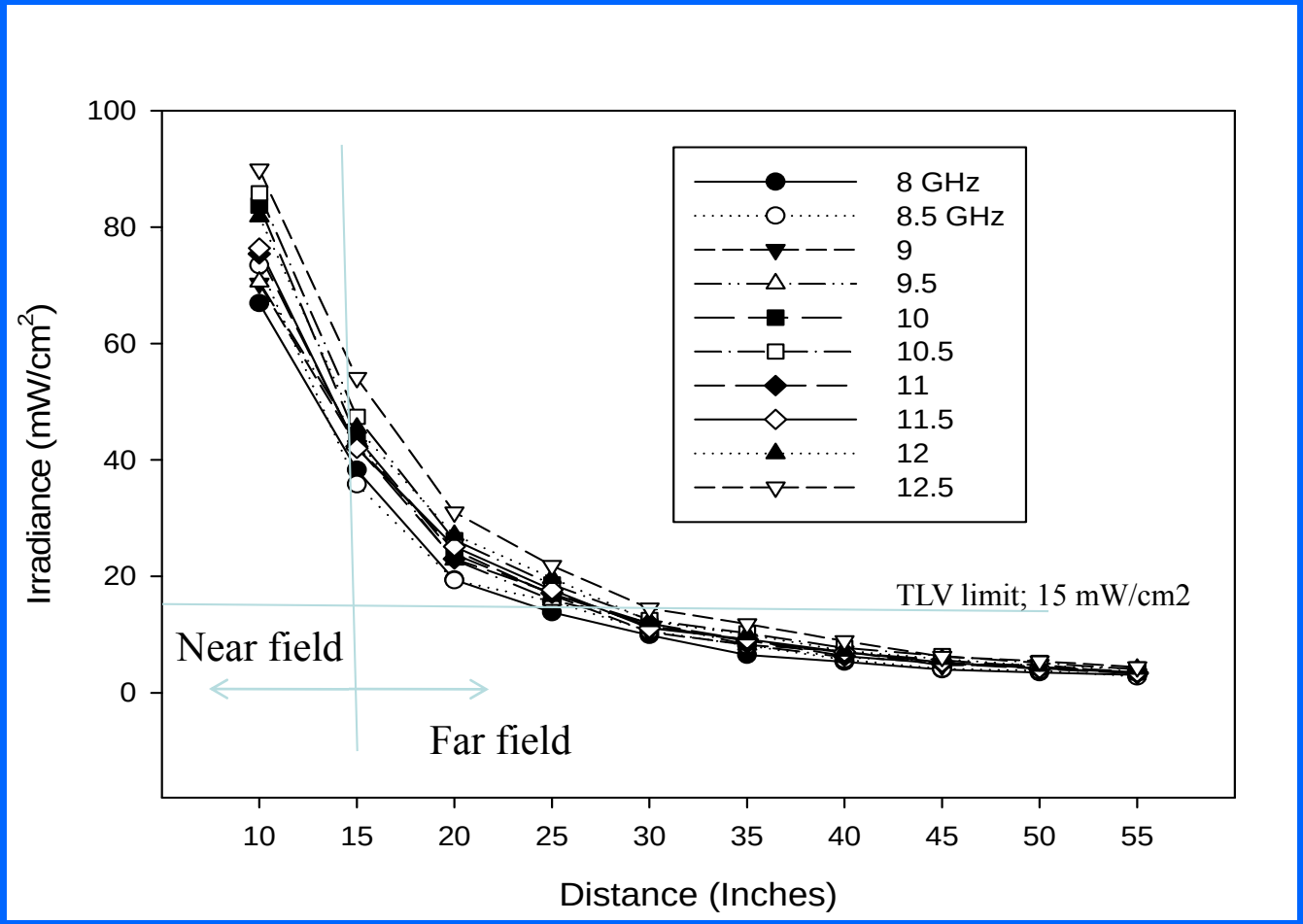


A Circuit of Patch Rectenna

