A New Look at Shielding to 20GHz and Beyond

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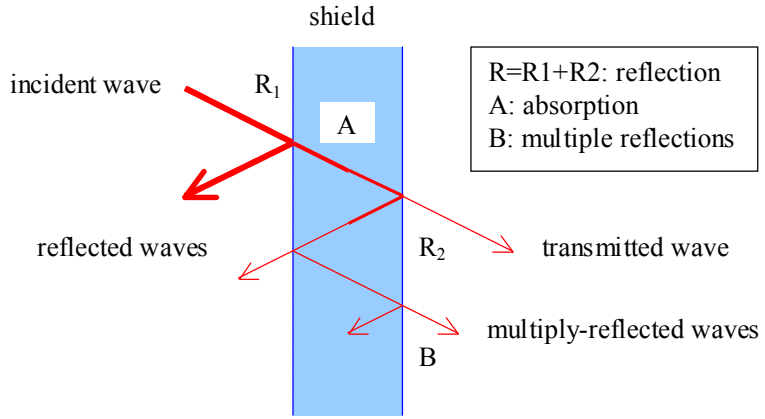
Shielding from DC to 20GHz+

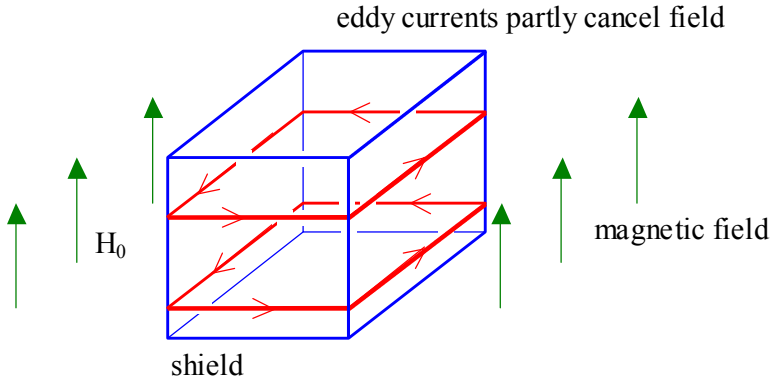
- Shielding models
- Internal resonances
- Reverberant environments
- Effect of contents: shadowing
- Some other uses for screened rooms

