Development of a Flat Phantom Setup for the Compliance Testing of Body-Mounted Wearable Transmitters Operating in the Frequency Range From 30MHz - 5800MHz

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IT'IS FOUNDATION

Background

standardized:

methods and procedures for the compliance testing of handheld devices (IEEE 1528(2003), IEC 62209 Part I (Draft 2004))

not standardized yet:

methods and procedures for the compliance testing of body-worn portable transceivers operating at frequencies between 30MHz and 6GHz at distances smaller than 200mm

Open Issues

- phantom
  - size
  - shape
  - tissue simulating liquid parameters
- testing positions
- measurement procedures & compliance criteria
- instrumentation and procedures for frequencies between 3GHz and 6GHz

Objectives

- fundamentals for the development of a flat phantom setup that shows high repeatability and yields a conservative estimate for the SAR inside the human body
- fundamentals for a low-power exclusionary clause

Knowledge Gap

- approximation formula for the peak spatial SAR (1g & 10g) inside a flat phantom for short antennas ($L<\lambda/2$).
- impact of body resonances for antennas operating at close distances
- impact of tissue layering on the peak spatial SAR
- low-power exclusionary clause

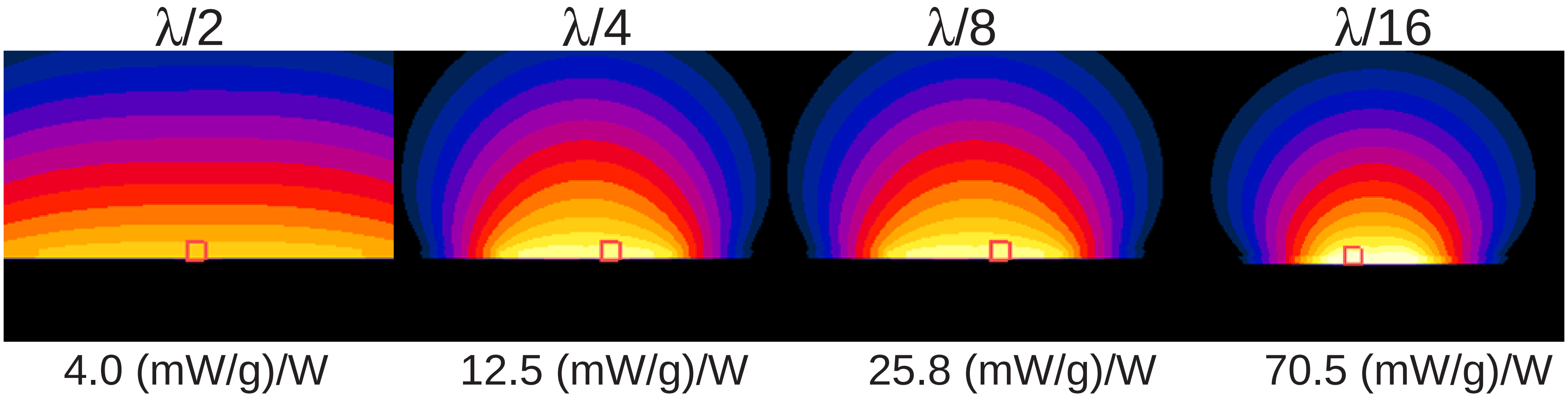
Methods

- FDTD simulations (SEMCAD)
- validation with MoM (FEKO)
- comparison with semi-analytical solutions (numerical integration)

Extended Approximation Formula

Peak Spatial SAR Depends on Antenna Length

Flat Phantom at 450MHz, antenna distance: 5mm, SAR: 0..-50dB



- So far: approximation formula **SAR =** $g\ (\varepsilon,\sigma,d,f)$
- Goal: Simple approximation formula of the following structure:

$$\mathbf{SAR} = g\ (\varepsilon,\sigma,d,f,L)$$

Approximation Formula (SAR) for Arbitrary Dipoles

$$SAR_{peak} = \frac{\sigma}{\rho}\frac{\mu\omega}{\sqrt{\sigma^2+\epsilon^2\omega^2}}(1+c_{corr}R)^2\frac{I_0^2}{4\pi^2 d^2}$$
$$\times\frac{1}{2\sin^2(\pi L/\lambda)}\left[3+\cos\left(\frac{2\pi L}{\lambda}\right)-4\cos\left(\frac{\pi L}{\lambda}\right)\cos\left(\frac{2\pi}{\lambda}\left(\sqrt{d^2+\frac{L^2}{4}}-d\right)\right)\right]$$

new term accounts for antenna length

$$R = \frac{2|n|}{|n+1|}-1$$

$$n = \sqrt{\epsilon_r - j\frac{\sigma}{\omega\epsilon_0}}$$

$$\hat{c}_{corr} = \begin{cases} 1 & \text{for } d \geq 0.16\lambda/R \\ \sin\left(\frac{\pi}{2}\frac{R}{0.16}\frac{d}{\lambda}\right) & \text{for } d < 0.16\lambda/R \end{cases}$$

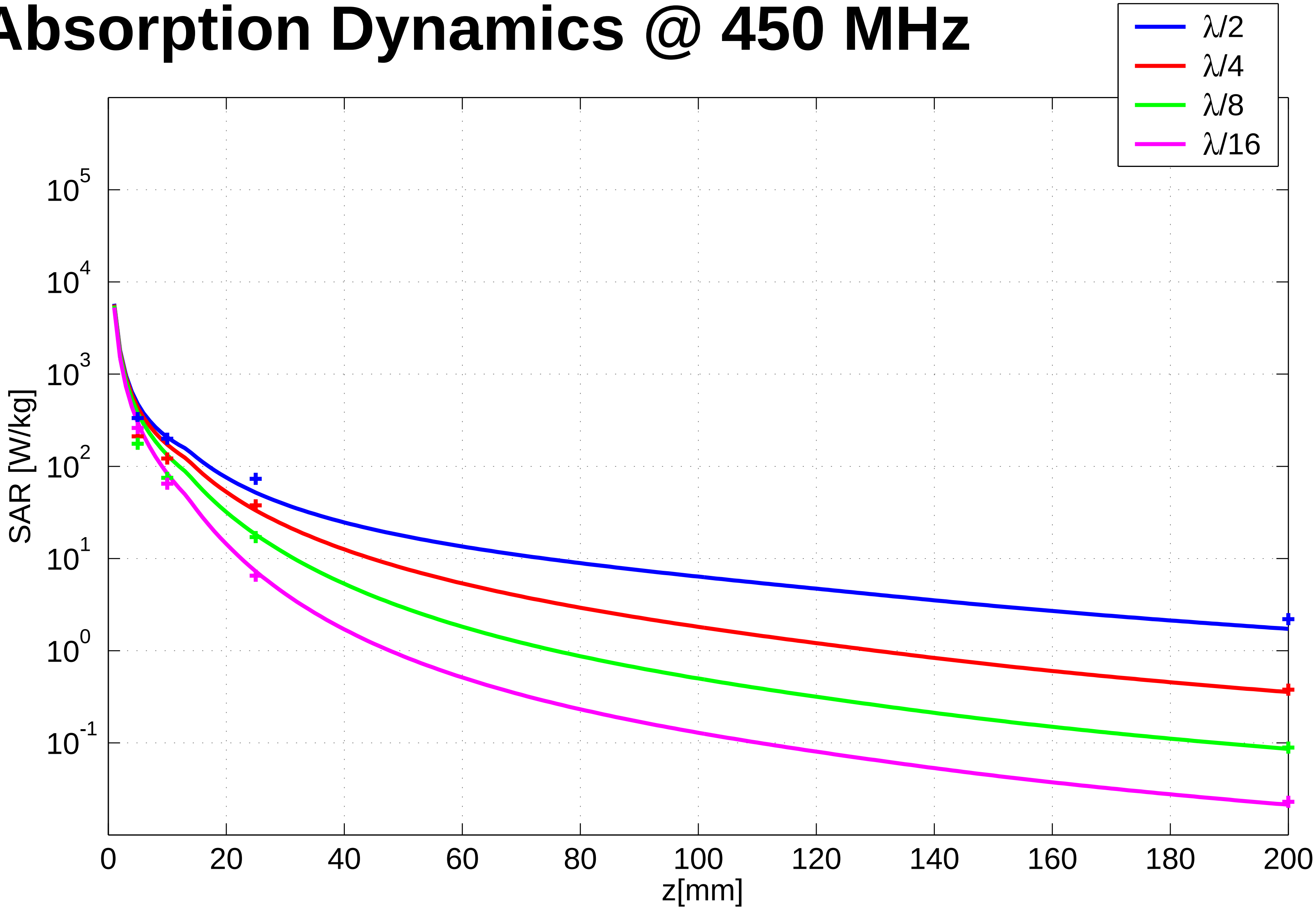
$$SAR_{1g} = SAR_{peak}\,\frac{\delta}{2s}\left(1-e^{-\frac{2s}{\delta}}\right)\gamma_{1g},\ \delta = 10mm$$
$$SAR_{10g} = SAR_{peak}\,\frac{\delta}{2s}\left(1-e^{-\frac{2s}{\delta}}\right)\gamma_{10g},\ \delta = 21.5mm$$

