Established Bioeffects and Medical Applications of Electromagnetic Fields Across the Spectrum

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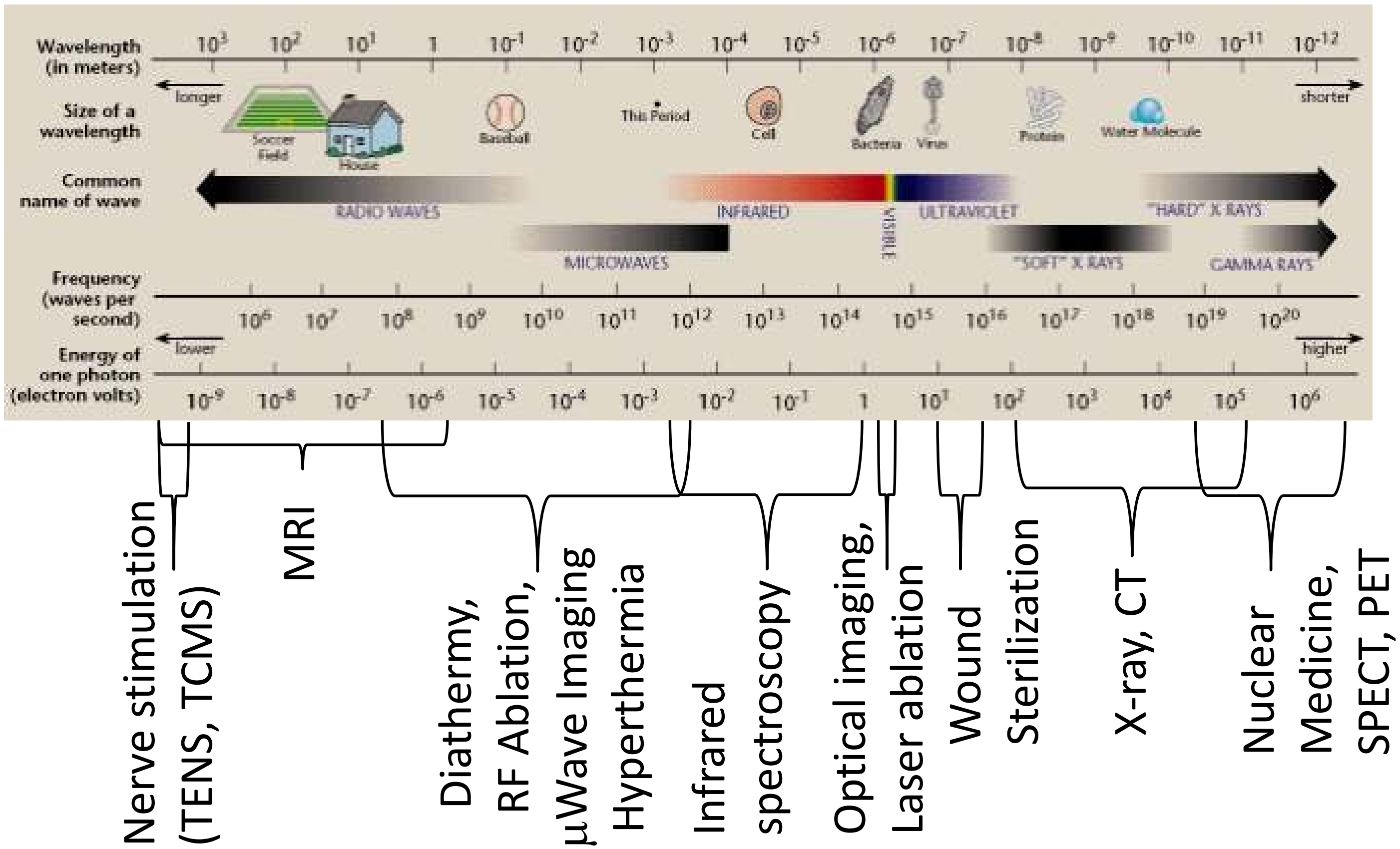
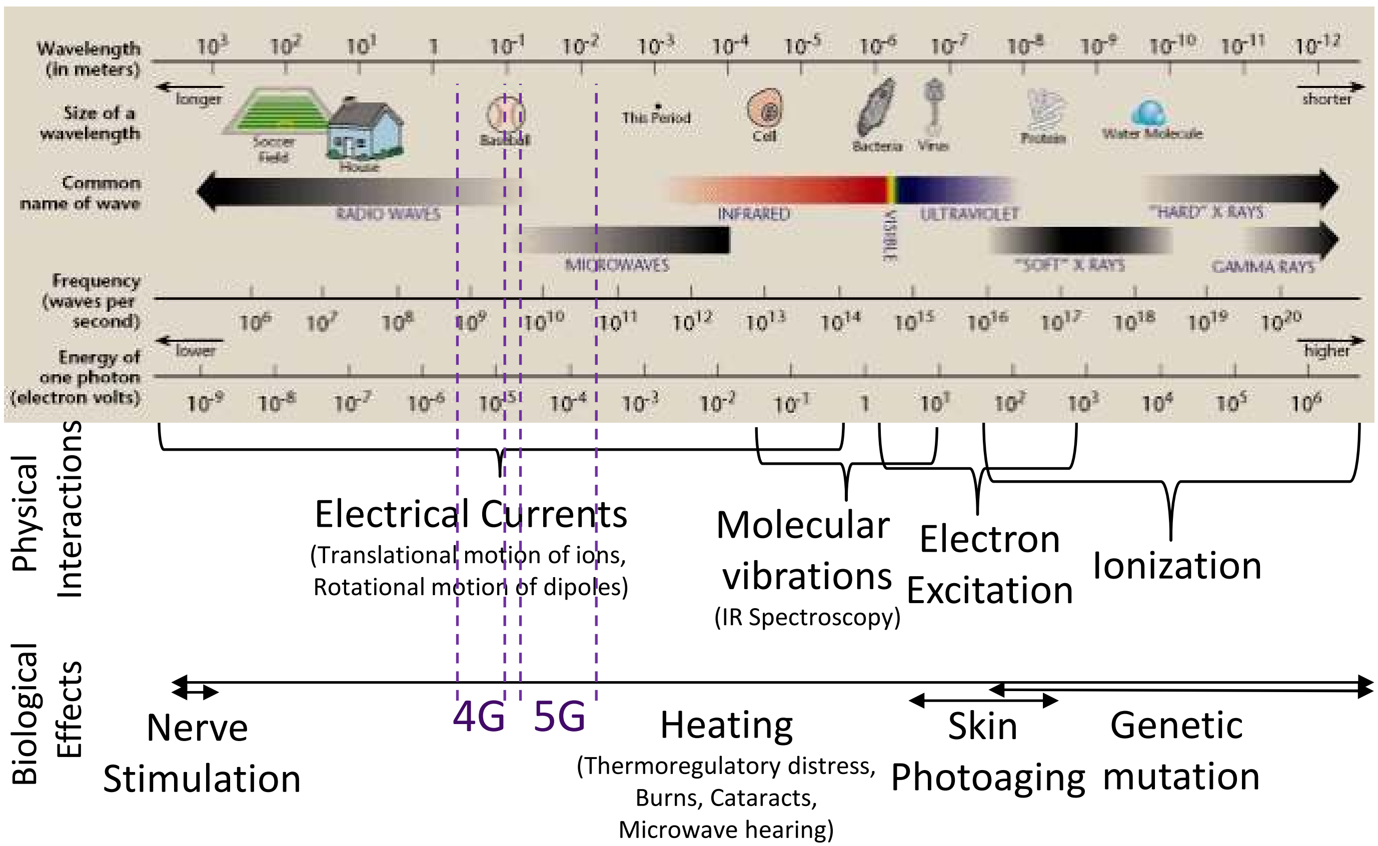
A little about me:

