Human-skin temperature elevation by EMF exposure at MMW and THz frequencies

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Upcoming wireless technologies (5G and WiGig)

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- The use of frequencies over 6 GHz is expected in 5th-generation (5G) mobile and wireless communications technologies
- WiGig using 60 GHz band is now commercially available.

https://www.tutorialspoint.com/5g/5g_technology.htm

https://www.extremetech.com/computing/89904-wigig-7gbps-data-display-and-audio-mid-range-networking-coming-in-2012

International safety guidelines up to 300 GHz

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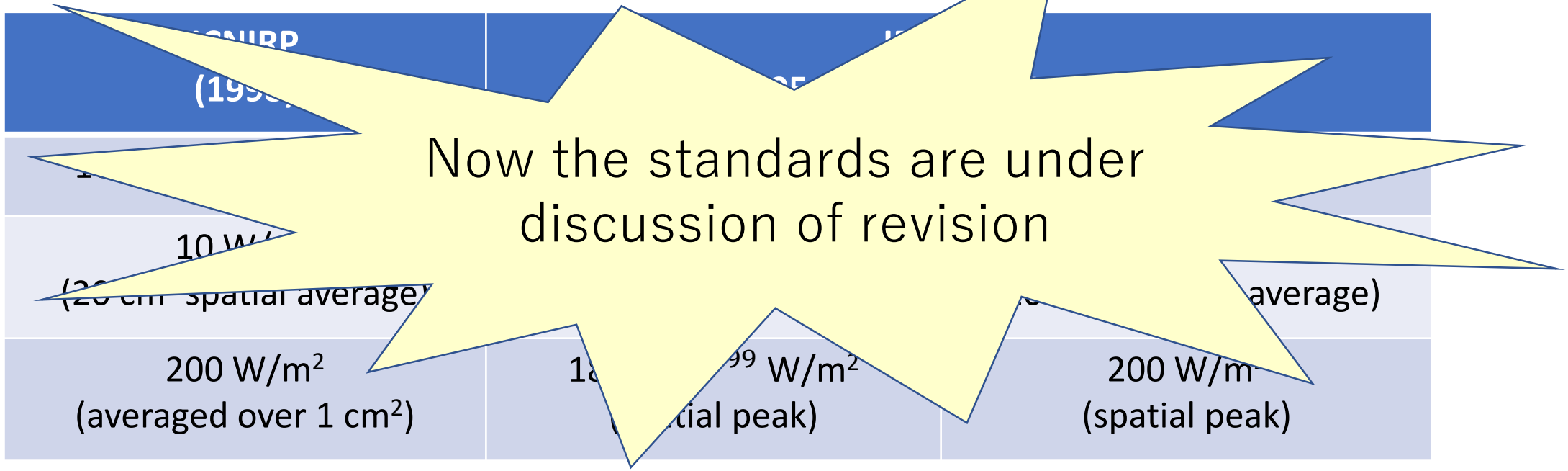
- Power density [W/m^2] is used as measure in the guidelines to protect humans from excessive temperature elevation over surface tissues: skin and eye tissues.
- Basic restrictions in power density in general public



10 W/		average)
200 W/m^2 (averaged over 1 cm^2)	1 99 W/m^2 tial peak)	200 W/m (spatial peak)

The exposure limits had been determined from limited scientific evidence when the guidelines had developed.