averaged SAR

$$L \geq \frac{\lambda}{16} \Rightarrow \gamma_m = \begin{cases} 1, & d \geq \frac{\lambda}{50} \\ 0.2+0.8\left(\frac{d}{\frac{\lambda}{50}}\right)^{\sqrt[3]{m}}, & d < \frac{\lambda}{50}. \end{cases}$$

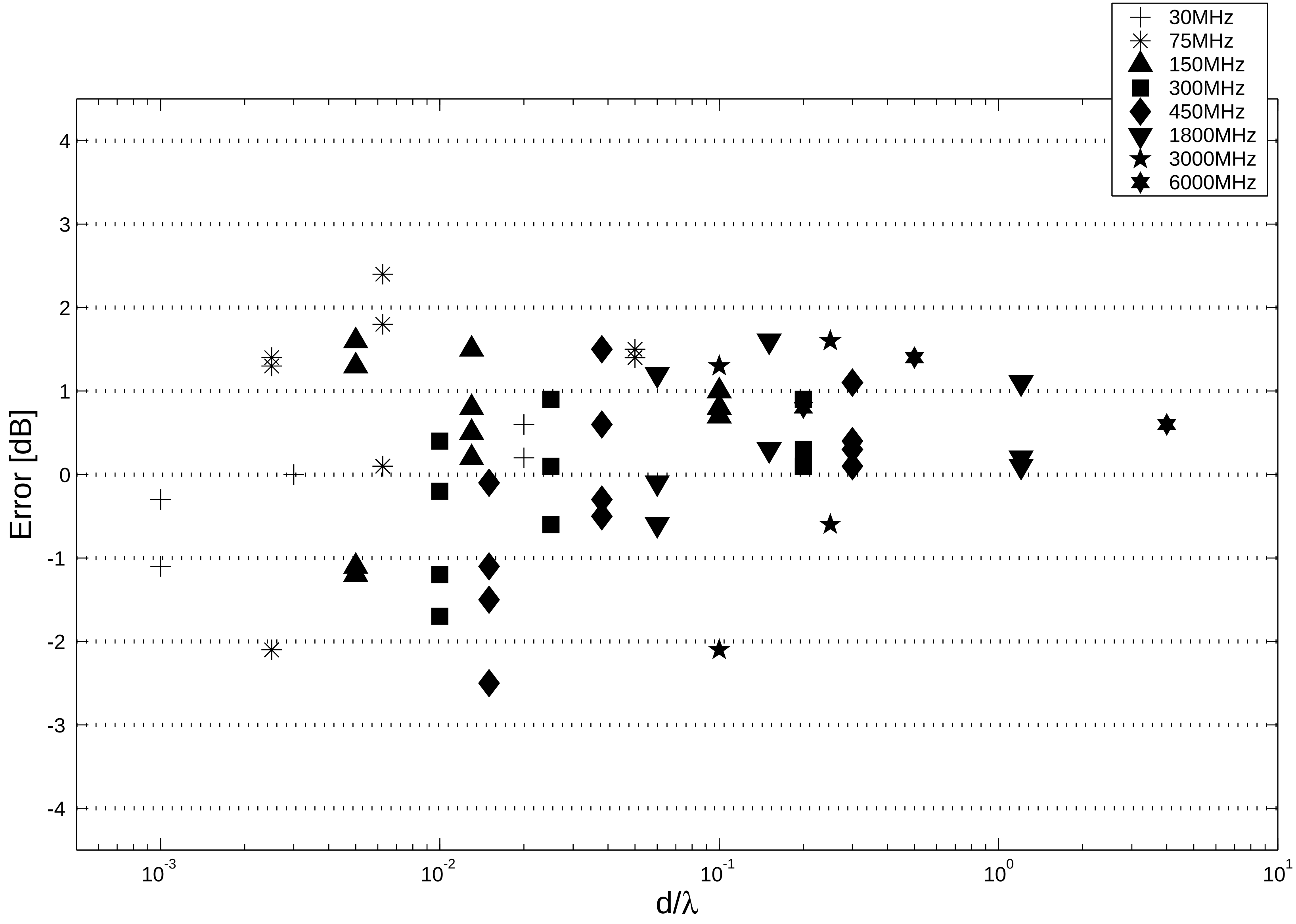
correction for small distances

Absorption Dynamics @ 450 MHz

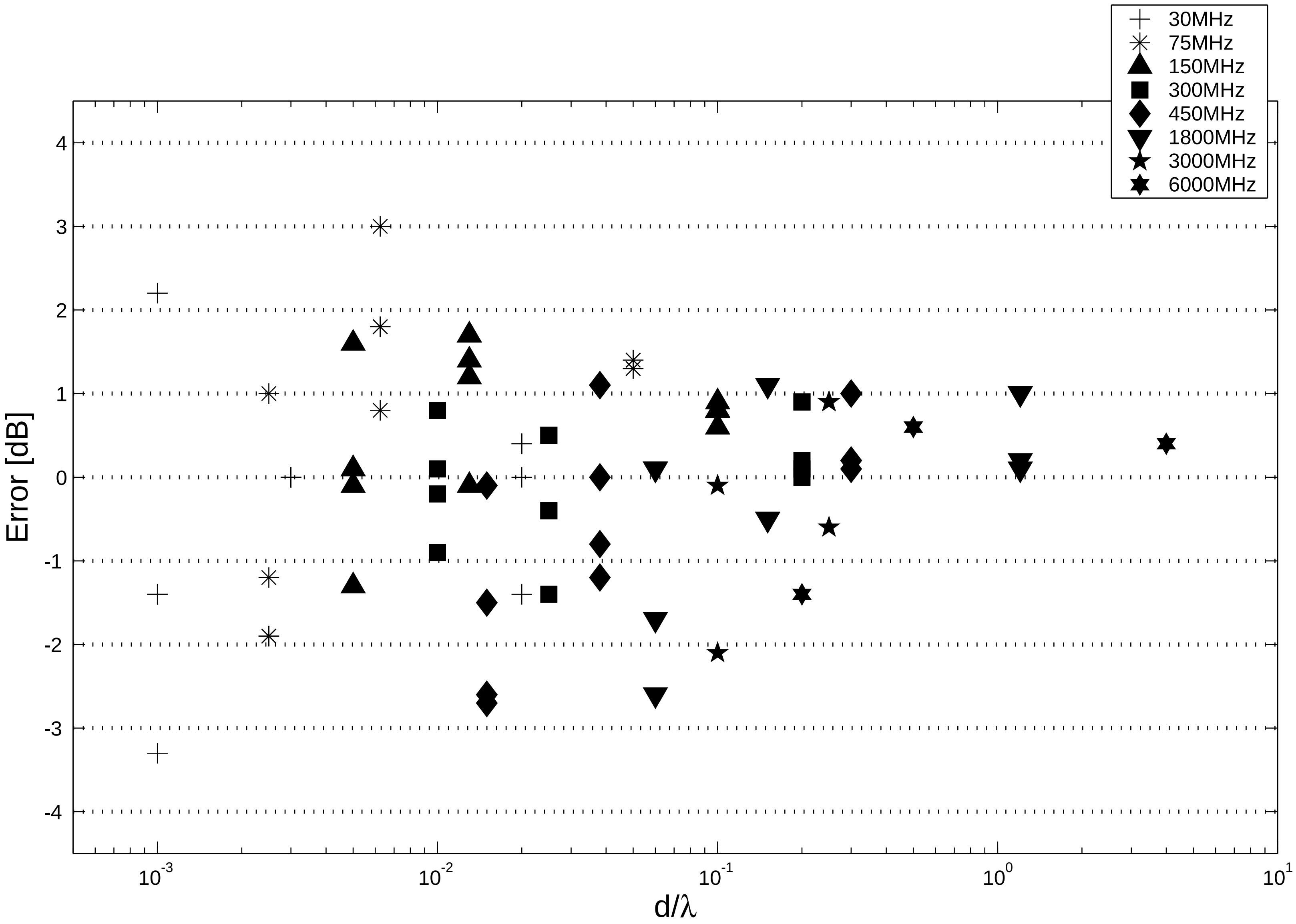


1g SAR normalized to feedpoint current of 1A

Approximation of 1g Spatial Peak SAR



Approximation of 10g Spatial Peak SAR

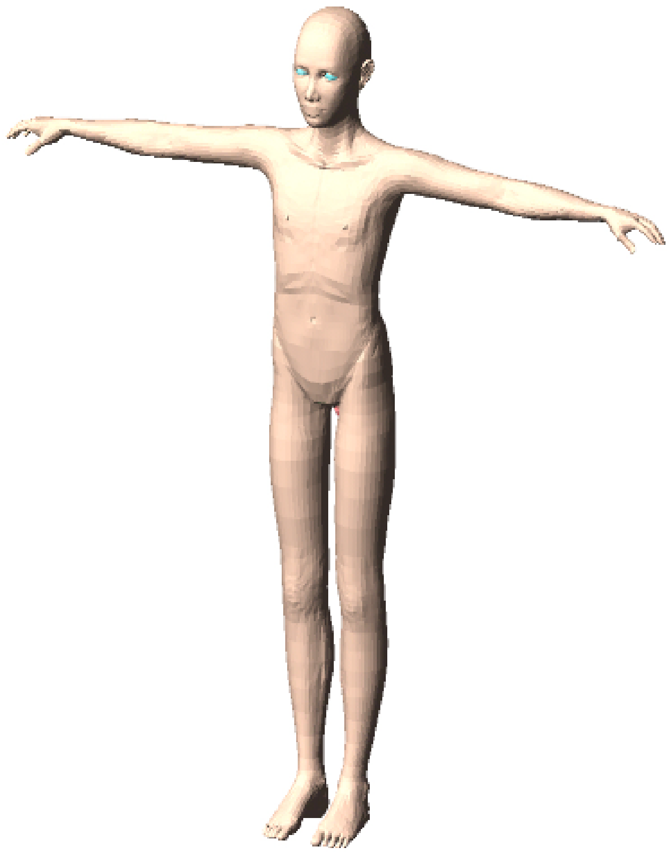


Conclusion of Approximation Formula

- good approximation of both 1g and 10g SAR for a large range of frequencies (30MHz to 6GHz), distances (10mm to 200mm) and antennas ($\lambda/2$ to $\lambda/16$)
- Dynamic range of spatial peak SAR: more than 60dB, accuracy ±3dB

