EMF Energy Absorption Mechanisms in the mmW Frequency Range

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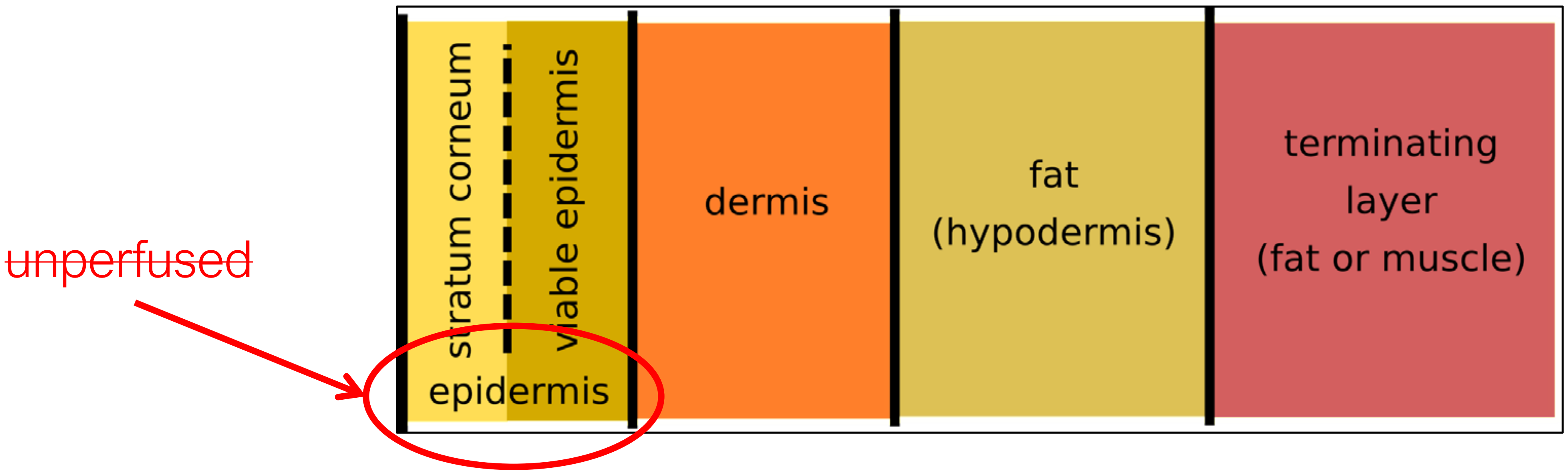
Background

- ~~The compliance of wireless devices up to the 4th generation is tested against the basic restrictions by measuring SAR.~~
- ~~The dielectric properties of the tissue simulants for the SAR measurements were determined by evaluation the plane-wave absorption in large numbers of head- and body-tissue combinations.~~
- ~~For body-tissue, constructive interference from the fat-muscle interface was observed that can lead to an increase of the psSAR of up to 3dB for far-field like exposure.~~
- ~~For head-tissue, no such effects could be identified.~~
- ~~Compliance testing for mmWave frequencies no longer uses a dosimetric approach.~~
- ~~The skin can no longer be regarded as bulk tissue for the characterization of the absorption of EM fields.~~

Objectives

- propose a stratified skin model for the analysis of EM energy absorption in the mmWave frequency range
- identify the skin layering structure that maximizes absorption
- ~~quantify EM energy absorption and the induced temperature increase for plane-wave exposure~~
- ~~characterize the near-field of a set of generic wireless devices with phased array antennas operating at 28GHz and 100GHz~~
- ~~quantify the induced temperature increase based on the incident E-field and the real part of the power density averaged over surfaces of 1cm², 4cm² and 100cm²~~

Stratified Skin Model – Biophysical Properties



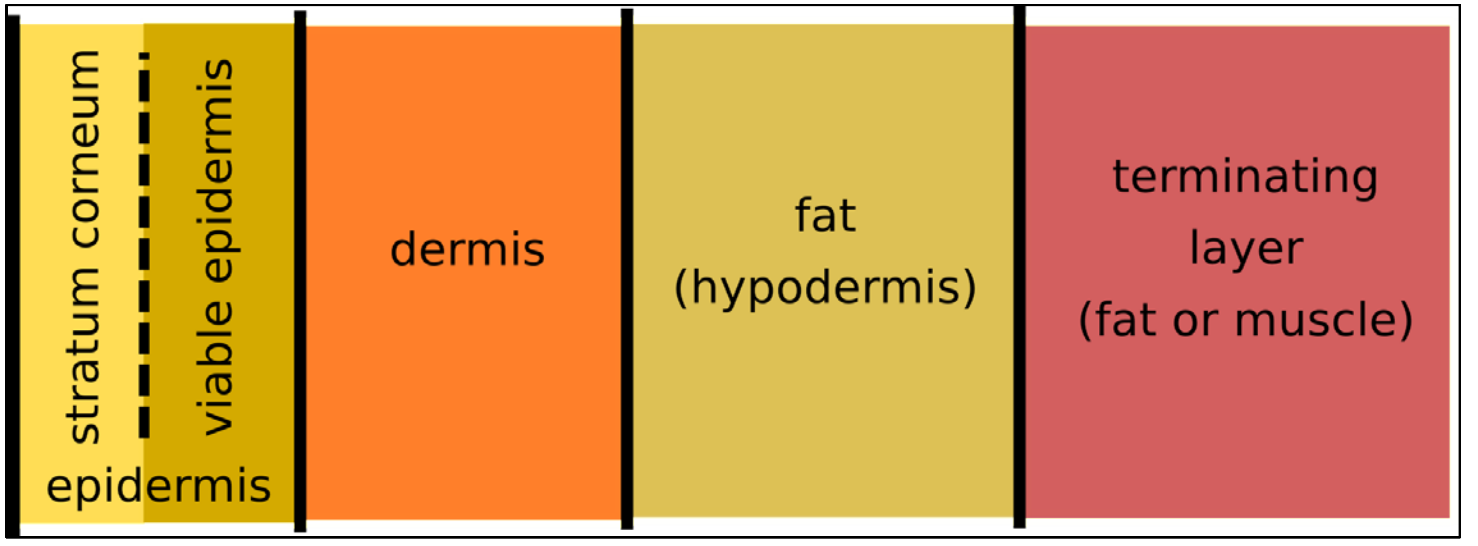
- unperfused epidermis modeled as stratum corneum and viable epidermis