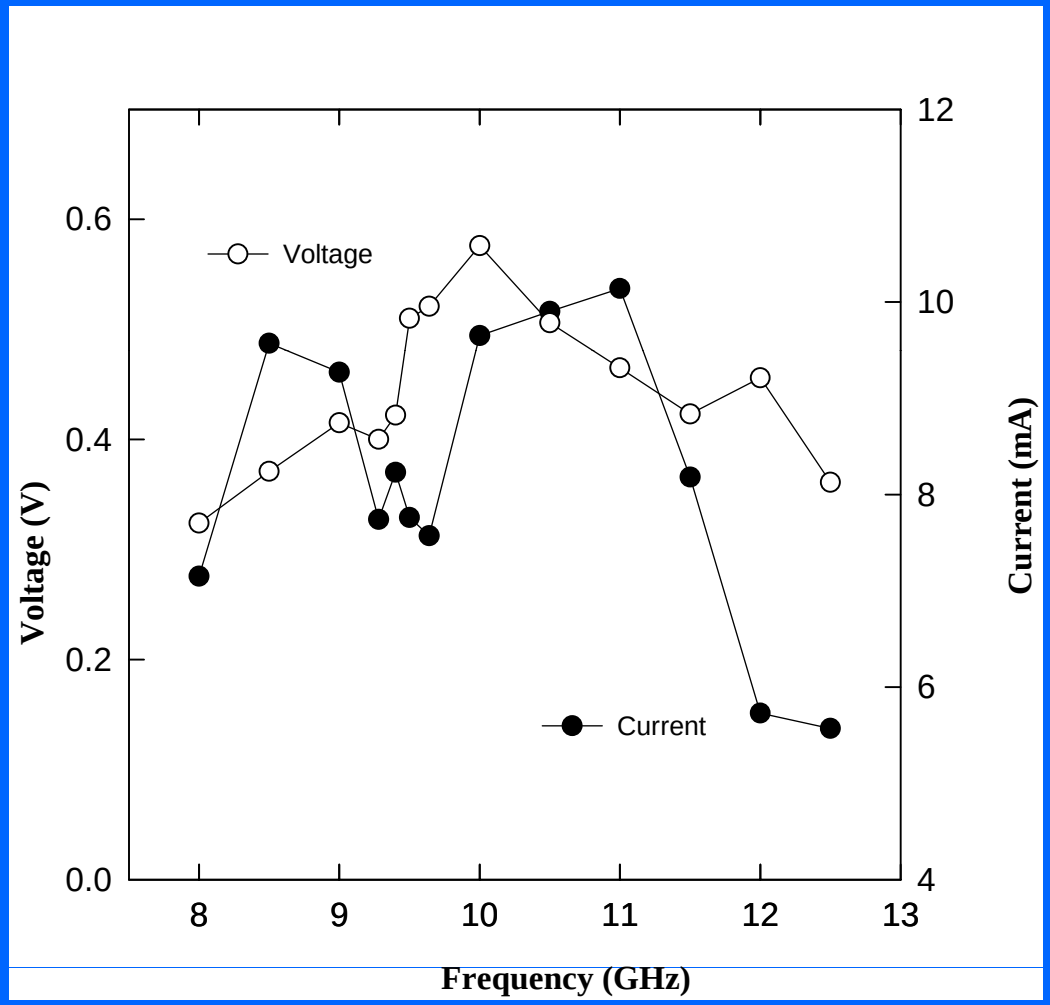
Output Voltage of Polyimide Rectenna vs Distances from the Horn