Purpose of this presentation

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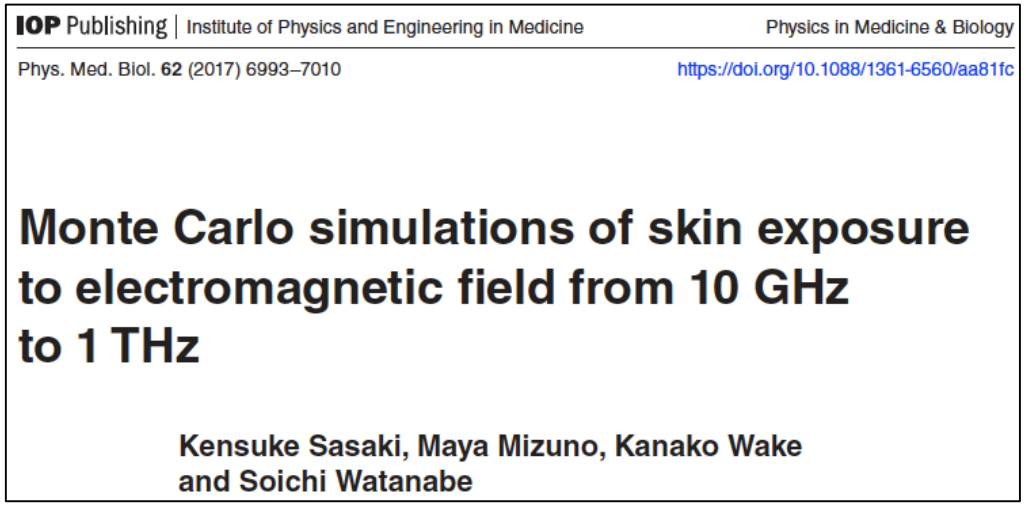
- Summarize recent works based on temperature elevation by skin exposure at 10 GHz and higher;
  1. Dielectric properties of skin tissues,
  2. Variation in the temperature elevation by skin tissues and by different body parts



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Monte Carlo simulations of skin exposure to electromagnetic field from 10 GHz to 1 THz