DC to Audio

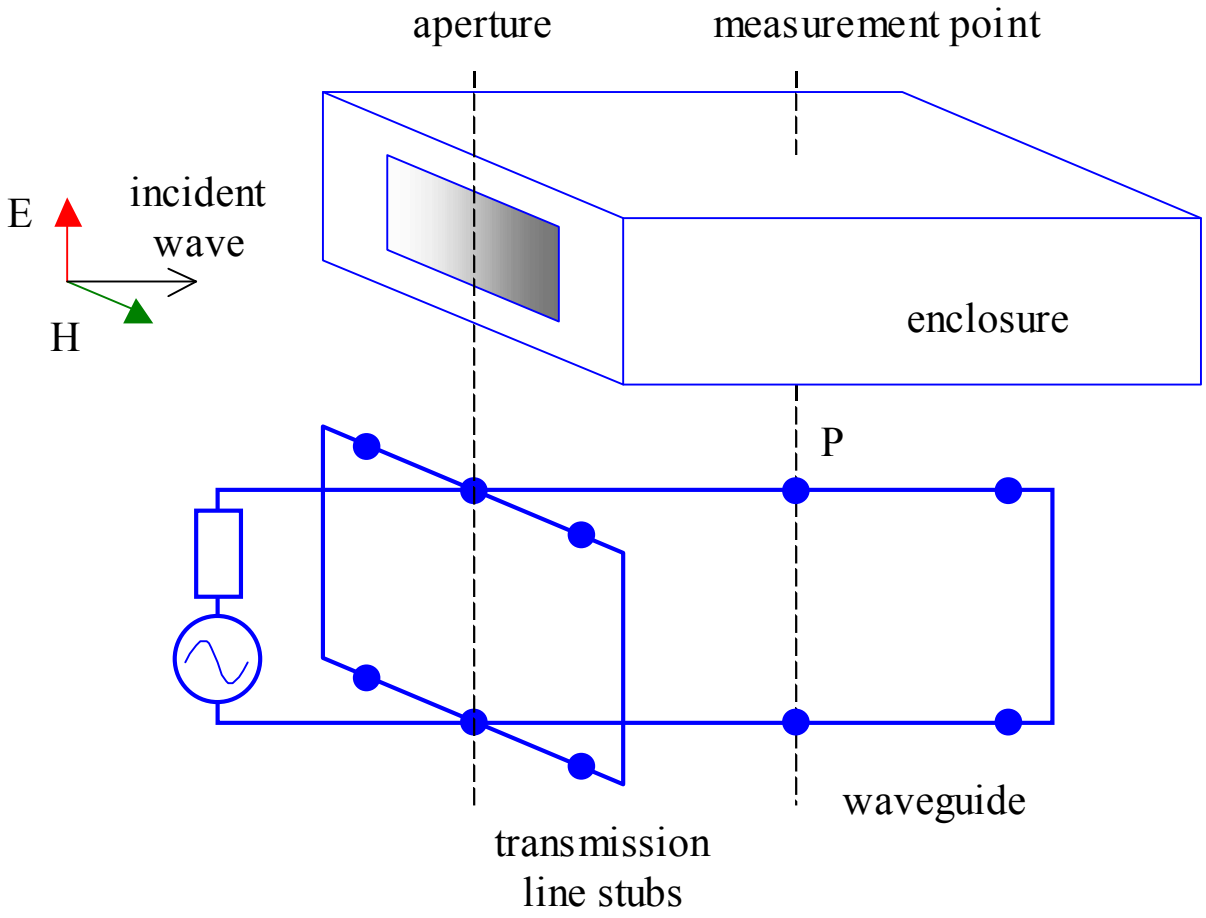
- Schelkunoff model for sheet materials



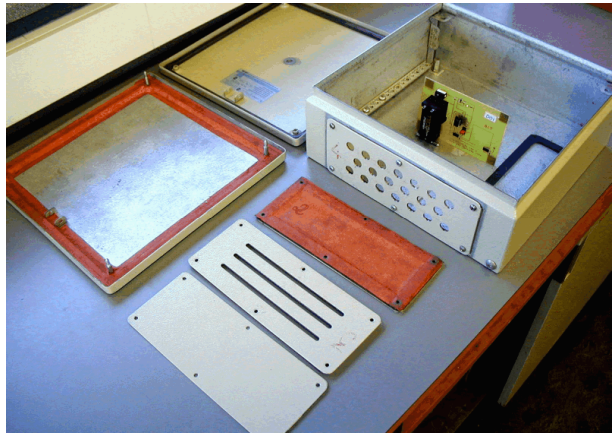
- Kaden model for enclosures

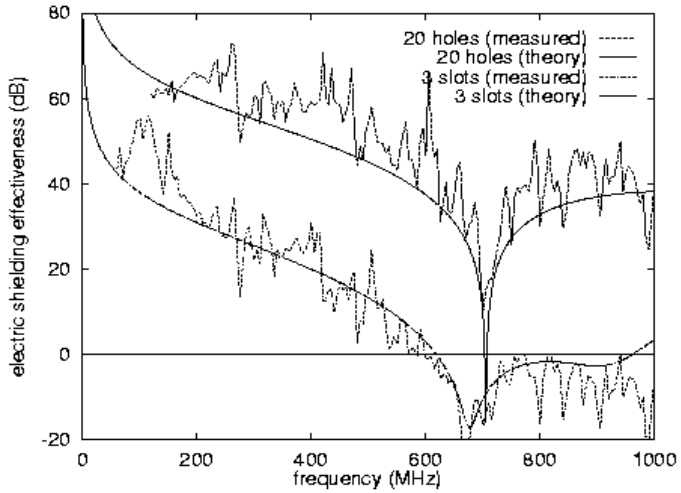


Audio to 1GHz



Transmission Line / Waveguide Model





- Intermediate level model
- Good agreement
- What's missing?
  - how to relate contents to losses
  - closely-spaced apertures, meshes
  - can only deal with a few resonances