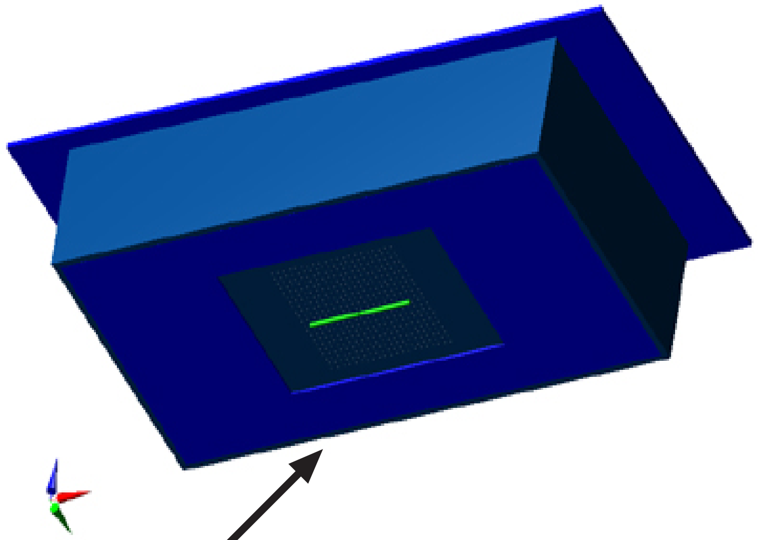
Resonance Issues

Phantoms Under Investigation



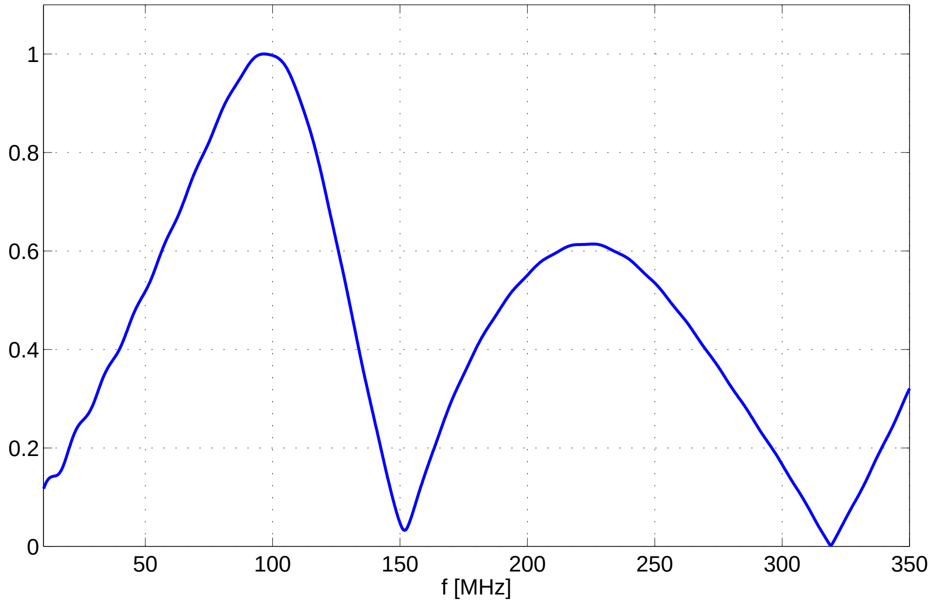
anatomical model of a 16 year old boy

tissue parameters:
generic: ε = 50, σ =0.35

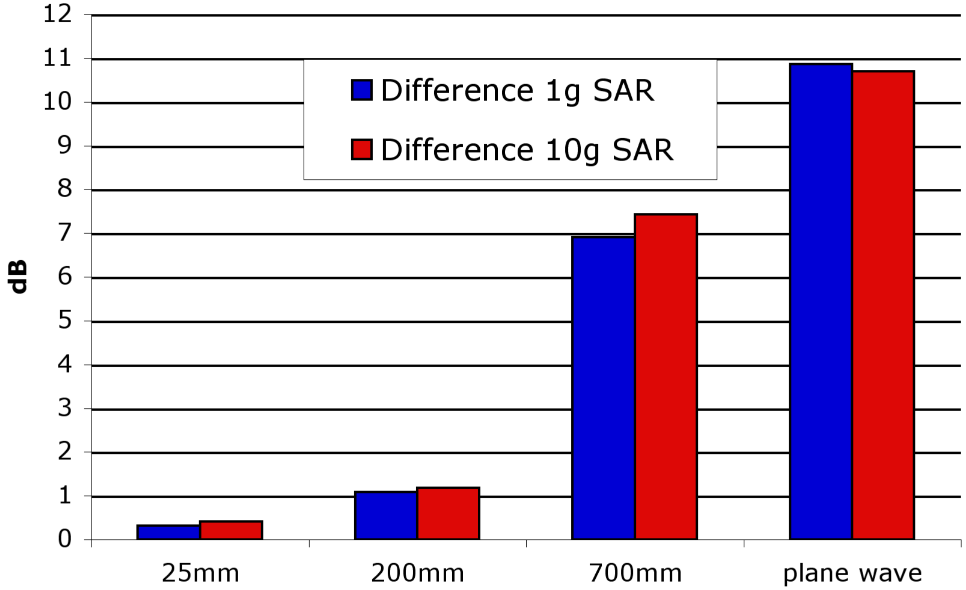


flat phantom

Flat Phantom Resonances



resonance curve for flat phantom

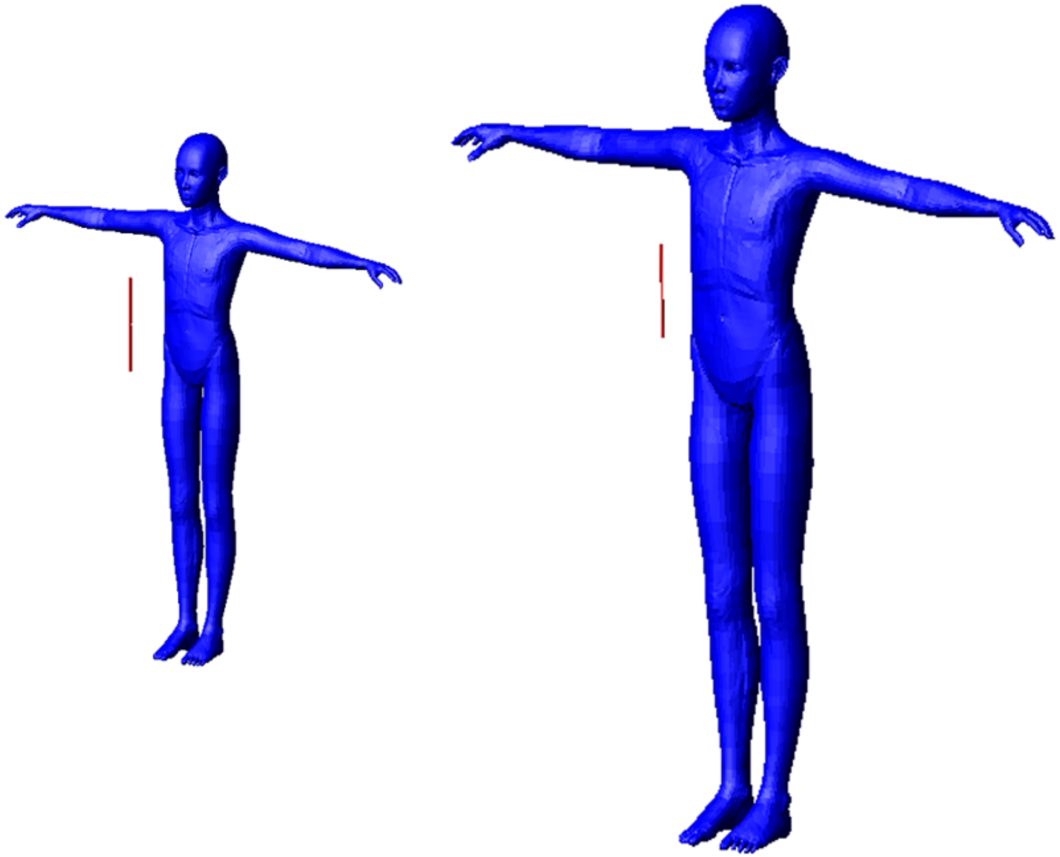


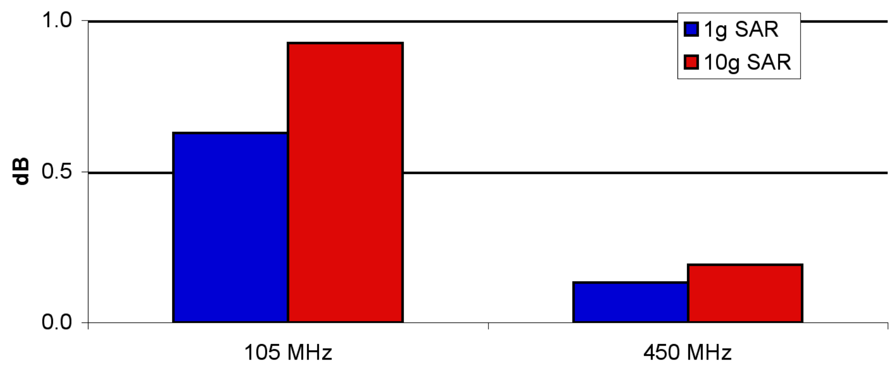