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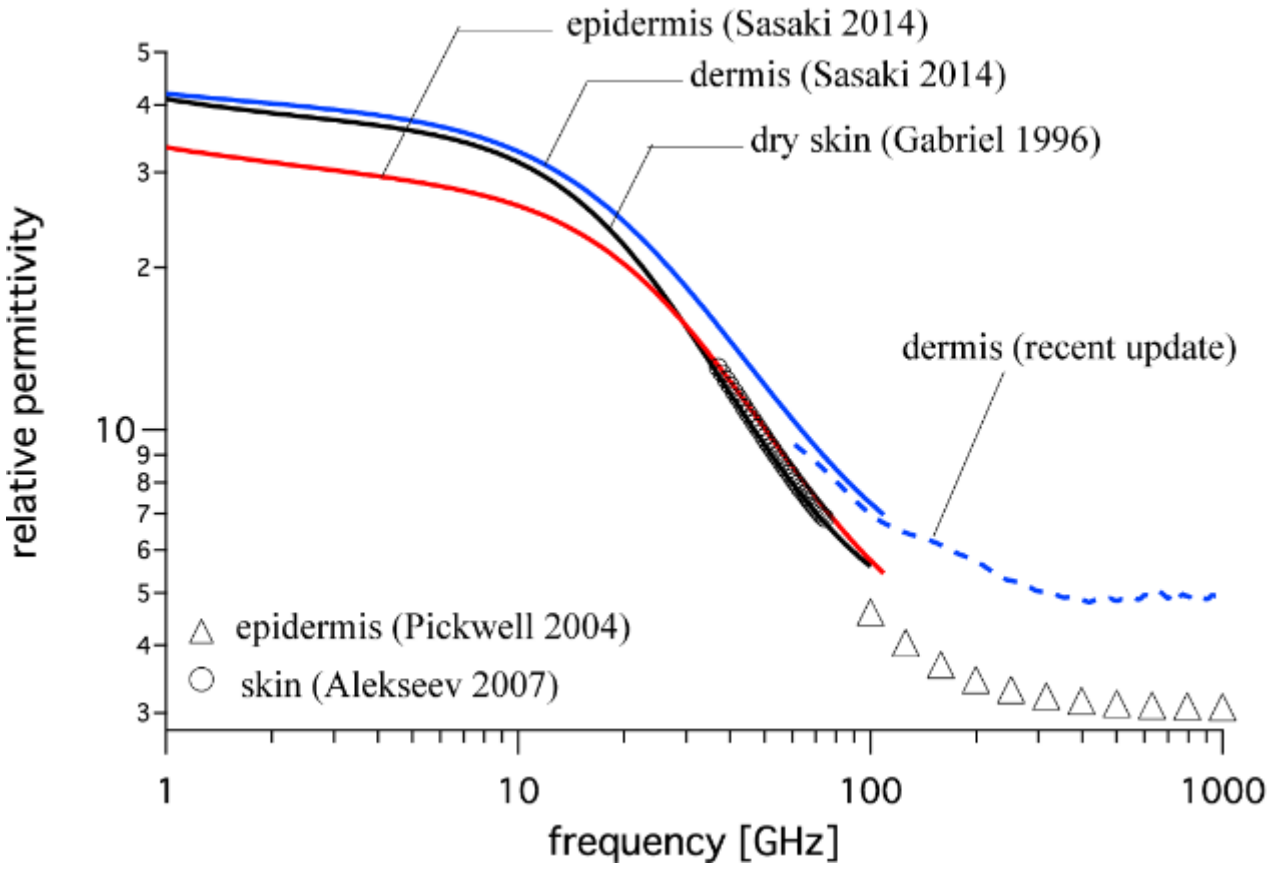
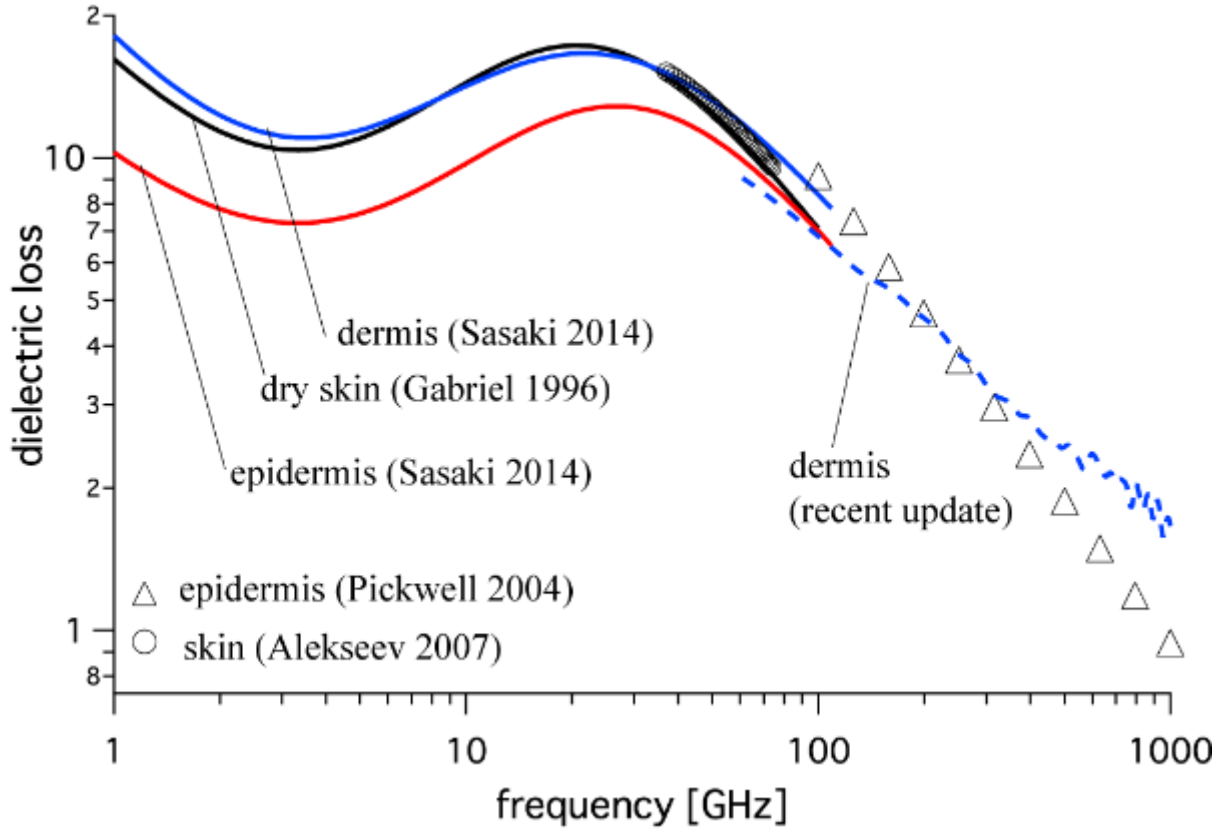
Dielectric data of skin tissues