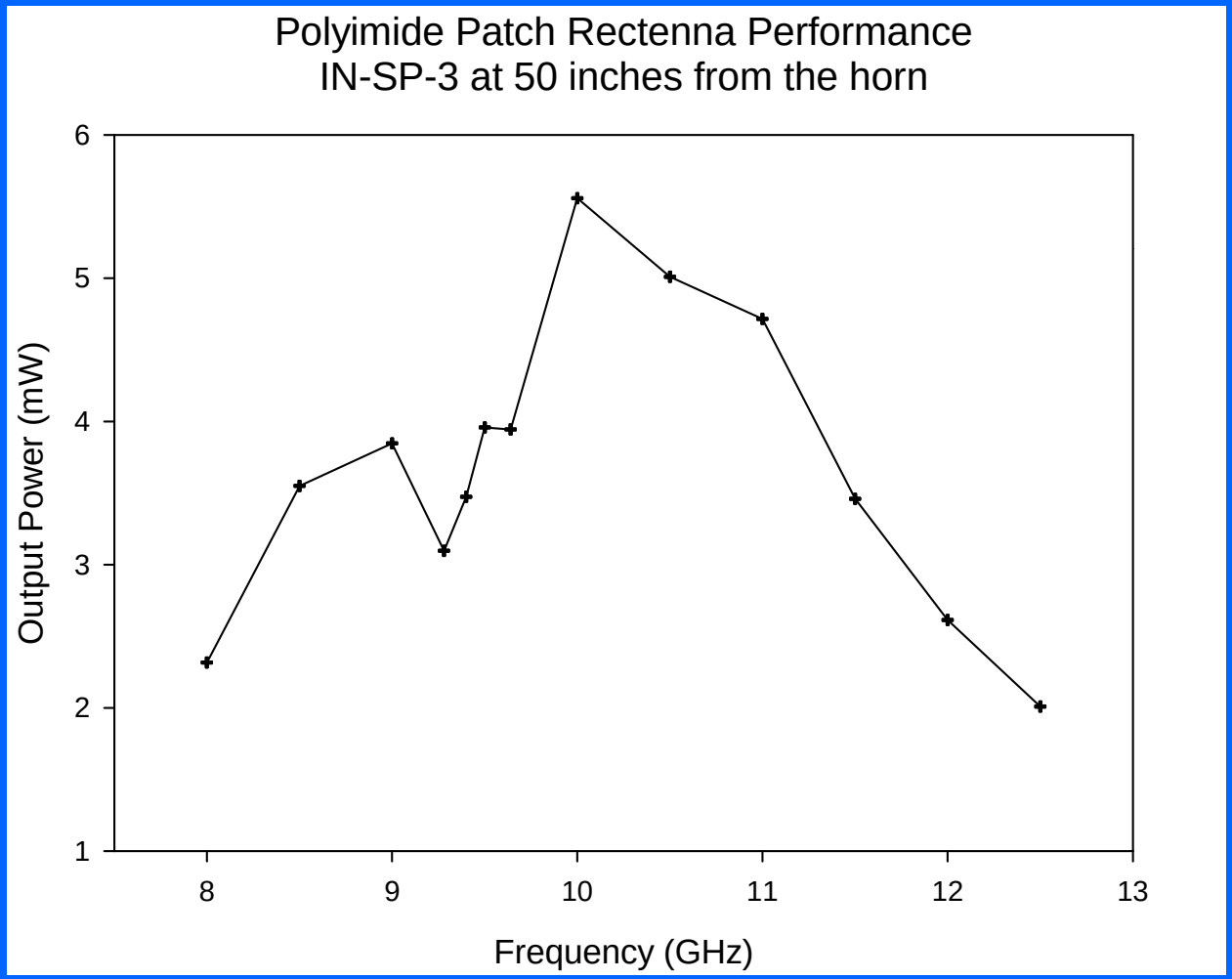
Irradiance of microwave along the distances