flat phantom vs half space

The peak spatial SAR in the flat phantom is compared to that of an infinite half space. The simulations were run at resonance frequencies ($\lambda/2$ dipoles) at 25mm, 200mm, and 700mm distance.

Impact of Human Body Resonances

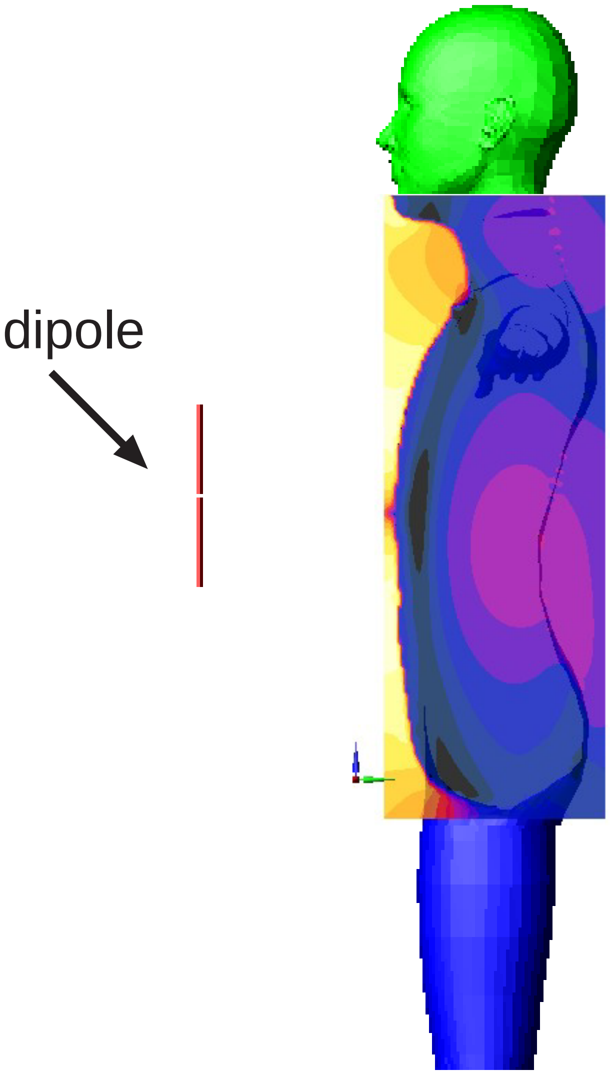
The spatial peak SAR in the small boy is compared to that inside the large boy at resonance and off resonance