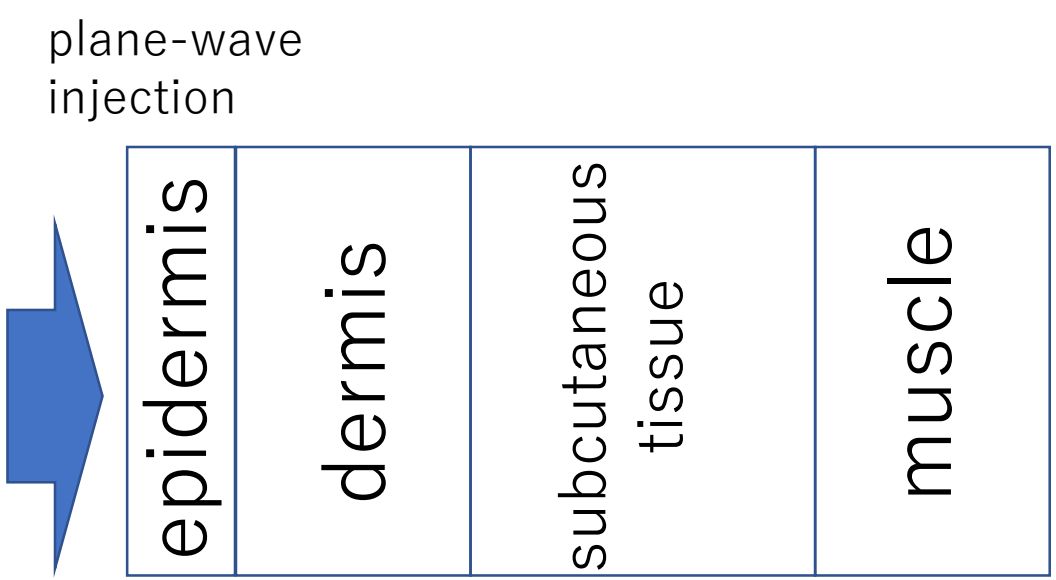
- Dielectric properties of epidermis are lower than those of dermis because of its water contents.





Temperature analysis using a multilayer plane model

- 4-layer plane model is used for assessment of energy absorption and temperature elevation analysis
  - ➢ solving boundary value problems of
    1. the Maxwell equation
    2. the Bio-heat equation



1D-Bioheat equation at steady states

$$\kappa \frac{d^2}{dx^2} T(x) + \frac{\sigma |\mathrm{E}(x)|^2}{2} + A - B(T(x) - T_{blood}) = 0$$

Heat generation source by energy absorption

basal metabolism

Blood circulation

Boundary condition at air-skin boundary:

$$\kappa \frac{d}{dx} T(x) = h(T(x) - T_{air})$$

h [W/(m^3 · ℃)]:
heat transfer coefficient

Conditions : thermal parameters

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- Thermal parameters for this study is as same as those used in [1].