- ~~Cole-Cole tissue properties:~~
  - ~~low water content for stratum corneum and hypodermis~~
  - ~~high water content for viable epidermis, dermis and muscle~~

- ~~adiabatic thermal boundaries as conservative estimate of live conditions~~

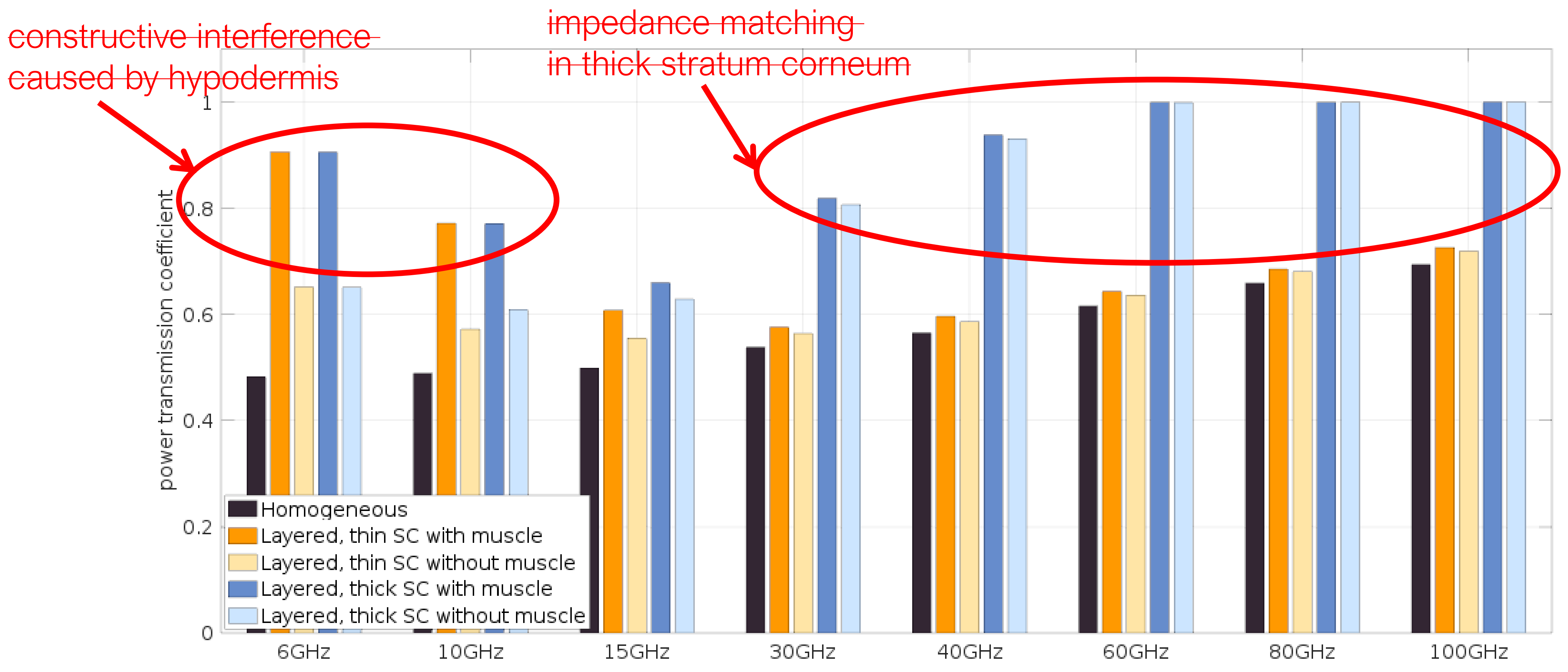
Stratified Skin Model – Layer Thicknesses

Layer	Thickness
thick SC	20 - 700μm
thin SC	10 - 20μm
viable epidermis	60 - 120μm
dermis	0.4 – 2.4 mm
hypodermis	1.1 – 5.6 mm or ∞
muscle	∞