Resonances of a 30x30x12cm Box

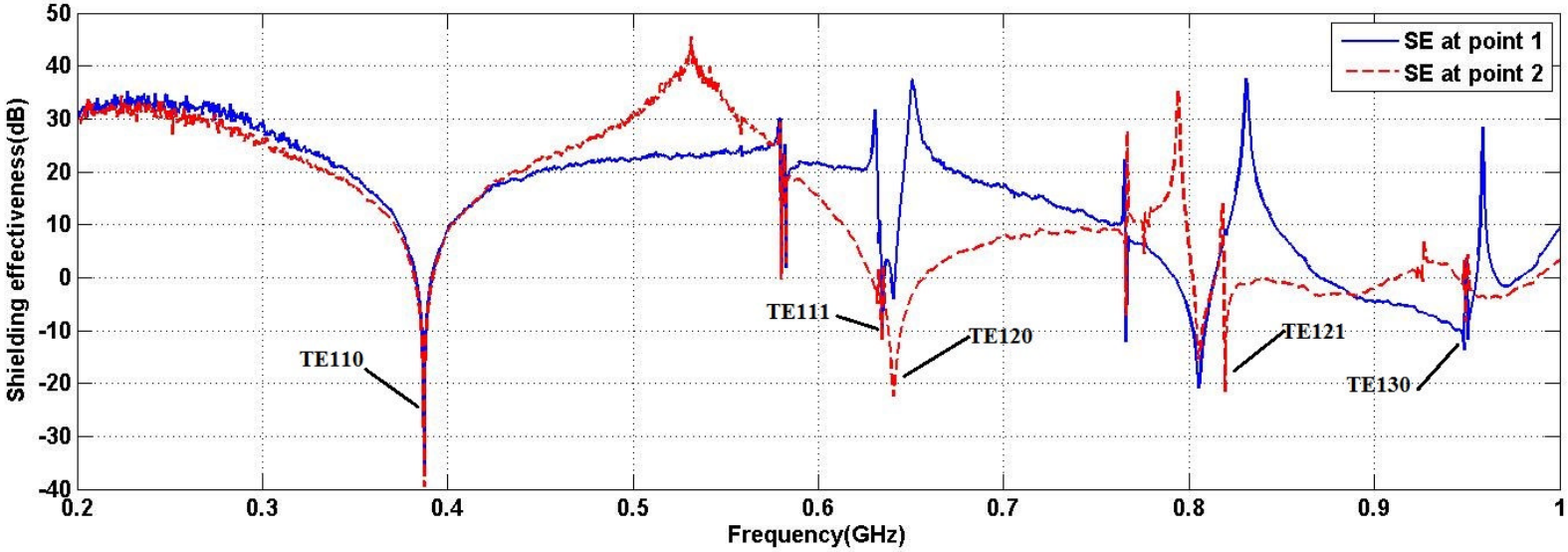
- 0-1 GHz 1 mode
- 1-2 GHz 17 modes
- 2-20 GHz 14,461 modes