[1] A. Hirata, et. al, Bioelectromagnetics, Vol. 27, pp. 602—612, 2006

	Epidermis	Dermis	Subcutaneous tissue	Muscle
κ [W/(m °C)]	0.42	0.42	0.25	0.5
ρ [kg/m^3]	1109	1109	911	1090
A [W/m^3]	1620	1620	300	480
B [W/(m^3 °C]	0	9100	1700	2700

Conditions: tissue thickness

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- Tissue thickness varies by body part and has individual difference.
- The variations in energy absorption and temperature elevation by exposures were assessed based on statistical data of tissue thickness using Monte-Carlo simulation.
- Tissue thickness was referred from those obtained by
  1. ultrasound imaging (fat & muscle)[1]
  2. biopsy (epidermis & dermis) [2]

Thickness of tissues (mean ±standard deviation)[1][2]

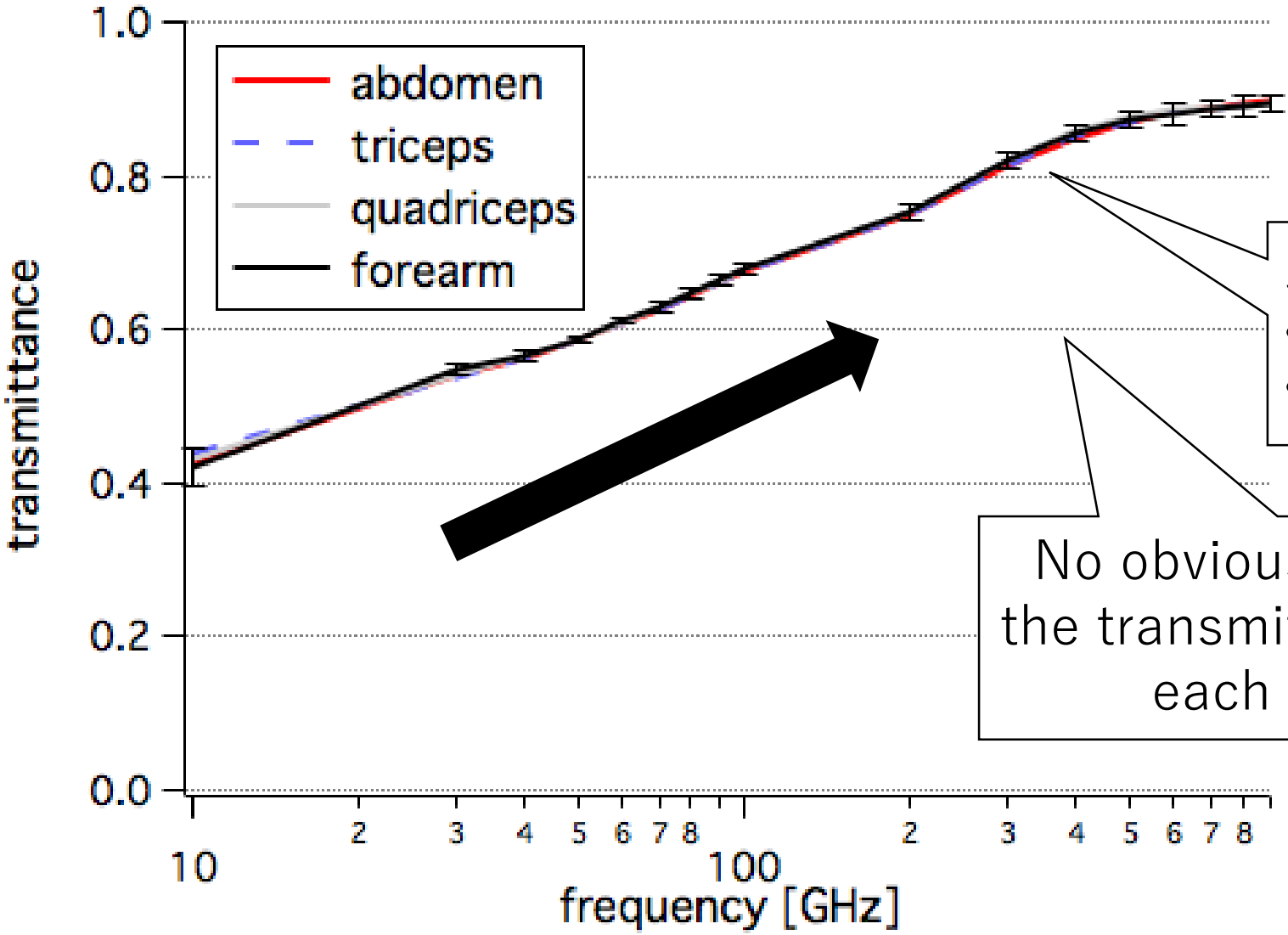
body parts	epidermis [μm]	dermis [μm]	subcutaneous tissue [mm]	muscle [mm]
forearm	102 ± 34	1080 ± 160	3.89 ± 1.40	23.3 ± 4.3
abdomen	79.4 ± 33.9	1250 ± 260	14.3 ± 7.5	14.4 ± 3.5