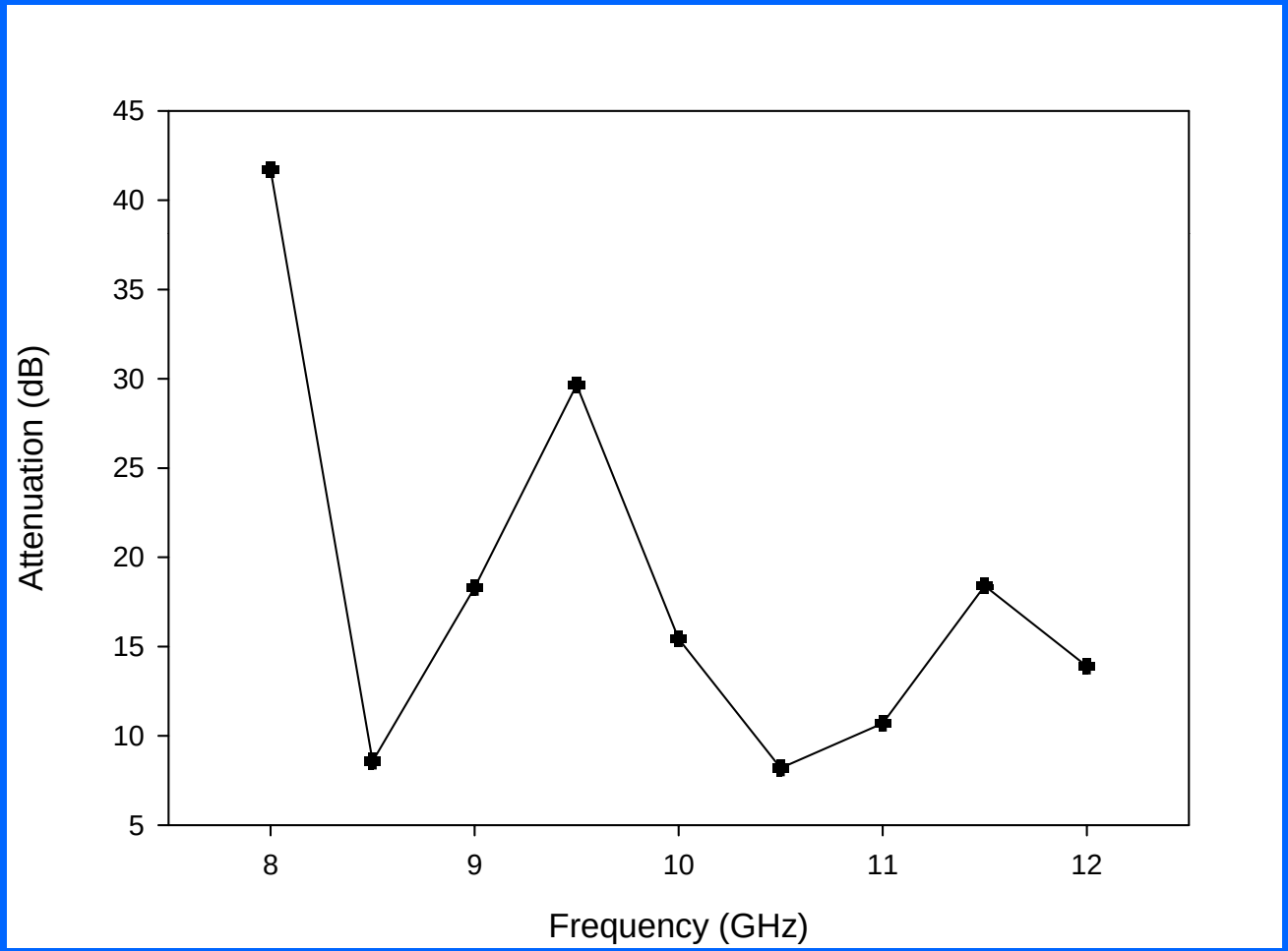
Output voltage and current from a polyimide rectenna (IN-SP-3)



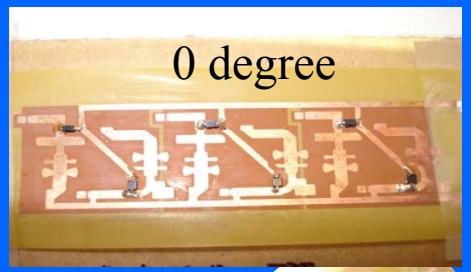
Output power of the polyimide rectenna (IN-SP-3) at 50 inches from the horn.