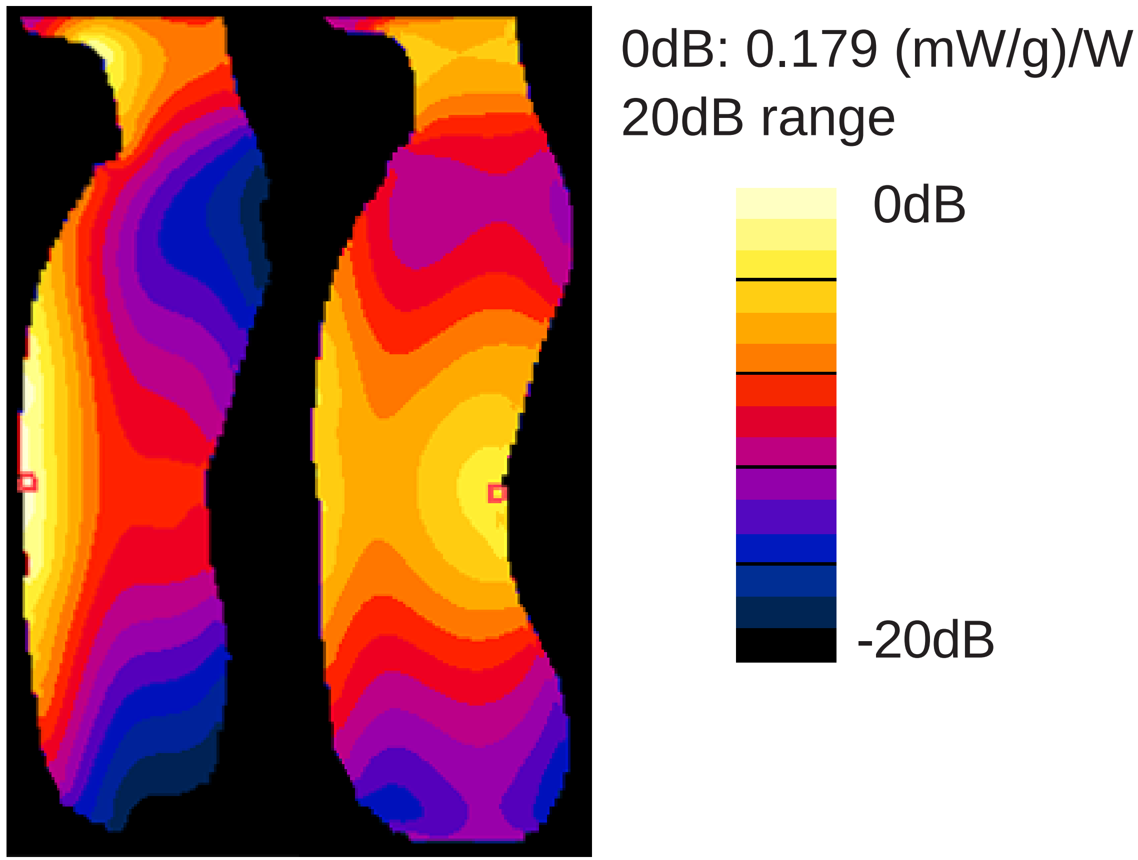




the SAR in both models only differs at resonance

SAR and E-Field Inside Anatomical Phantoms





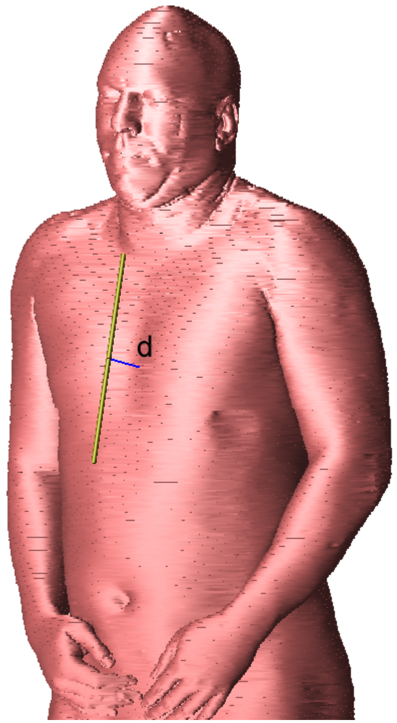
E-field and SAR distribution inside an anatomical boy model

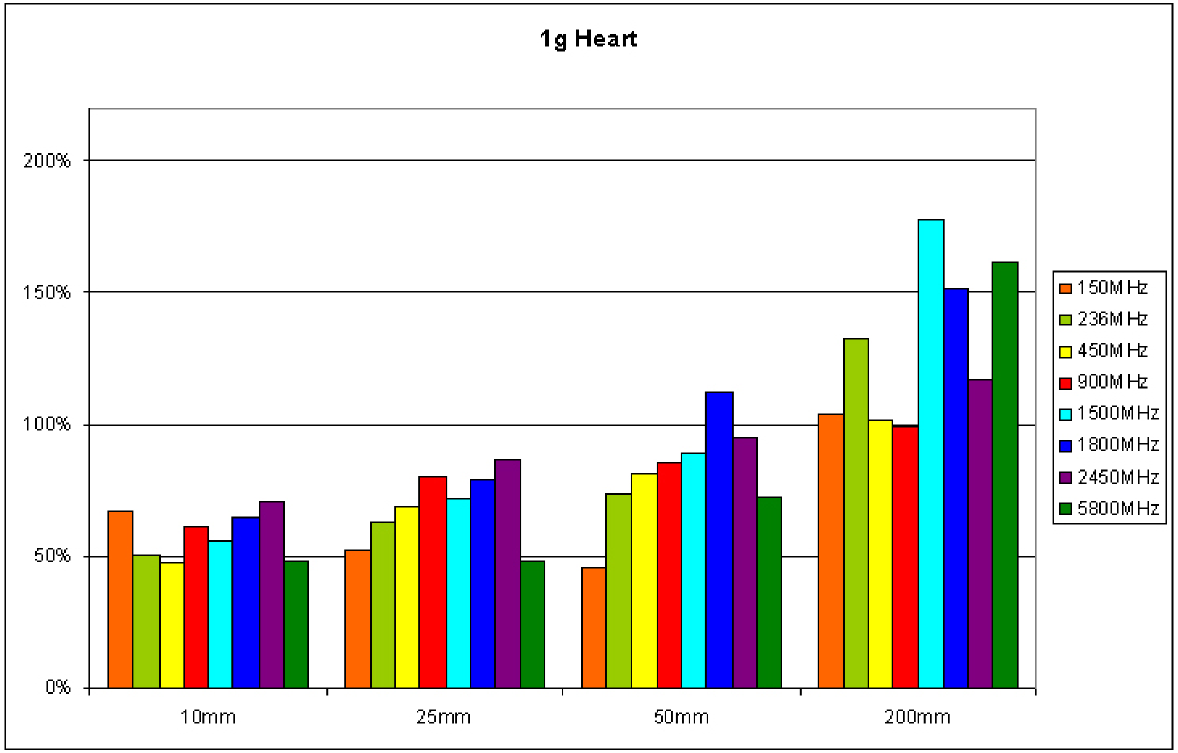
Summary of Resonances

- peak spatial SAR is significantly affected by body resonances only for large distances between antenna and body (>10dB)
- for distances < 200mm, the effect is less than 1dB