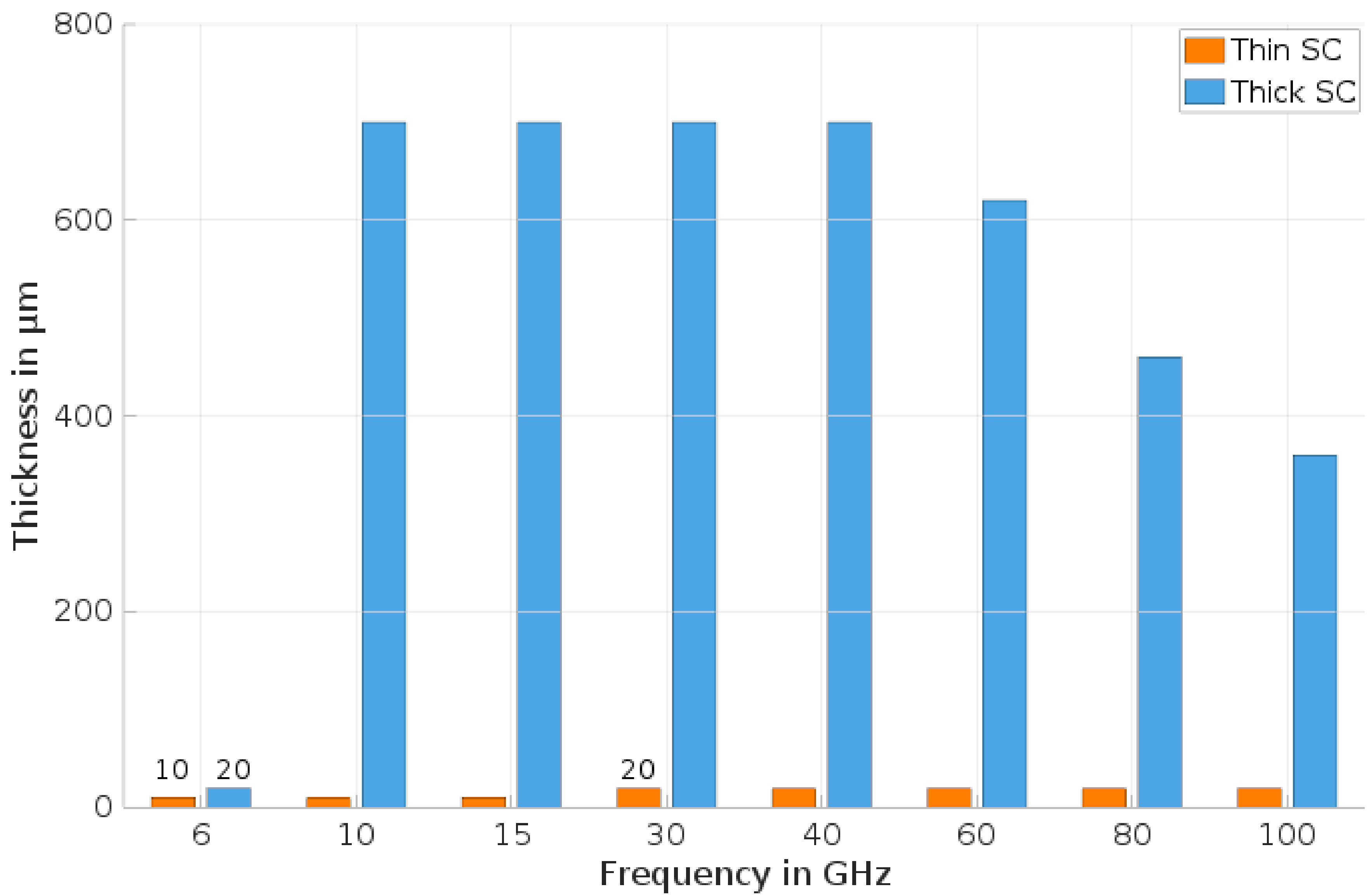
- two body regions distinguished depending on stratum corneum thickness:
  - ~~thick stratum corneum: fingers, palm, soles of the feet~~
  - ~~thin stratum corneum: everywhere else on the body~~
- ~~large variability for stratum corneum thickness of the hands depending on individual manual activities~~
- ~~hypodermis or muscle as terminating layer~~

Power Transmission Coefficient

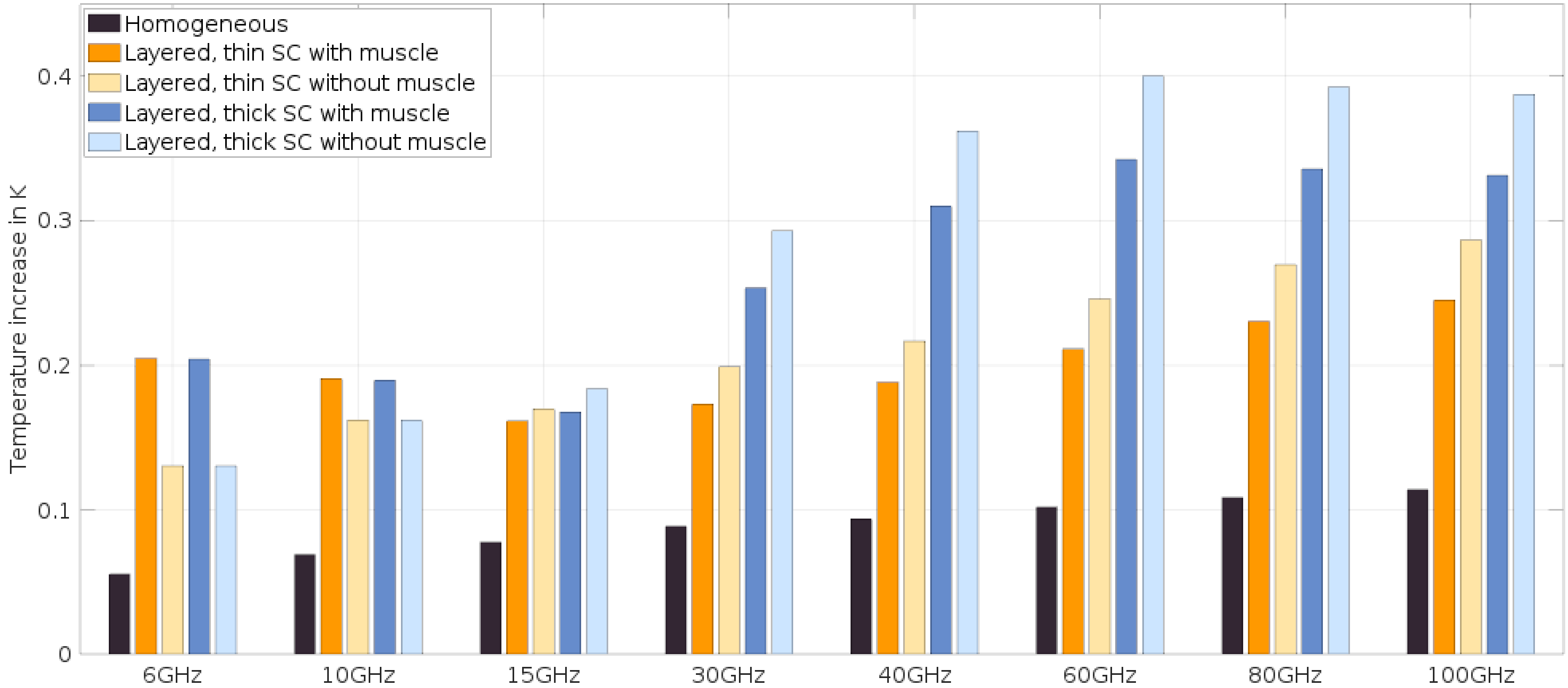


- plane wave power transmission always > 45%, may exceed 90%
- enhanced absorption due to constructive interference below 15GHz
- enhanced absorption due to impedance matching above 15GHz