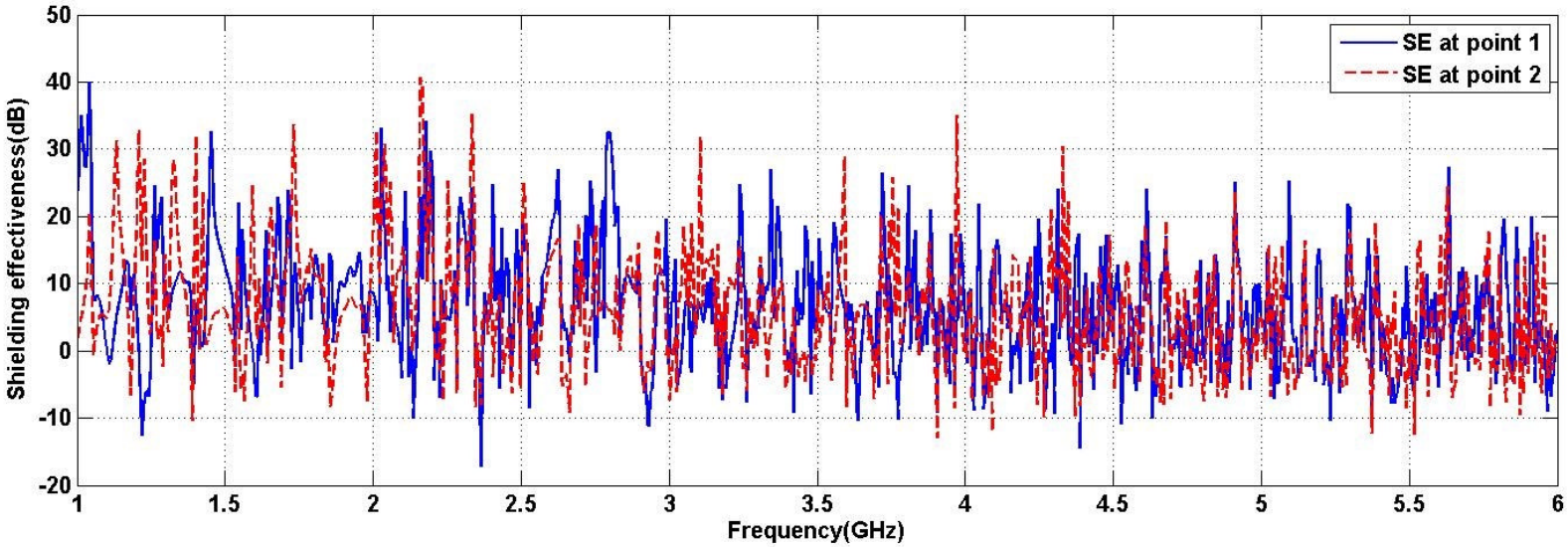
- Statistical methods needed

Resonant Frequencies

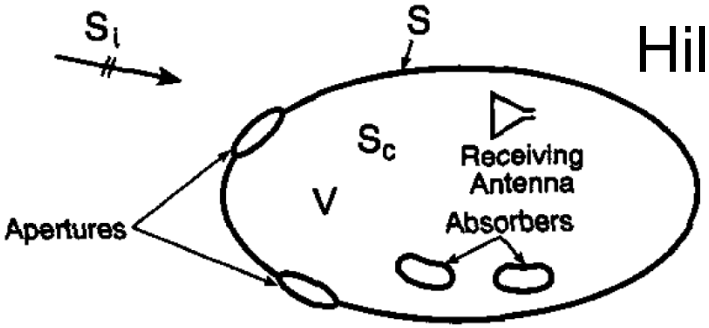
- 706 MHz
- 1,115 MHz
- 1,119 MHz
- 1,344 MHz
- 1,346 MHz
- 1,413 MHz
- 1,435 MHz
- …
- …
- 19,998 MHz
- 19,998 MHz
- 19,998 MHz
- 19,999 MHz
- 19,999 MHz
- 19,999 MHz
- 20,000 MHz

More Modes / Hz – Need Stats Approach





Power Balance in Shielded Enclosures



Hill: $Q^{-1}=Q_{wall}^{-1}+Q_{abs}^{-1}+Q_{ap}^{-1}+Q_{ant}^{-1}$

- Energy enters & leaves via apertures
- But some power is absorbed in contents: PCB's etc.
- This lowers Q-factors and generally improves shielding effectiveness

Absorption Cross-Section

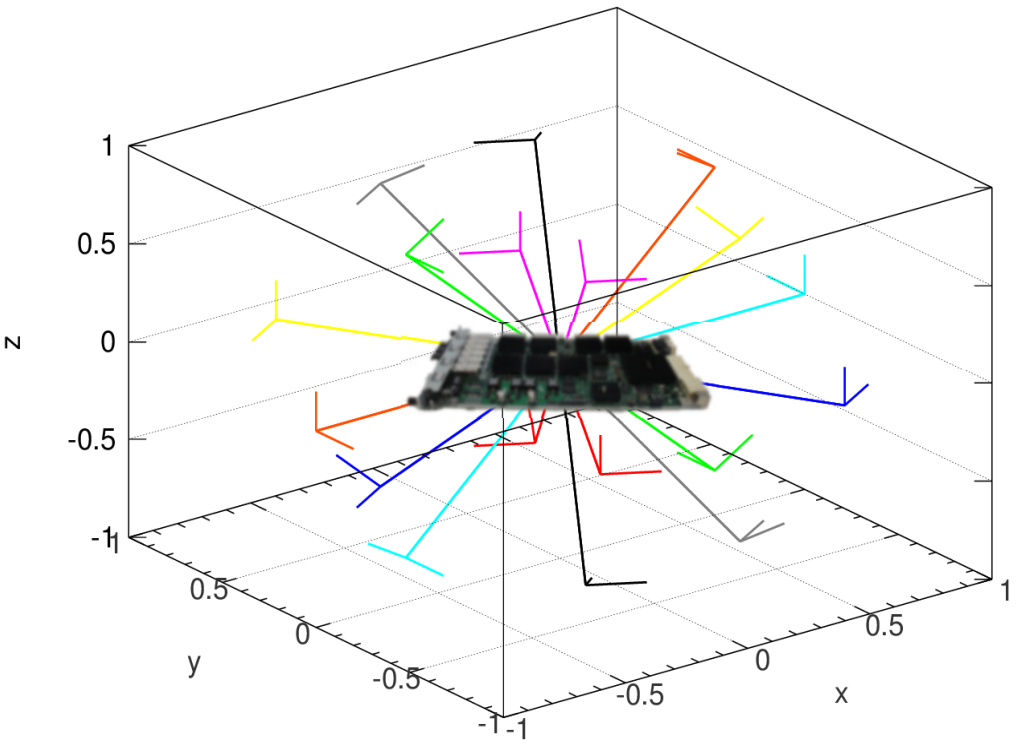
- Shielding effectiveness (SE) traditionally measured with an empty enclosure
- Finding absorption cross-section (ACS) of PCBs enables us to calculate effect on actual shielding