- Professor of Radiology at NYU's School of Medicine
- 25+ years experience in Engineering and safety assurance for MRI
- Taught medical imaging to undergraduate and graduate students, safety of medical imaging (all modalities) to MDs
- Since coming to NYU, worked with Ted Rappaport on Safety of 5G
- (Senior member of IEEE)

Biomedical Applications of Electromagnetic Energy



Physical interactions between EM fields and tissue



Simulations of Temperature with mmWave Exposure: One-dimensional models of tissue in far field

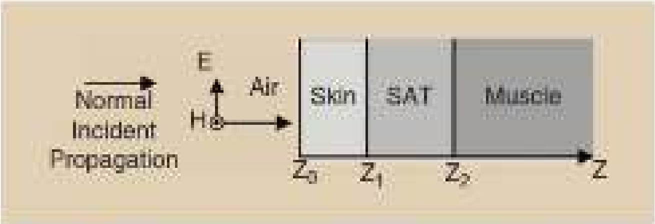


Figure 8. *A 1-D three-layer model of human tissue containing skin, SAT, and muscle.*

TABLE 8. The adopted relative permittivity and conductivity in the three-layer tissue model.

f (GHz)	Skin		SAT		Muscle	
	ε_r	σ	ε_r	σ	ε_r	σ
40	11.69	31.78	5.21	6.58	18.24	43.13
60	7.98	36.38	4.4	8.39	12.86	52.8
80	6.4	38.38	3.95	9.66	10.17	58.58
100	5.6	39.42	3.67	10.63	8.63	62.47

TABLE 9. The adopted mass density, thermal constant, and tissue thickness in the three-layer tissue model.

	Skin	SAT	Muscle	Blood
ρ (kg/m^3)	1,109	911	1,090	1,050
c (J/kg/°C)	3,391	2,348	3,421	3,617
k (W/m/°C)	0.37	0.21	0.49	0.52
w (mL/kg/min)	106	33	37	10,000
Q_m (W/m^3) [72]	1,620	300	480	0
Tissue thickness (mm)	1	3	31	/

Wu, Rappaport, & Collins, IEEE Microwave Magazine, March 2015

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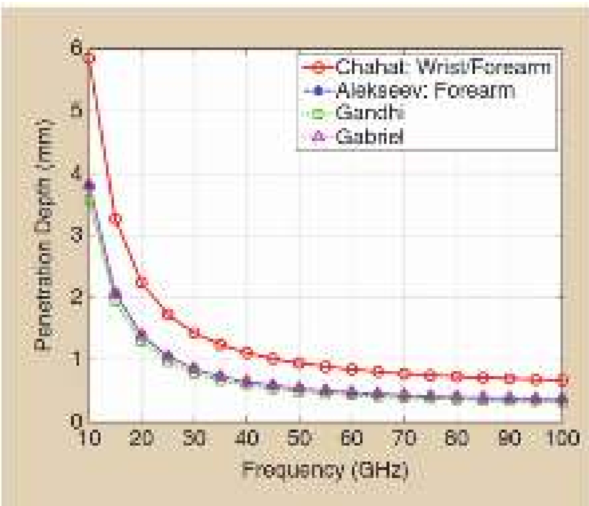


Figure 6. *The penetration depth in the human skin with the increase of exposure frequency.*

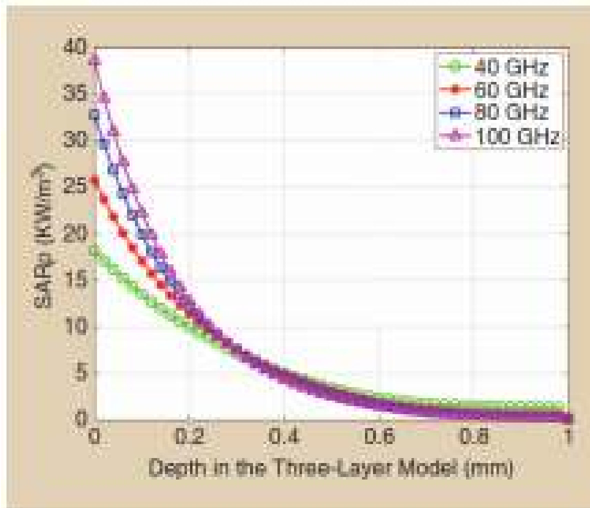


Figure 9. *The SARρ distribution due to 10 W/m² mmWave radiation at 40, 60, 80, and 100 GHz.*