SC Thickness for Maximum Transmission

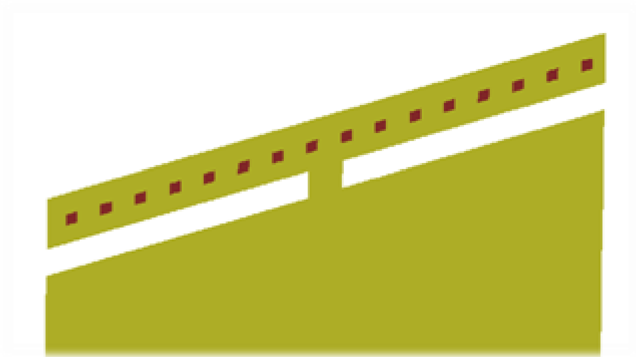


Temperature Increase



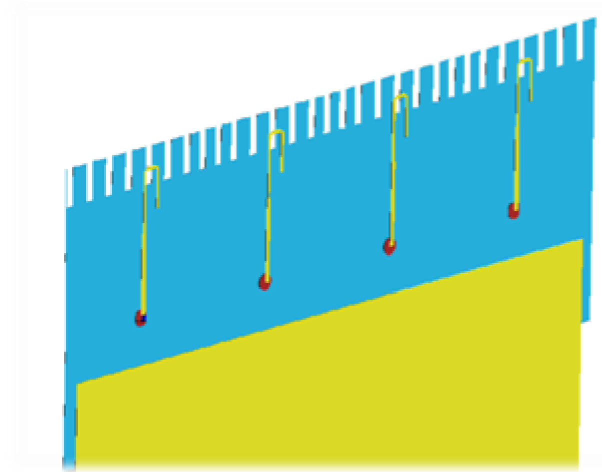
- ~~temperature increase ΔT for adiabatic boundary conditions normalized to an indicent power density of 10W/m²~~
- ~~ΔT in layered tissue up to 4 times higher than in homogeneous tissue due to increase in power transmission coefficient and reduced perfusion (epidermis, fat)~~

Generic Transmitters – 28GHz



F28b

F28t



N28

- ~~F28b - generic phone with 16 PIFA elements on the back of the ground plane operating at 28GHz~~
- ~~F28t - generic phone with 16 PIFA elements on the bent top of the ground plane operating at 28GHz~~
- ~~N28 - generic phone with four folded feeding ports and 30 parasitically coupled notch antenna elements operating at 28GHz~~