Standard SE Test


Reality

ACS in Reverberation Chamber

- Stirred-mode measurement
- Equivalent to illuminating PCB from all directions



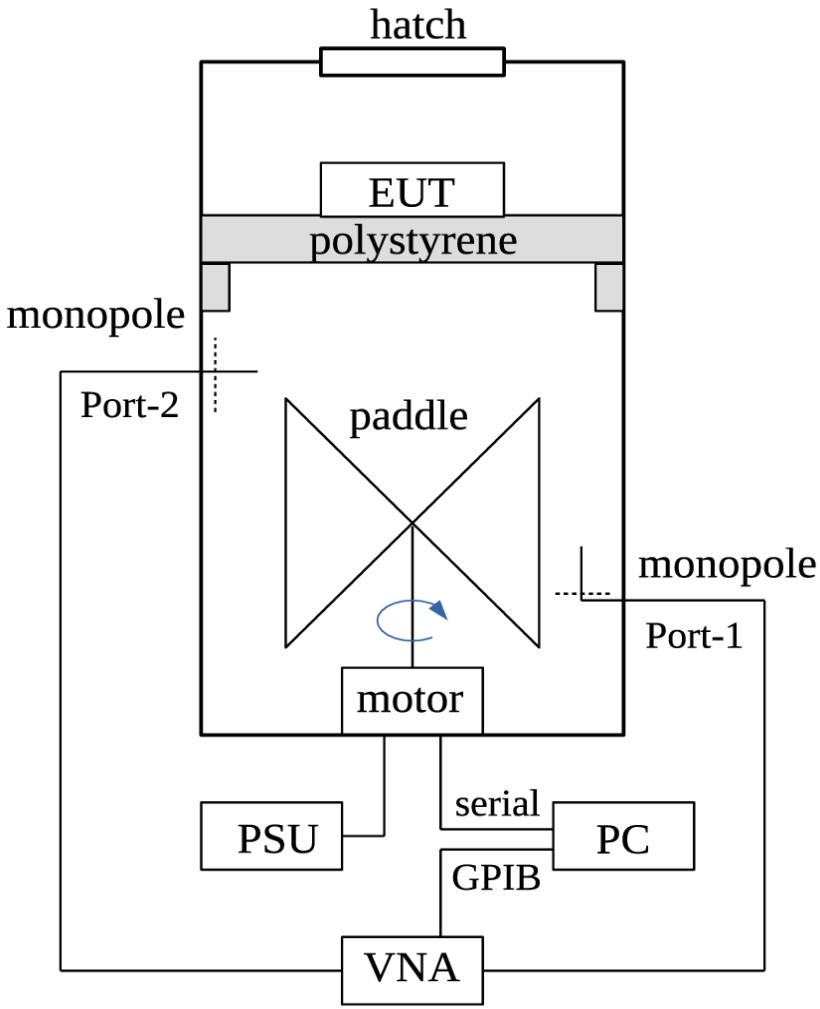
Measurement of ACS

- Determined by difference in insertion loss between loaded and unloaded chamber

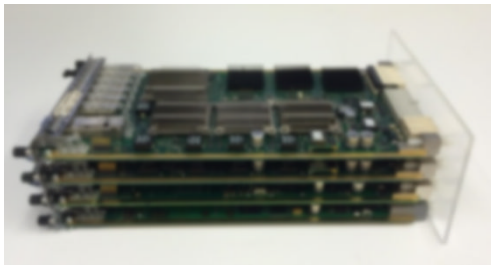
$$\langle \sigma_{\mathrm{EUT}}^{\mathrm{a}} \rangle = \frac{\lambda^2}{8\pi} \eta_1^{\mathrm{T}} \eta_2^{\mathrm{T}} (IL_{\mathrm{load}} - IL_{\mathrm{unl.}})$$