Impact of Tissue Layering

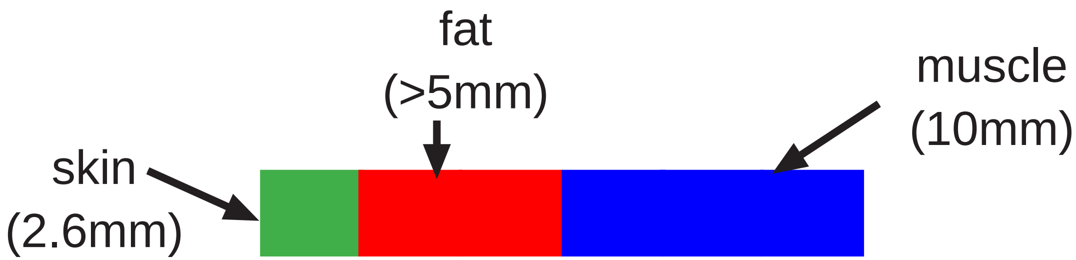
Flat Phantom vs Visible Human

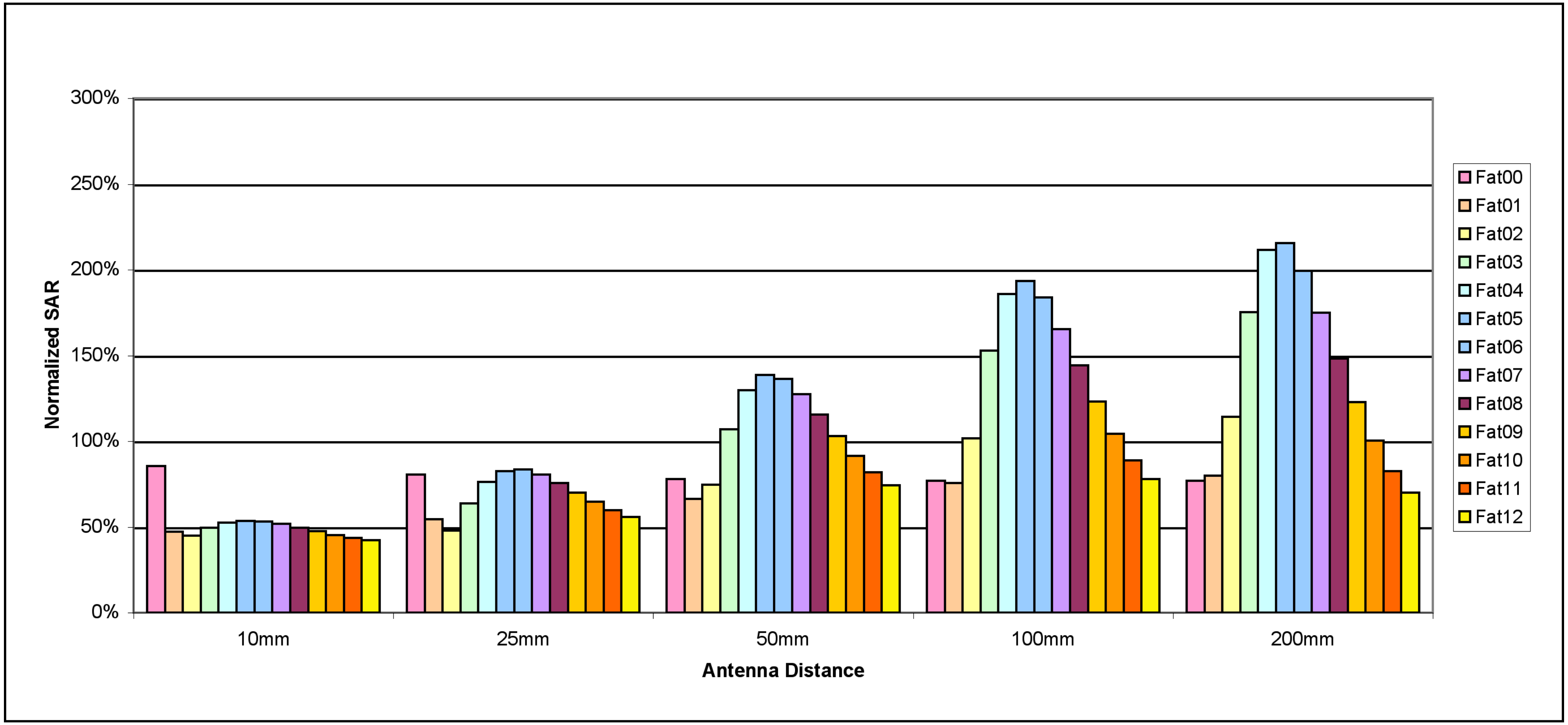




- exposure of the human body to radiation from dipole antennas
- different locations and distances (10mm-200mm, heart, kidney, spine, leg)
- deteriorating overestimation of the SAR for increasing distances

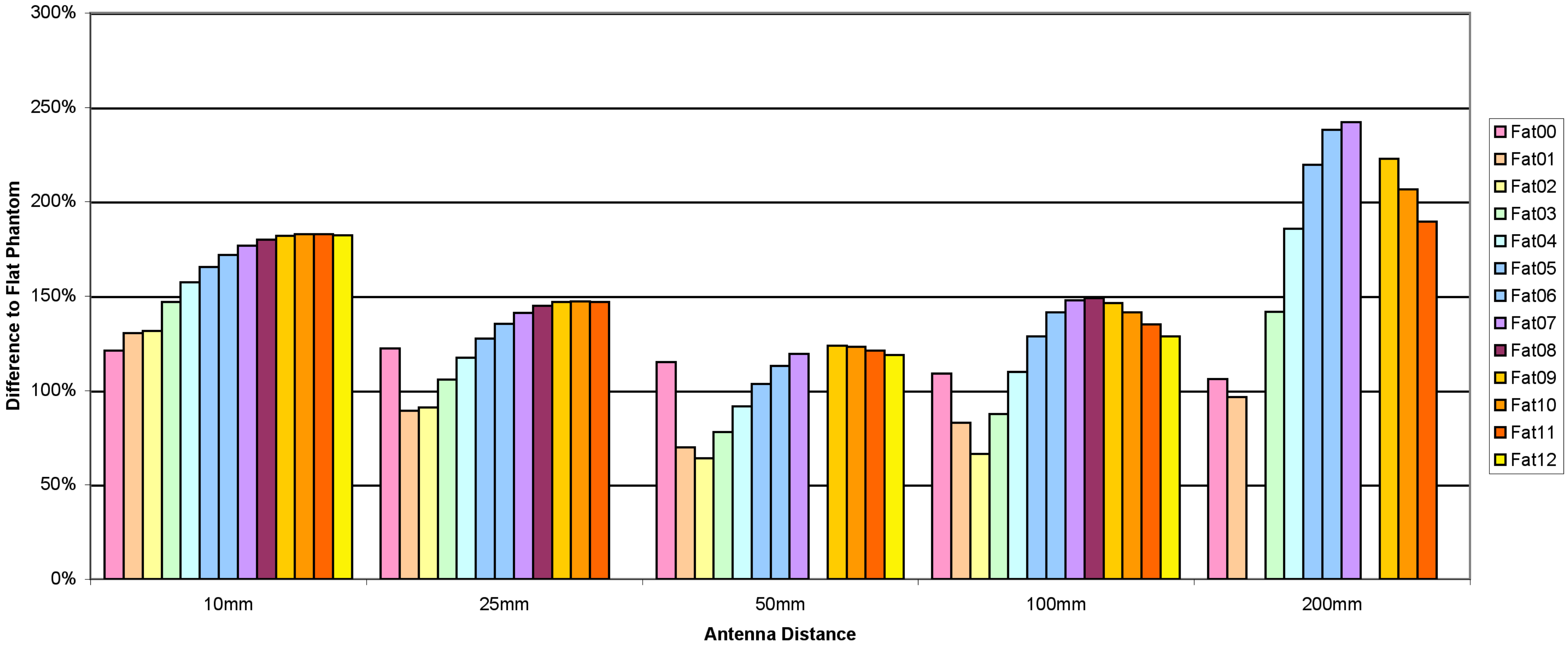
1g SAR, 900MHz, Layered vs Homogeneous, Helix Antenna





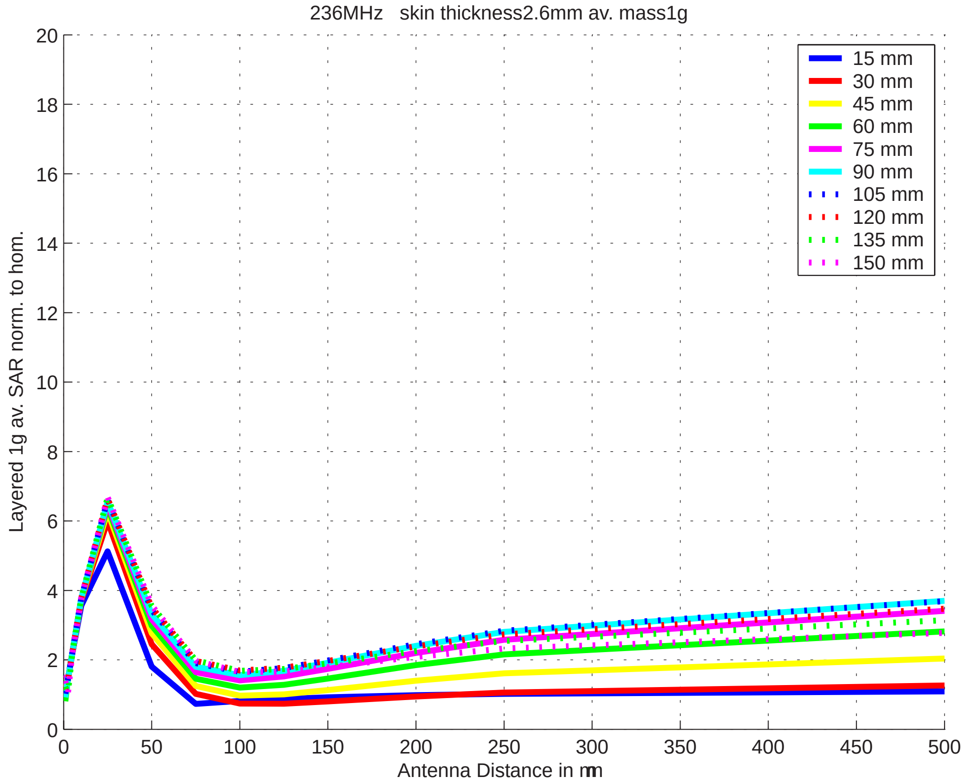
at high frequencies effect only for certain fat thickness and large distances: standing waves