Generic Transmitters – 100GHz

F100b

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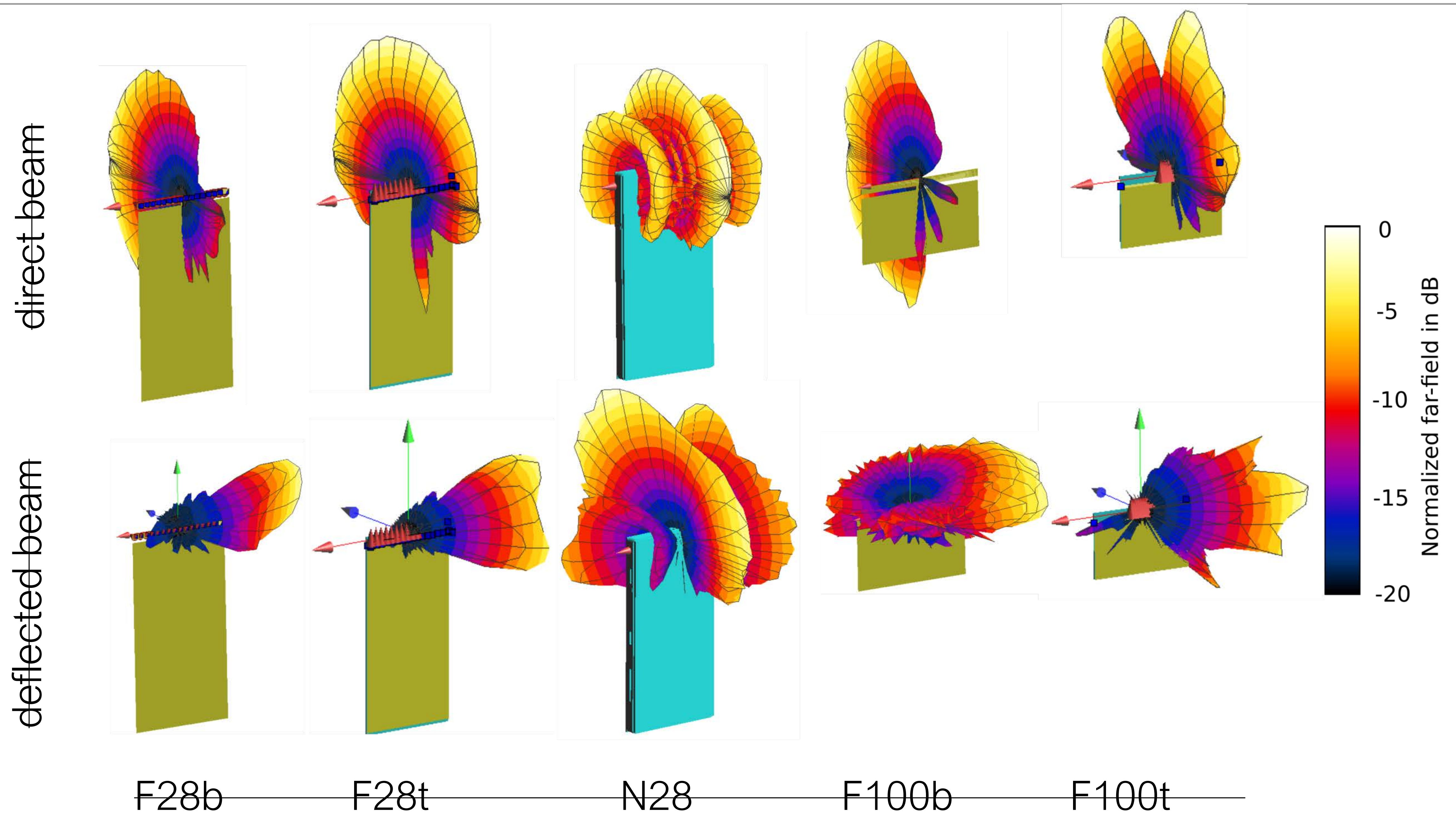
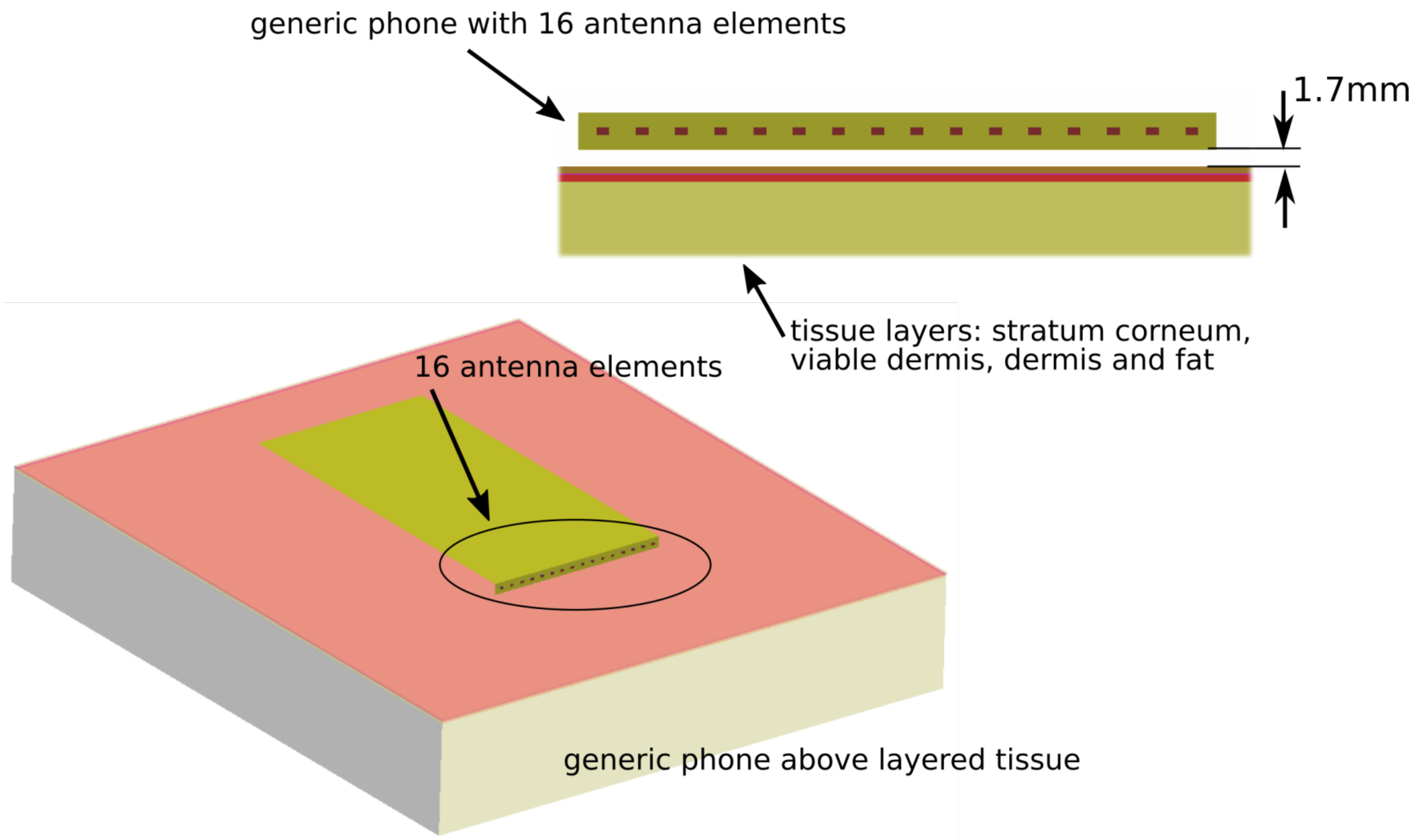
F100t

- ~~P100b - generic phone with 16 patch antenna elements on the back of the ground plane operating at 100GHz~~
- ~~P100t - generic phone with 16 patch antenna elements on the top of the bent top of the ground plane operating at 100GHz~~