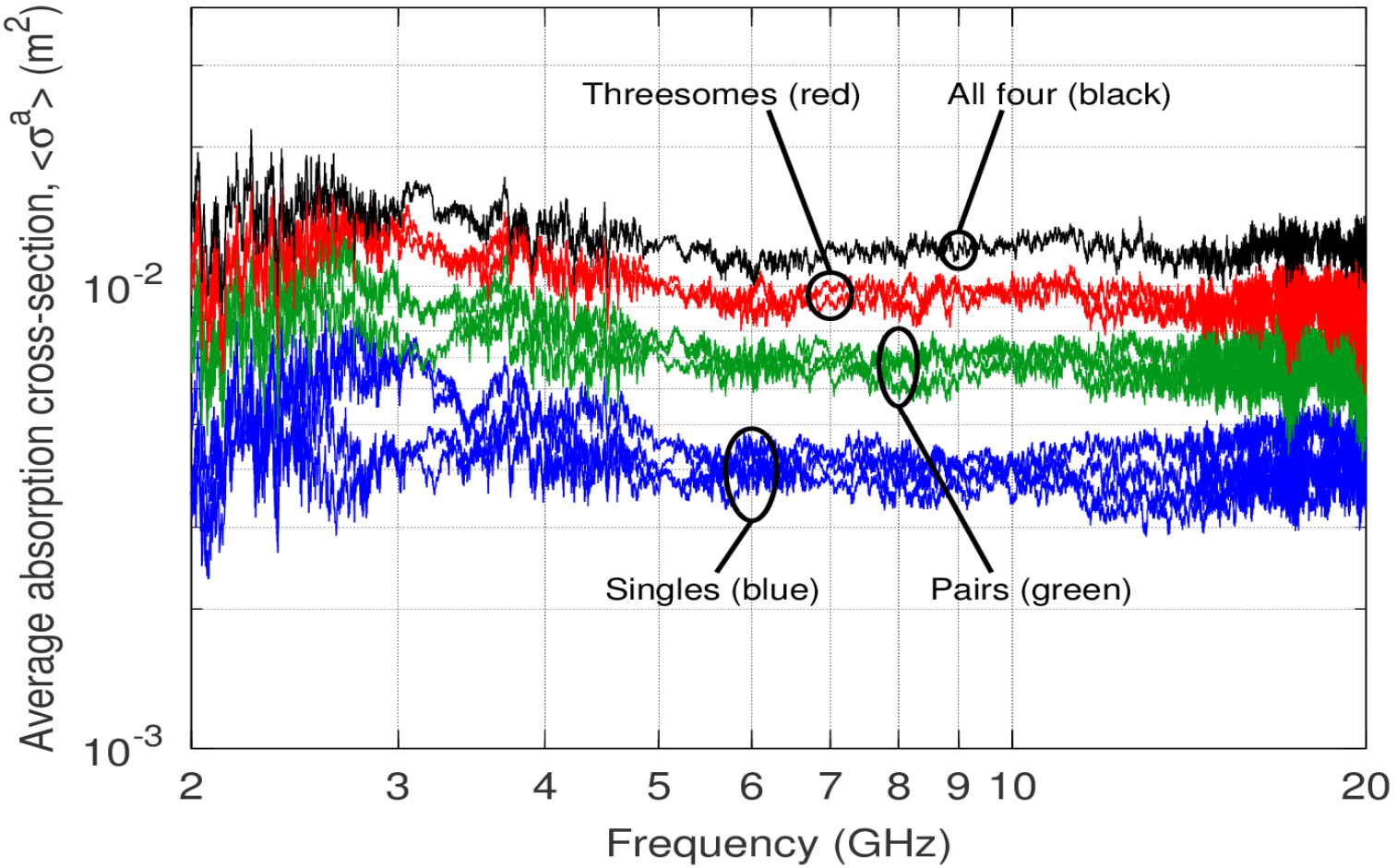
$$IL = \frac{1}{\langle |S_{21}|^2 \rangle}$$