1g SAR, 236MHz, Layered vs Homogeneous, Helix Antenna

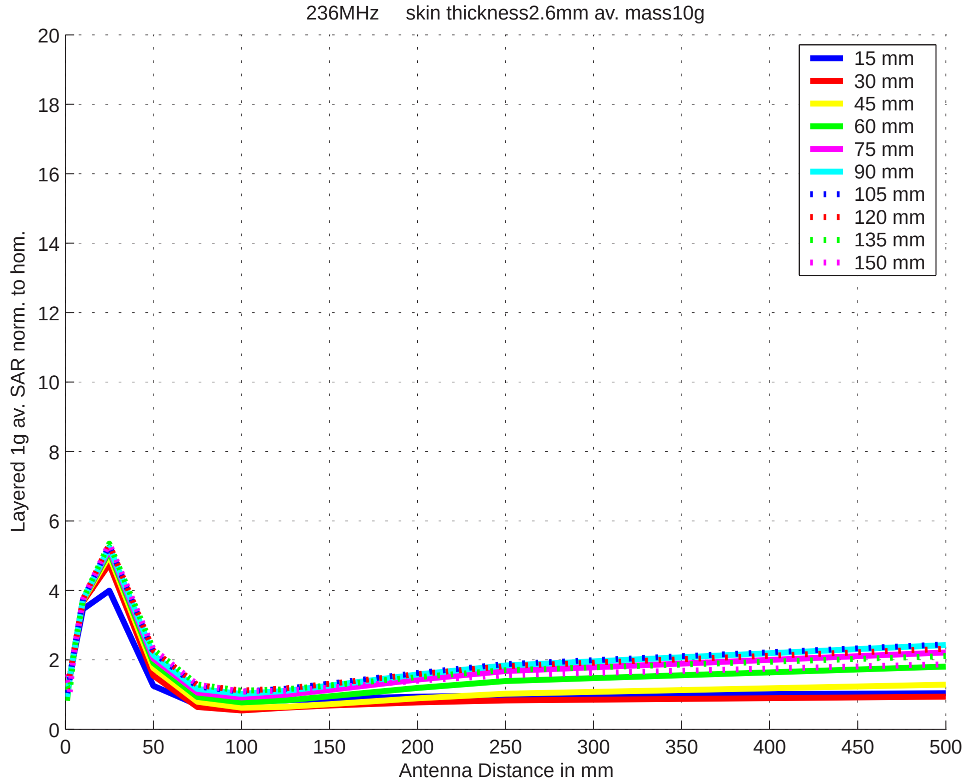


flat phantom underestimates also for small distances: new effect

SAR Ratio Layered vs Homogeneous at 236MHz



1g average



10g average

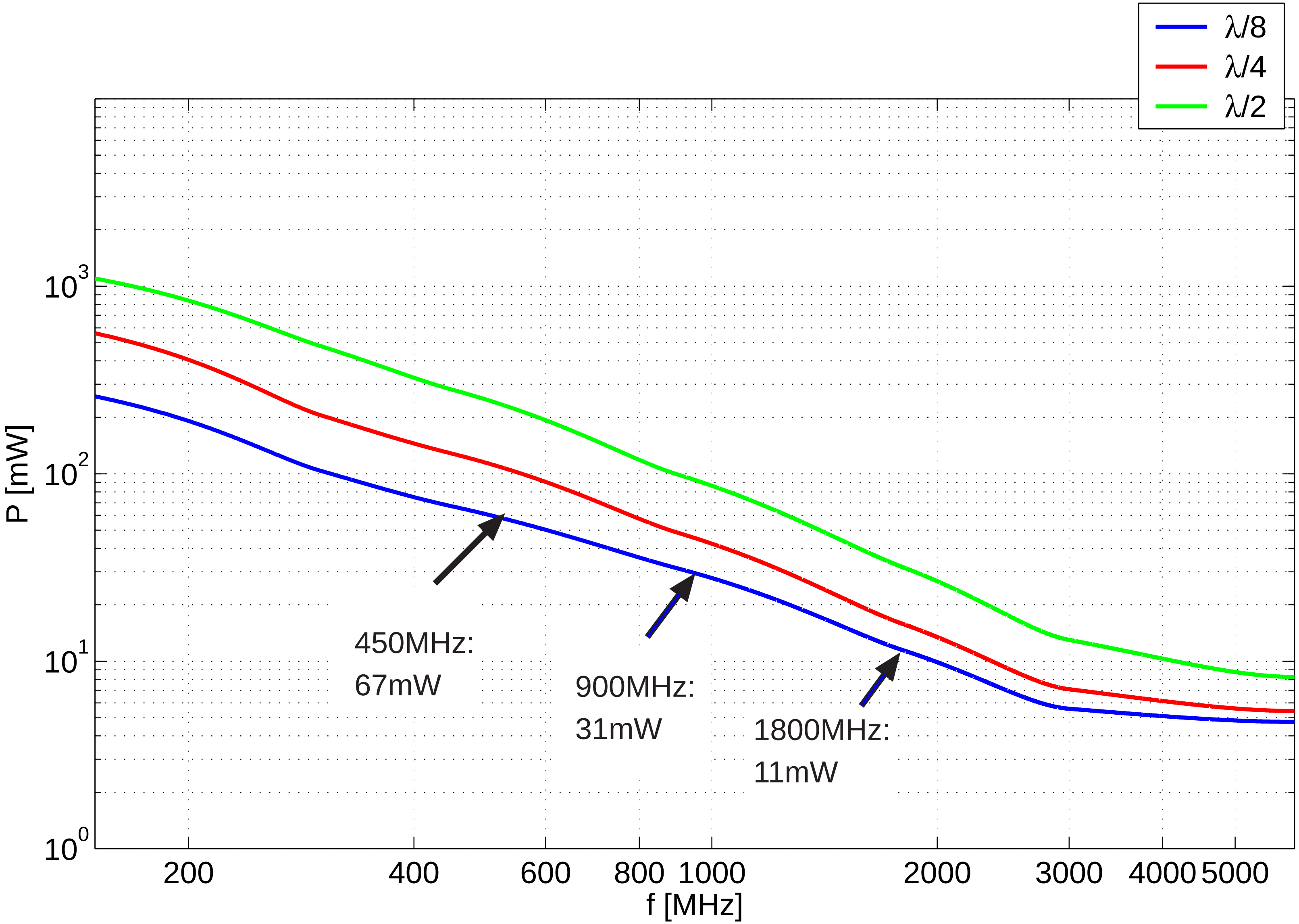
Sommerfeld integrals used to reproduce the findings for short distances

Conclusion for Layered Tissues

- layering has a significant impact on the spatial peak SAR
- effects of layering already significant at low distances (10mm)
- necessity of a correction factor