Farfield Patterns of the Generic Transmitters



Positioning of the Generic Transmitters



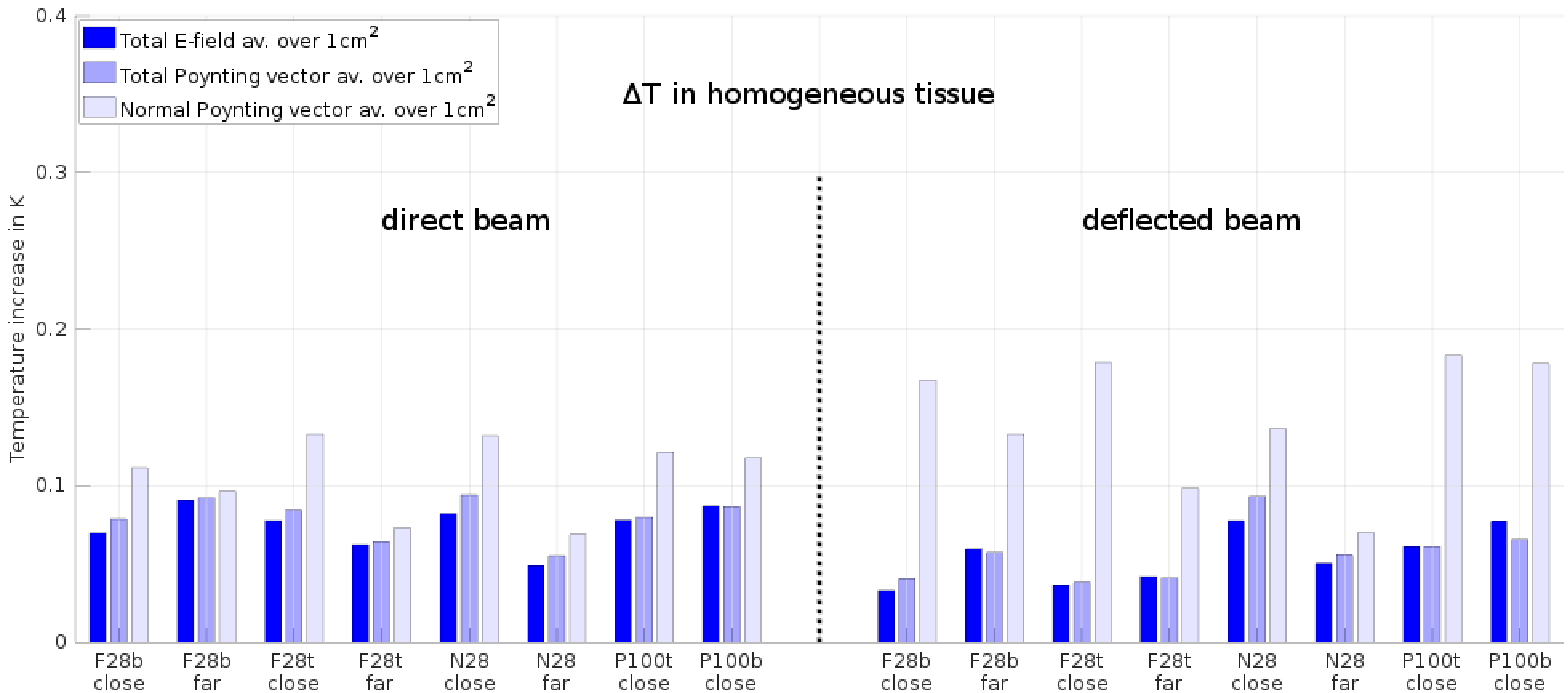
- close distance: 1.7mm between ground and tissue corresponding to λ/6 at 28GHz (N28: 4.2mm distance because of case)

- ~~far distance: increased by 8mm~~

Calculation of the Temperature Increase

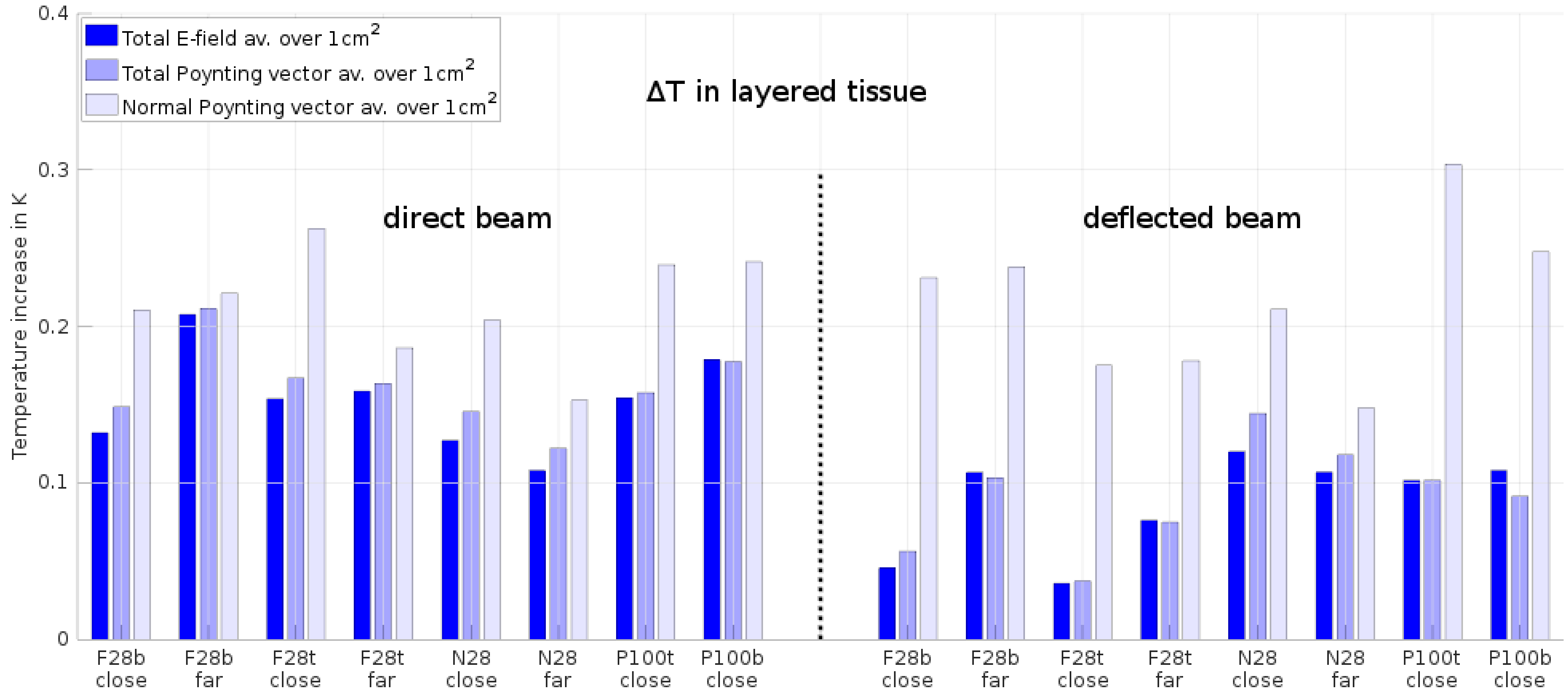
- ~~fields averaged over square surfaces of 1cm², 4cm² and 100cm²~~
  - ~~absolute value of the E-field vector~~
  - ~~real part of the Poynting vector~~
  - ~~normal component of the real part of the Poynting vector~~
- ~~temperature increase simulated applying the antenna power required to reach an incident power density of 10W/m²~~
- ~~close and far distance, direct and deflected beam, homogeneous and layered (worst-case) skin, adiabatic boundary conditions~~