$$\eta_i^{\mathrm{T}} = \eta_i^{\mathrm{rad}} (1 - |\langle S_{ii} \rangle$$

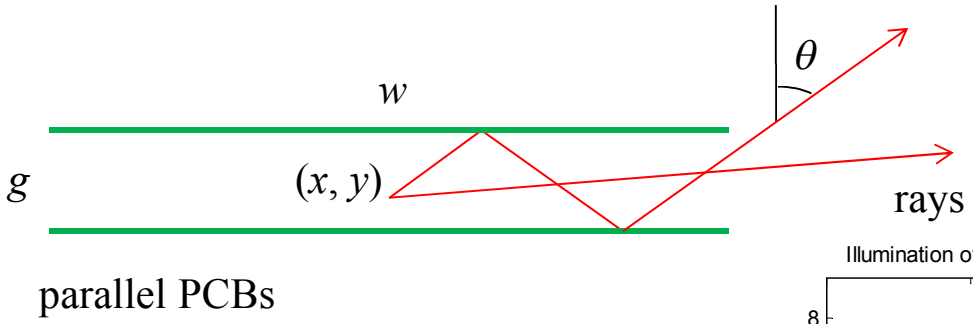


ACS of PCB Stacks

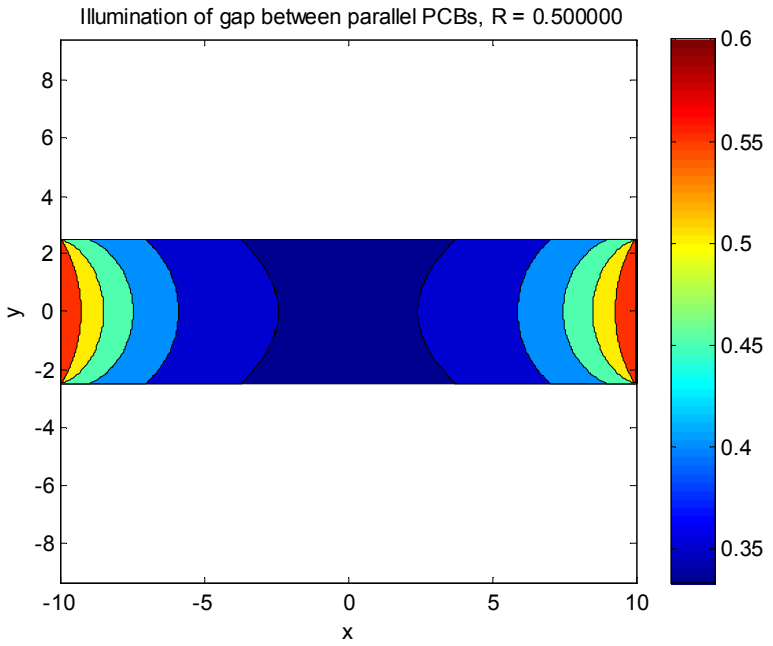