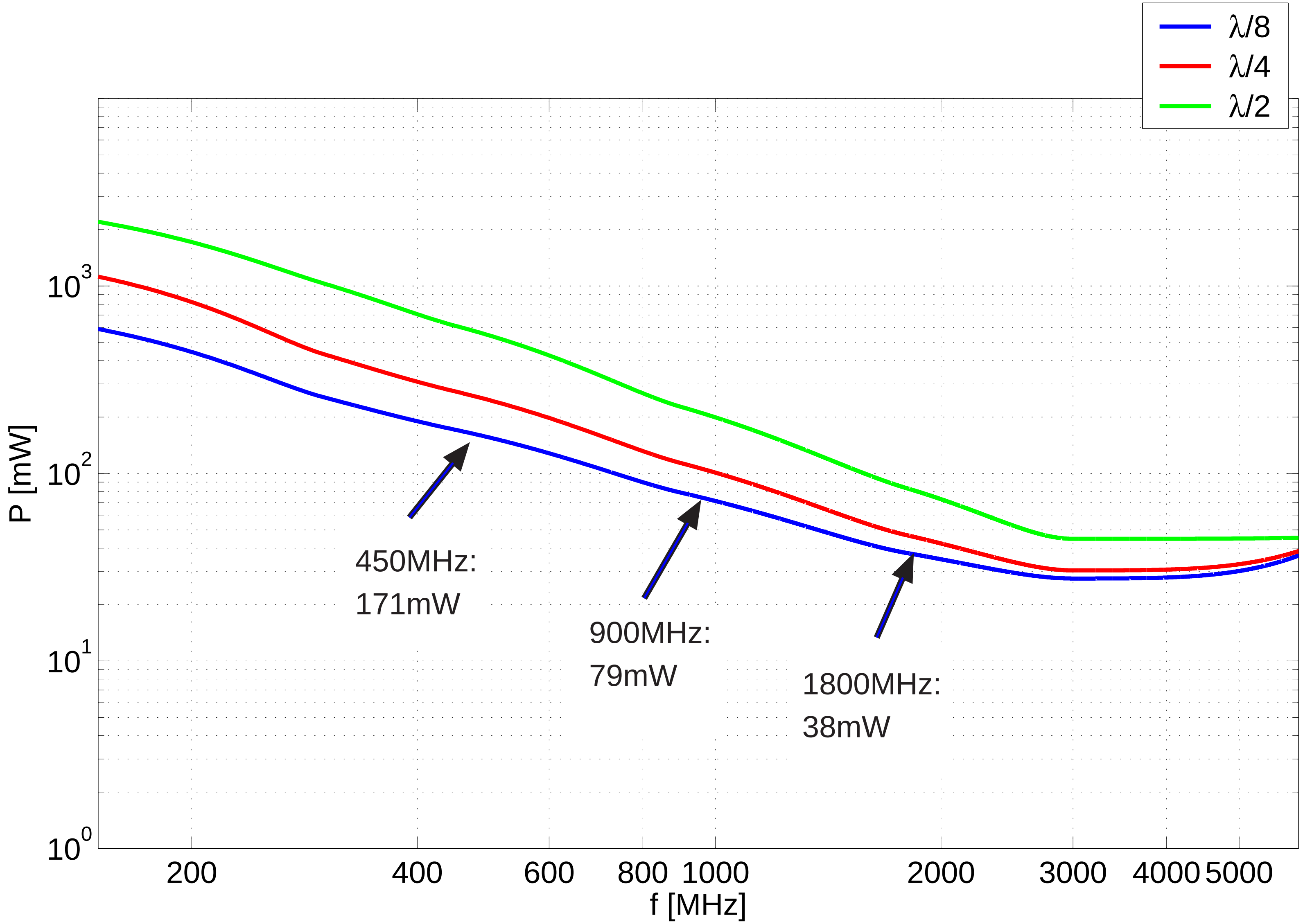
Low Power Exclusionary Clause

Antenna Input Power for a 1g SAR of 1.6 mW/g, Distance: 5mm



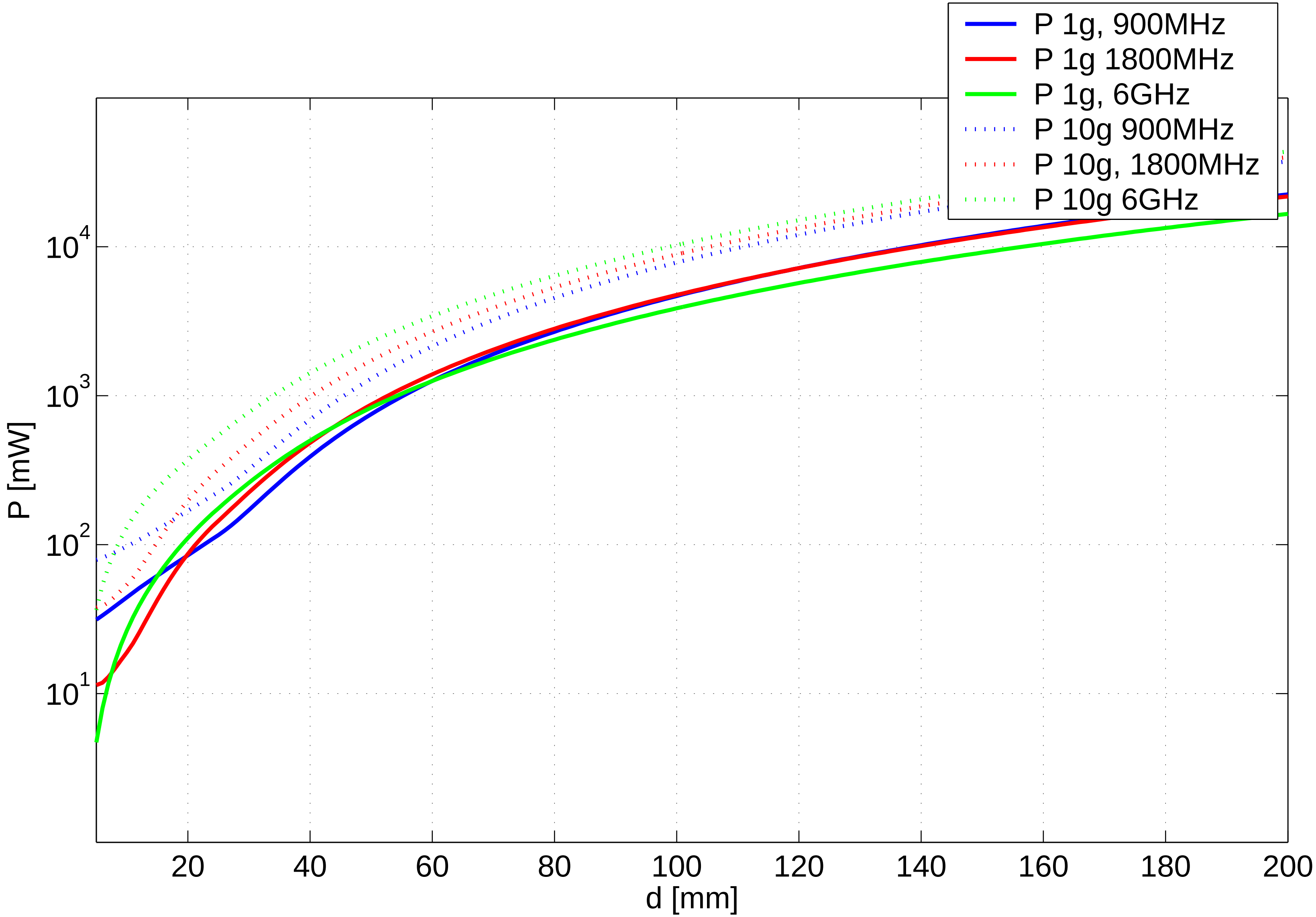
theoretical limit: 1.6mW, real limit: 4mW

Antenna Input Power for a 10g SAR of 2.0 mW/g, Distance: 5mm



theoretical limit: 20mW, real limit: 30mW

Input Power as Function of Distance, λ/8 Dipole



Conclusion for Low Power Clause

- power input power strongly depends on antenna length and distance
- exclusionary clause based on feedpoint current represents worst-case
- exclusionary clause based on power is only possible if maximum power is derived from load-pod???
- the minimum power is close to the theoretical limits (1g: 4mW vs 1.6 mW, 10g: 30mW vs 20mW)
- relaxiation possible when frequency is considered

Conclusion & Outlook

- The fundamentals of a flat phantom were thoroughly investigated.
- The critical parameters for a low-power clause were shown.
- Outlook: more anatomical models, development of a complete phantom