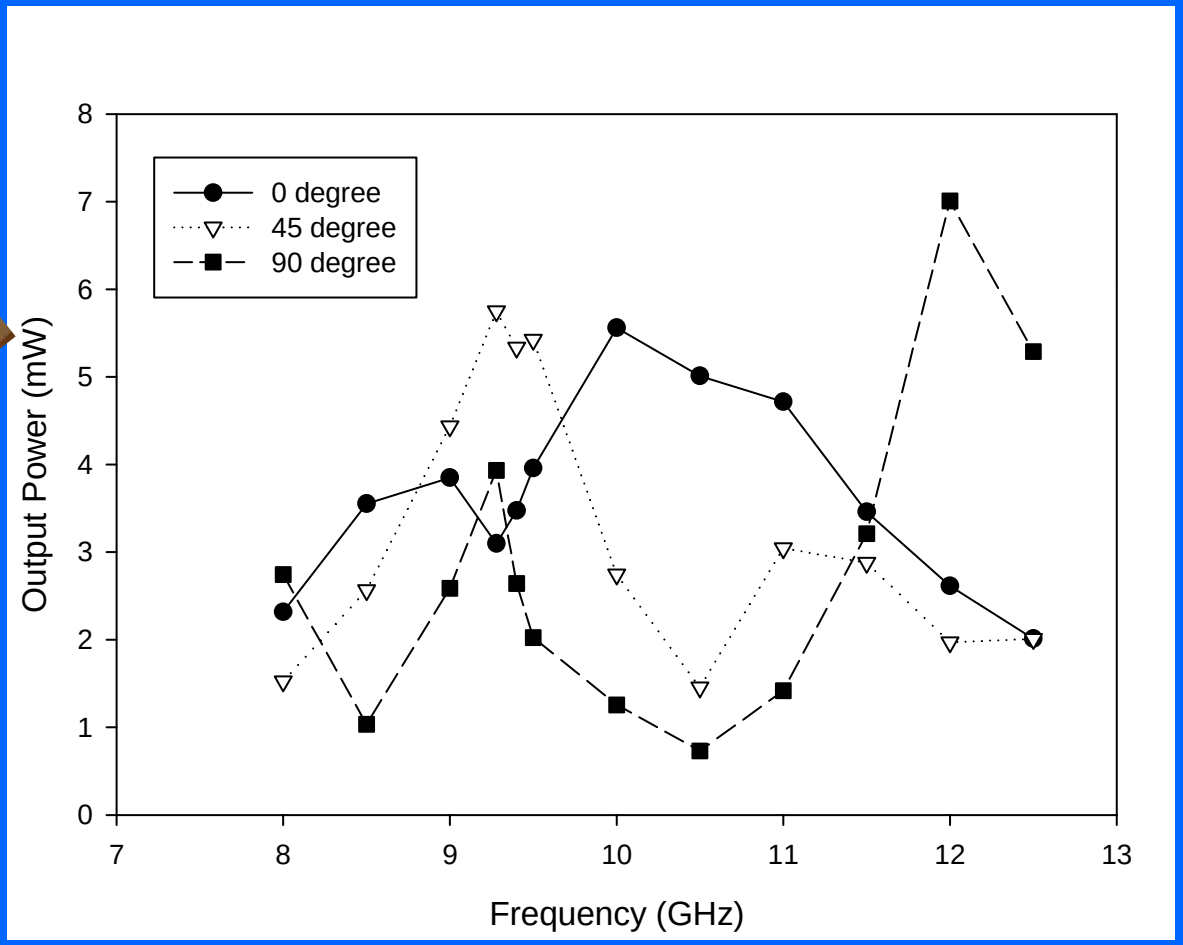


Attenuation in power in swine skin (0.067 – 0.09”) from 8-13 GHz



Output power vs Rotational angles





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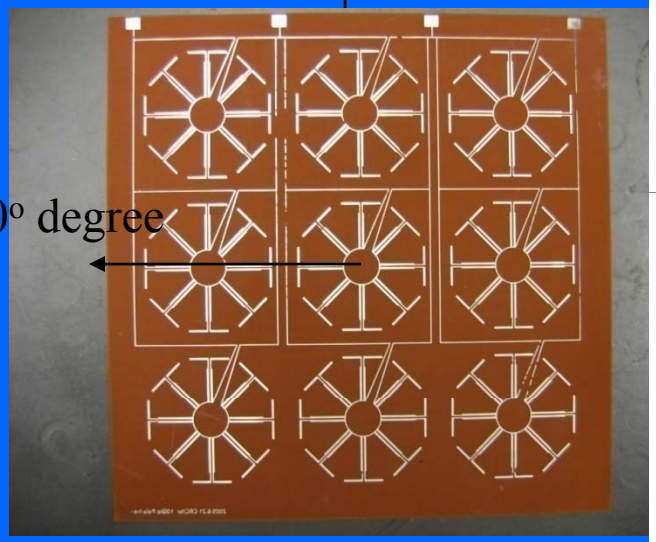
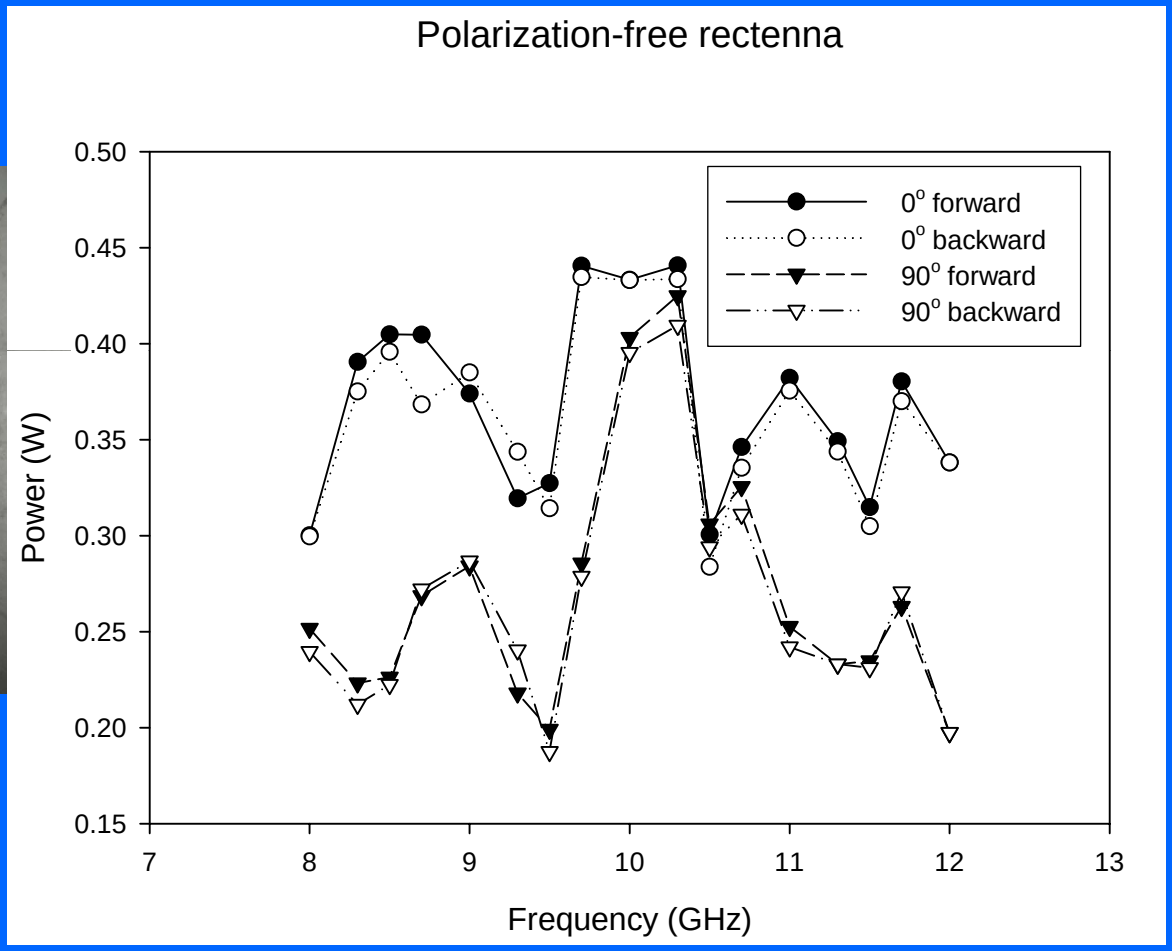
Compact and Polarity-free enhanced Dipole Rectenna Array



3 x 3 flexible rectenna



Summary

- The possible RF radiation effects are reviewed.
- A swine skin used in simulation of human skin-tissues have tested with a microwave power in ranges of 8 to 12.5 GHz.
- Based on the result of the experiment, the attenuation of the swine skin is significantly depends on frequency.
- The attenuation will also contribute to absorption in the skin that will increase biological effects by this radiation.
- It is necessary to measure any effects on the human body by radiation such as prolonged exposure with cumulative effects that could lead to carcinogenic effects.

Questions?