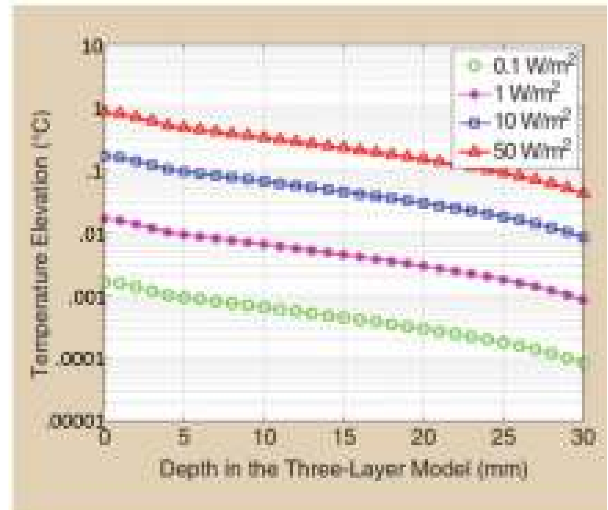


Figure 10. *The steady-state temperature elevation in the three-layer human tissue model at 60 GHz with different incident power densities.*

Wu, Rappaport, & Collins, IEEE Microwave Magazine, March 2015

Established effects in 4G and proposed 5G bands originate with heating:

- “Established” means shown to be repeatable by multiple independent investigators.
- Increase in temperature can cause a range of predictable and sometimes surprising effects.
- As frequency increases, depth of penetration into the body decreases
- If power levels are kept low enough to cause negligible temperature increase, we expect no adverse effects
- Example of routine exposure to high-power, high-frequency radiation: walking outside on a sunny day

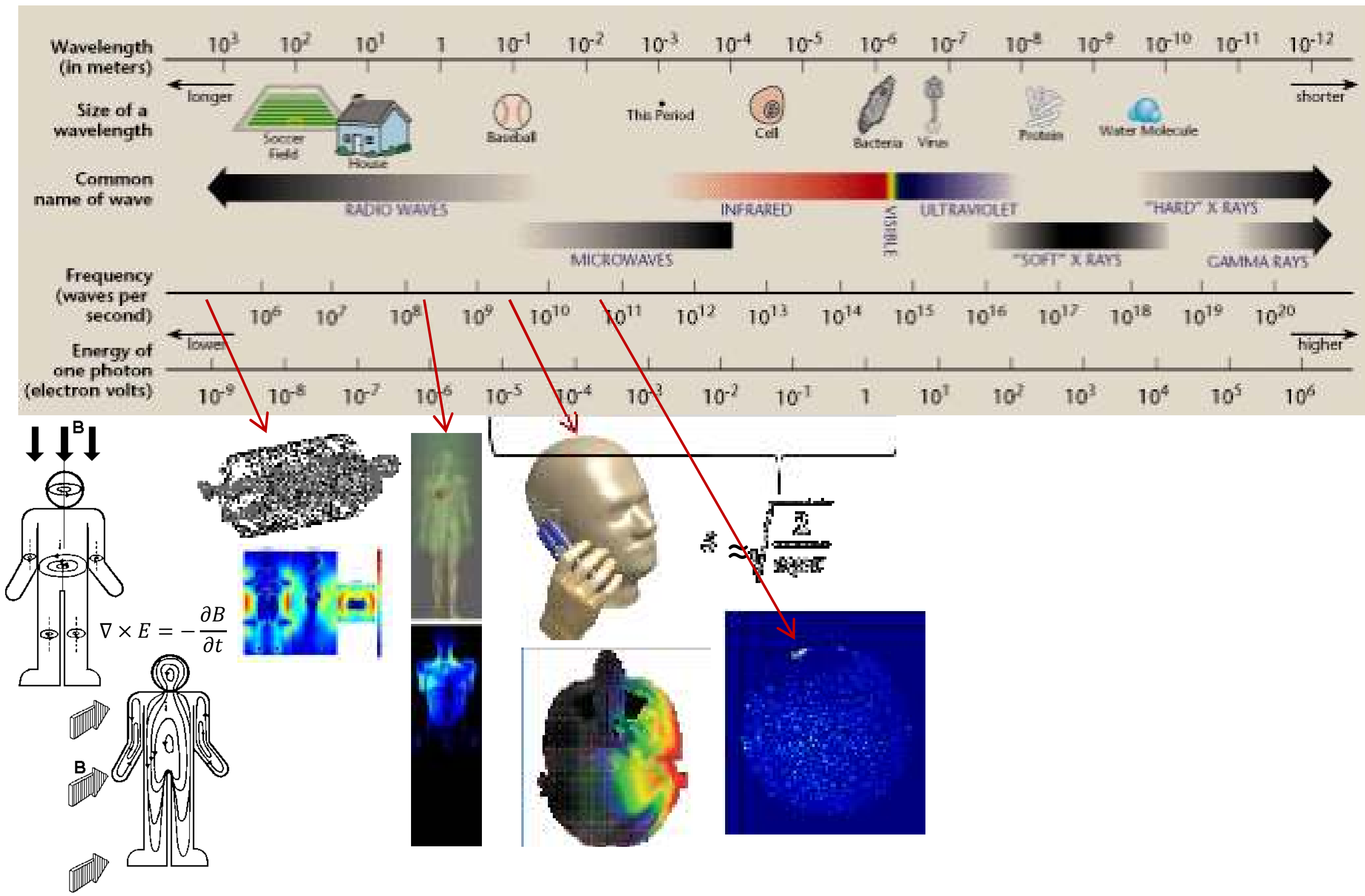
Nonthermal effects in 4G and proposed 5G bands?