[1] Ishida Y, et al., 1992 American Journal of Human Biology 4 511–20
[2] Lee Y and Hwang K, 2002 Sur. Radiol. Anat. 24 183–9

Results: power transmittance into the skin

Transmittance=1-$|R_{skin}|^2$ (R_{skin}: reflection coefficient)

skin



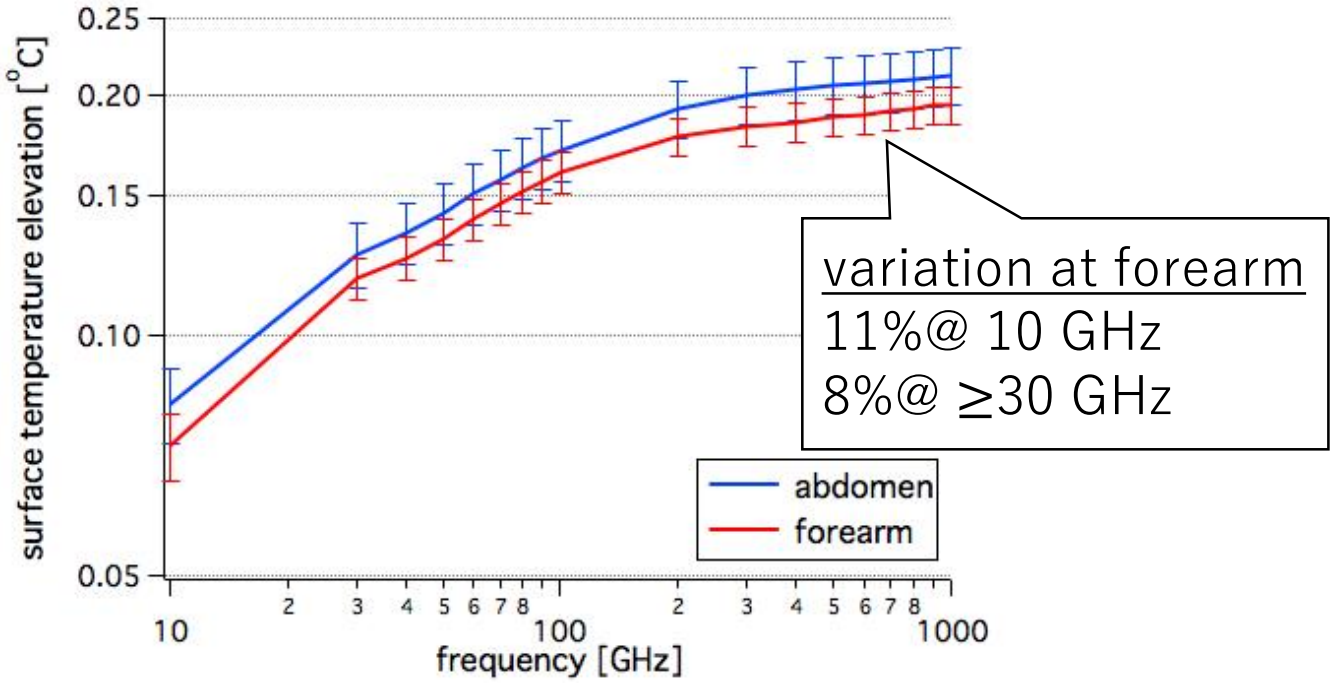
SD by tissue thickness are
- 6%@10 GHz
- 2%@ ≥30 GHz