ΔT Averaged Over $1cm^2$ – Homogeneous Skin



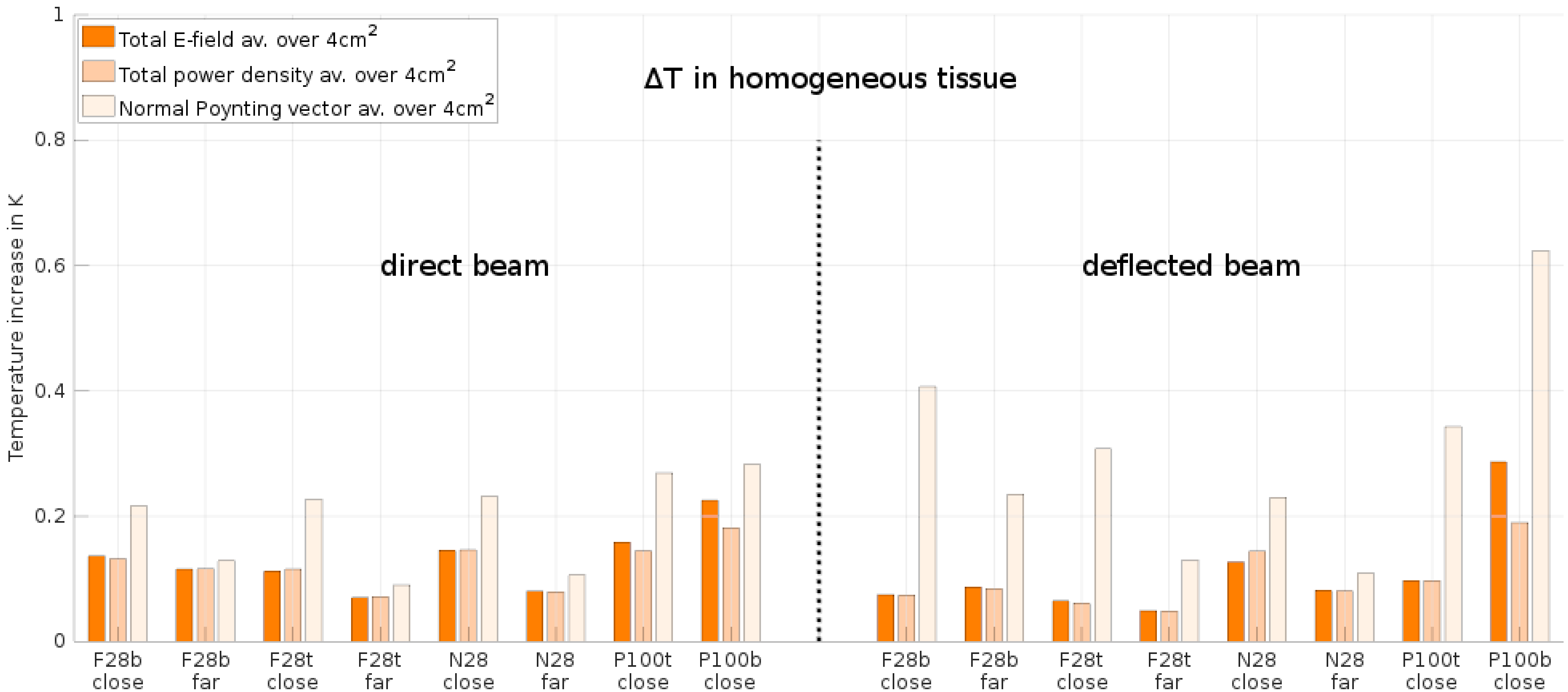
- ~~similar ΔT for av. E-field and av. total Poynting vector~~
- ~~generally higher ΔT for av. normal Poynting vector~~
- ΔT ~~dependent on device and distance~~

ΔT Averaged Over 1cm² – Layered Skin



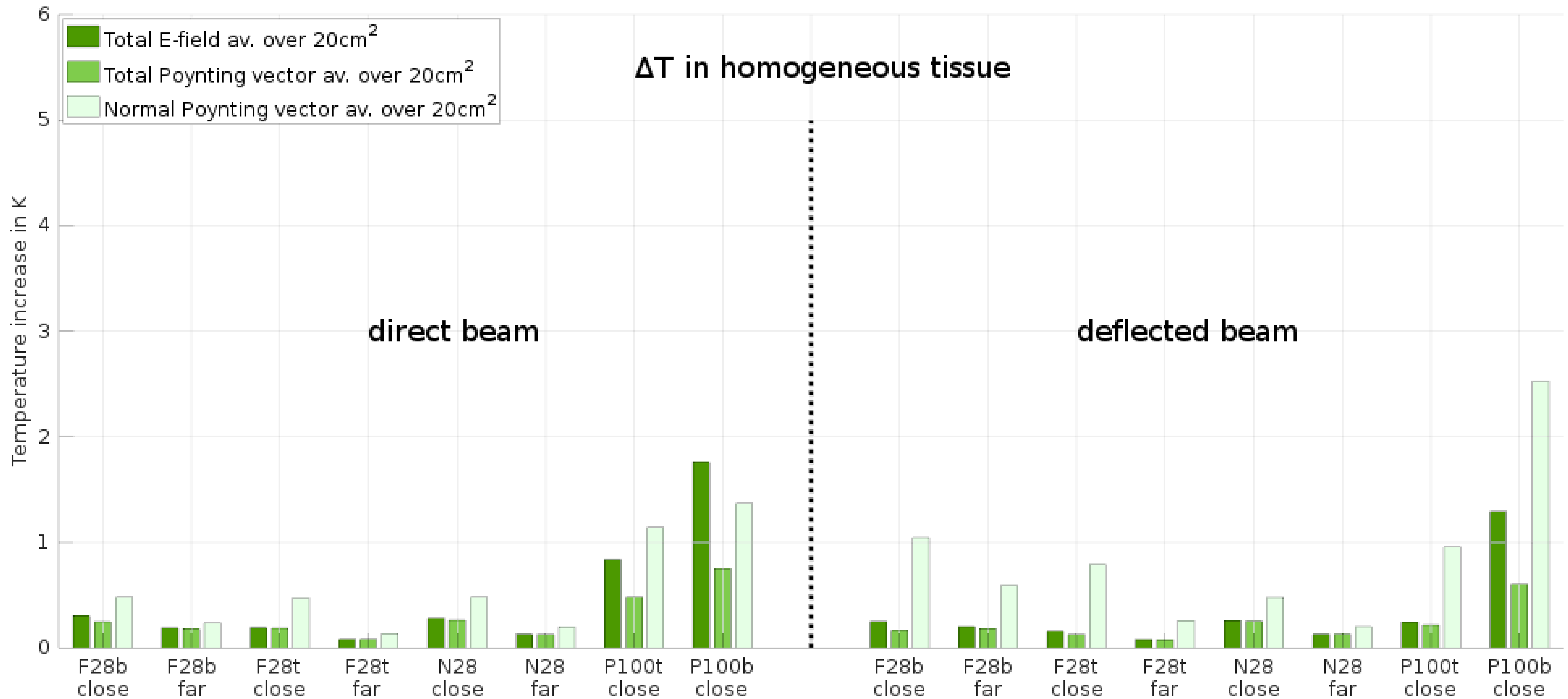
- ~~ΔT generally higher by about a factor of 2~~
- ~~otherwise, similar characteristics as for homogeneous tissue~~