- *Lots* of individual studies reporting a range of effects
- At this time, either not shown to be repeatable or are possibly thermal in nature (or both)

Case study in recently-reported "nonthermal" adverse effect:

- **National Toxicology Program study on rats and mice (2018)**
- Exposed thousands of mice and rats of different strains to 4G cell-phone type frequencies 10 minutes on, 10 minutes off almost all day (~9.2 hours "on" each day), every day from conception through death (2 year lifespan of rats)
- Classified exposure as non-thermal because a single 10-minute exposure raised the body temperature by less than 1 degree Celsius
- Found a statistically significant increase in cancer of the heart in males of one strain of rat
  - No other statistically significant *adverse* effects found in that or any other groups
- Acknowledged that power levels were higher than what would be expected for human exposures, but didn't really put it into context
- Whole-body SAR levels of 1.5, 3, and 6 W/kg with the exposure patterns used would result in increasing the body temperature of the rats by 12, 25, or 50 degrees Celsius each day if not for the thermoregulatory mechanisms of the rat – an extreme, chronic thermal load
- The rat's main method of thermoregulation is vasodilation (esp. the tail), such that the hearts of exposed rats would need to work MUCH harder to maintain body temperature

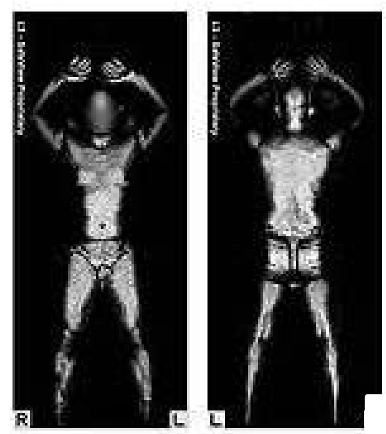
5G (mmWave) energy will not penetrate to deep tissues



Exposures of Humans to mmWaves

Airport mmWave scanners

- 24-30 GHz, <.006 W/m^2, seconds
- Millions of exposures
- No known biological effects
- The energy clearly only interacts with the surface of the body, or else we wouldn't get the images we see of just the surface



Other Resources

- NIH National Cancer Institute page on cell phones and cancer:
    - https://www.cancer.gov/about-cancer/causes-prevention/risk/radiation/cell-phones-fact-sheet
- FDA site on cell phone safety:
    - https://www.fda.gov/radiation-emitting-products/home-business-and-entertainment-products/cell-phones
- Review of literature on “electromagnetic hypersensitivity” (45 papers, ~1200 subjects):
    - https://onlinelibrary.wiley.com/doi/abs/10.1002/bem.20536
- NYU Wireless paper on safety of 5G:
    - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4629874/