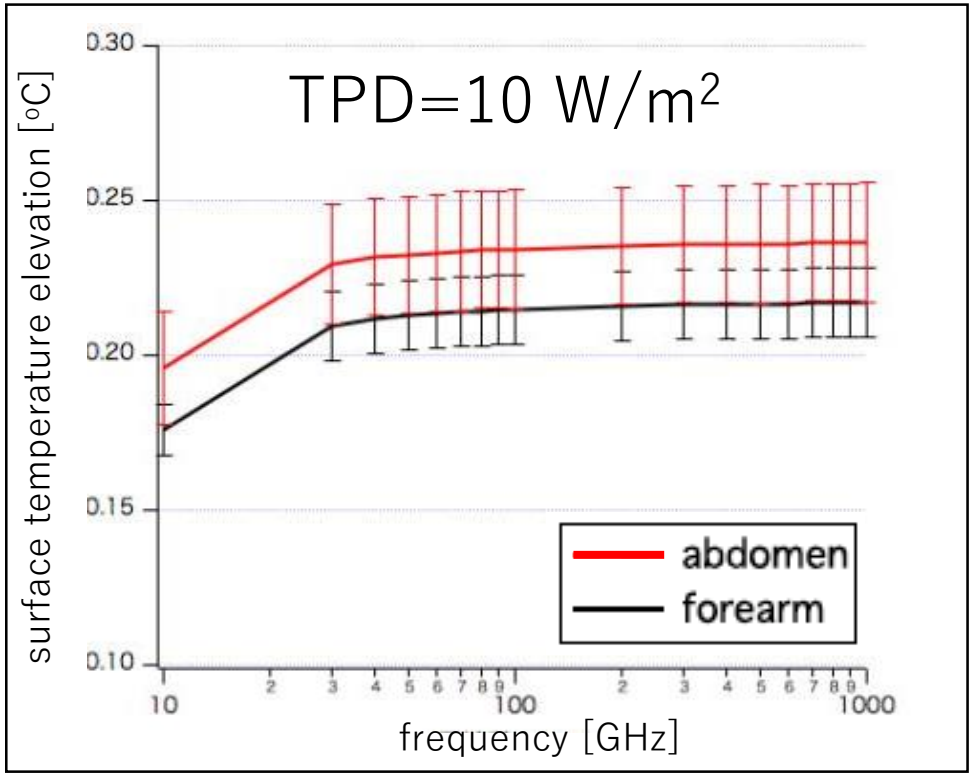
No obvious difference in the transmittance between each body part

Number of iterations for Monte Carlo simulation: 10^5

Results: temperature elevation (IPD=10 W/m^2)

- Frequency dependence shows similar tendency to that of the transmittance.
- Temperature elevations for abdomen were 8～12% higher than that for the forearm.
  - those for triceps, quadriceps, and abdomen are perfectly agreed each other.





Temperature elevation at steady state by plane wave exposure is sufficiently small to cause thermal burn at 10 W/m^2: exposure limit for general public up to 300 GHz.

Conclusion

- Dielectric properties of tissues composing skin at body temperature were summarized.
  1. skin composing tissues: epidermis and dermis
  2. subcutaneous tissue
- Power transmittance into the skin was assessed using multilayer plane model:
  1. increases from 40% to 90% with increasing of frequencies from 10 GHz to 1 THz.
  2. no significant difference was observed at body parts.
- Temperature elevation at steady states (normal incidence):
  1. similar frequency dependence to power transmittance.
  2. a little difference is observed between forearm and other body parts, because of tissue thickness of subcutaneous tissue.
  3. below 0.25^{o}C with exposure limit in general public up to 300 GHz, i.e., sufficiently small to cause thermal burn at skin (threshold of thermal burn is 9-10^{o}C increase from skin temperature at normal ambient condition).

Thank you for the kind attention

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