ΔT Averaged Over 4cm² – Homogeneous Skin



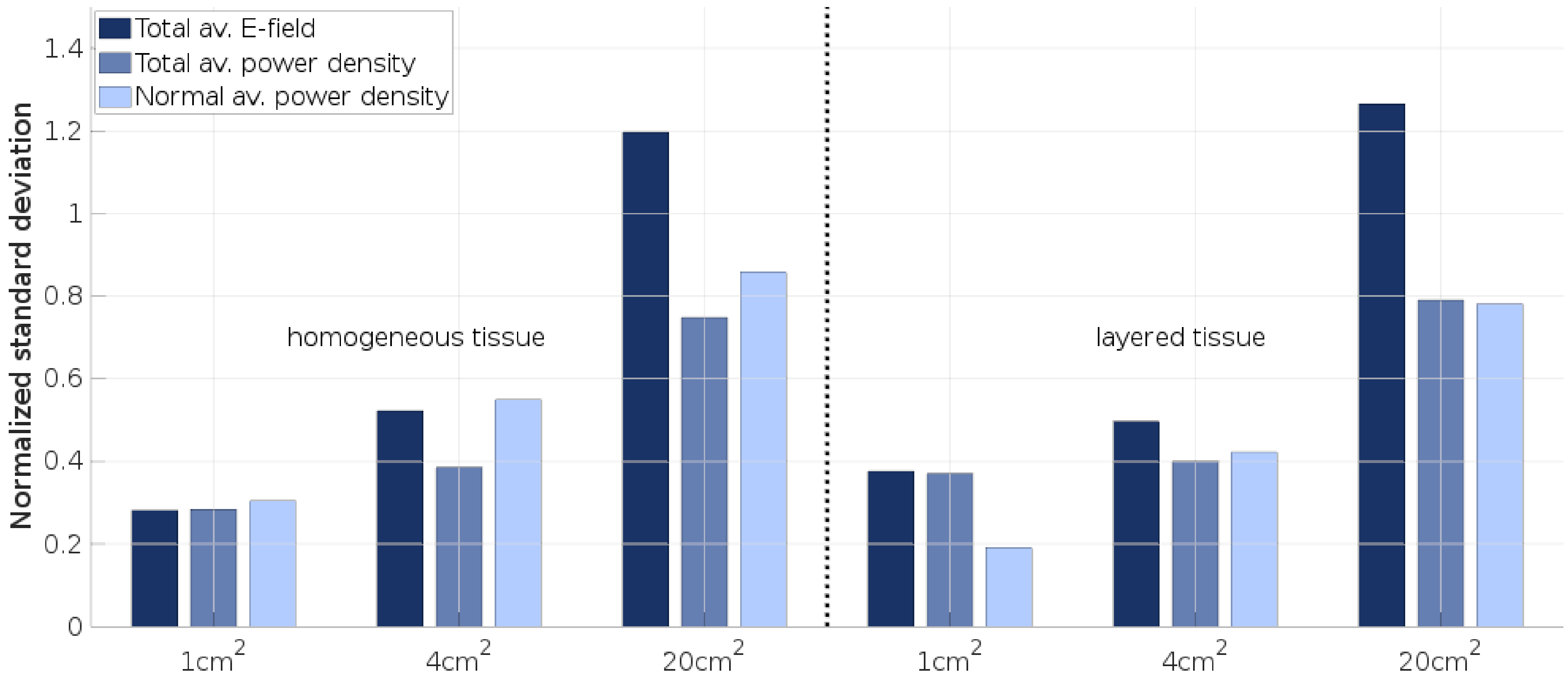
- ~~ΔT generally higher than for an averaging surface of 1cm²~~
- ~~reduced correlation between temperature increase and power density~~
- ~~otherwise, similar characteristics as for homogeneous tissue~~

ΔT Averaged Over 20cm² – Homogeneous Skin



- ~~ΔT higher than for an averaging surface of 1~~cm² and 4cm²
- ~~significantly reduced correlation between temperature increase and power density~~

Correlation of ΔT and Power Density



- ~~standard deviation of~~ ΔT ~~with power density increases with size of averaging area indicating higher dependence of~~ ΔT from device type
- ~~improved correlation for normal av. Poynting vector in layerd tissue for an averaging area of 1cm~~$_2$

Summary and Conclusions

- Layered modeling of the skin yields an increase of the induced ΔT by up to a factor of 4 in comparison to homogeneous skin mainly in the palms and fingers. This can be attributed to impedance matching and reduced perfusion in the outer skin layers.
- Normalization of the temperature increase to the normal av. Poynting vector yields a higher temperature increase in comparison to the total av. Poynting vector, but shows a better correlation, i.e., larger independence of the incident field.
- The observed temperature increase remains under 1K if an averaging area of $1cm^2$ is used and the averaged power density does not exceed the exposure limit for the general public of $10W/m^2$.
- At distances $>\lambda/6$ (1.7mm at 28GHz), the impact of reactive fields is negligible. Further evaluations may be necessary for lower frequencies (10GHz).