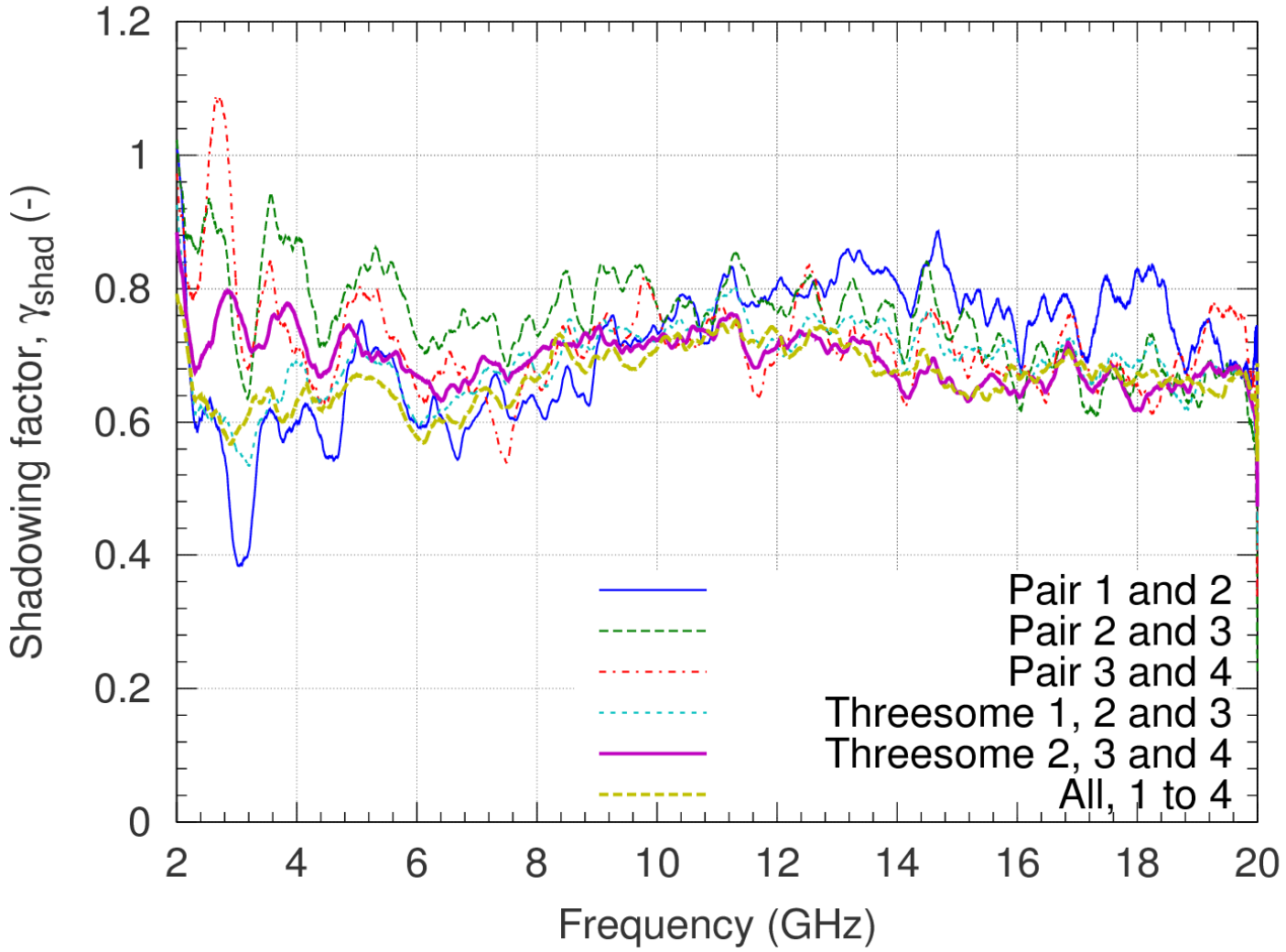
Shadowing Effect



- It's "darker" at the centre of the gap between the PCBs

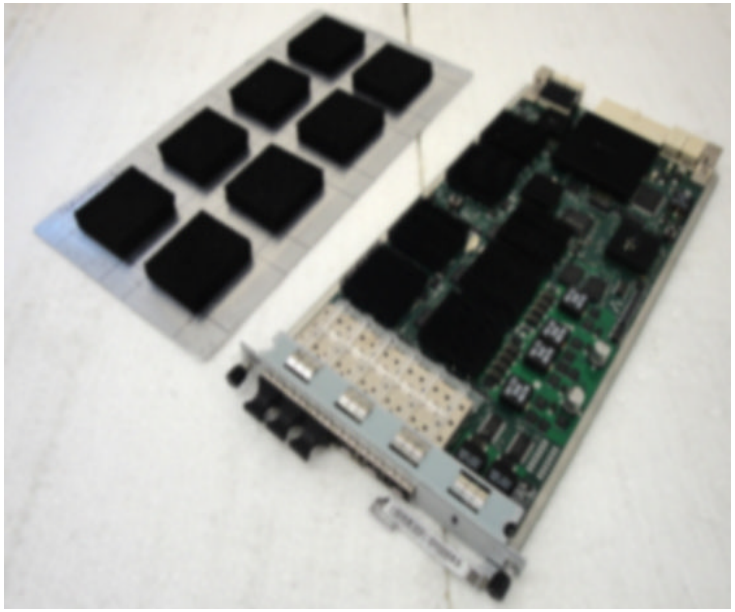


Shadowing Factors

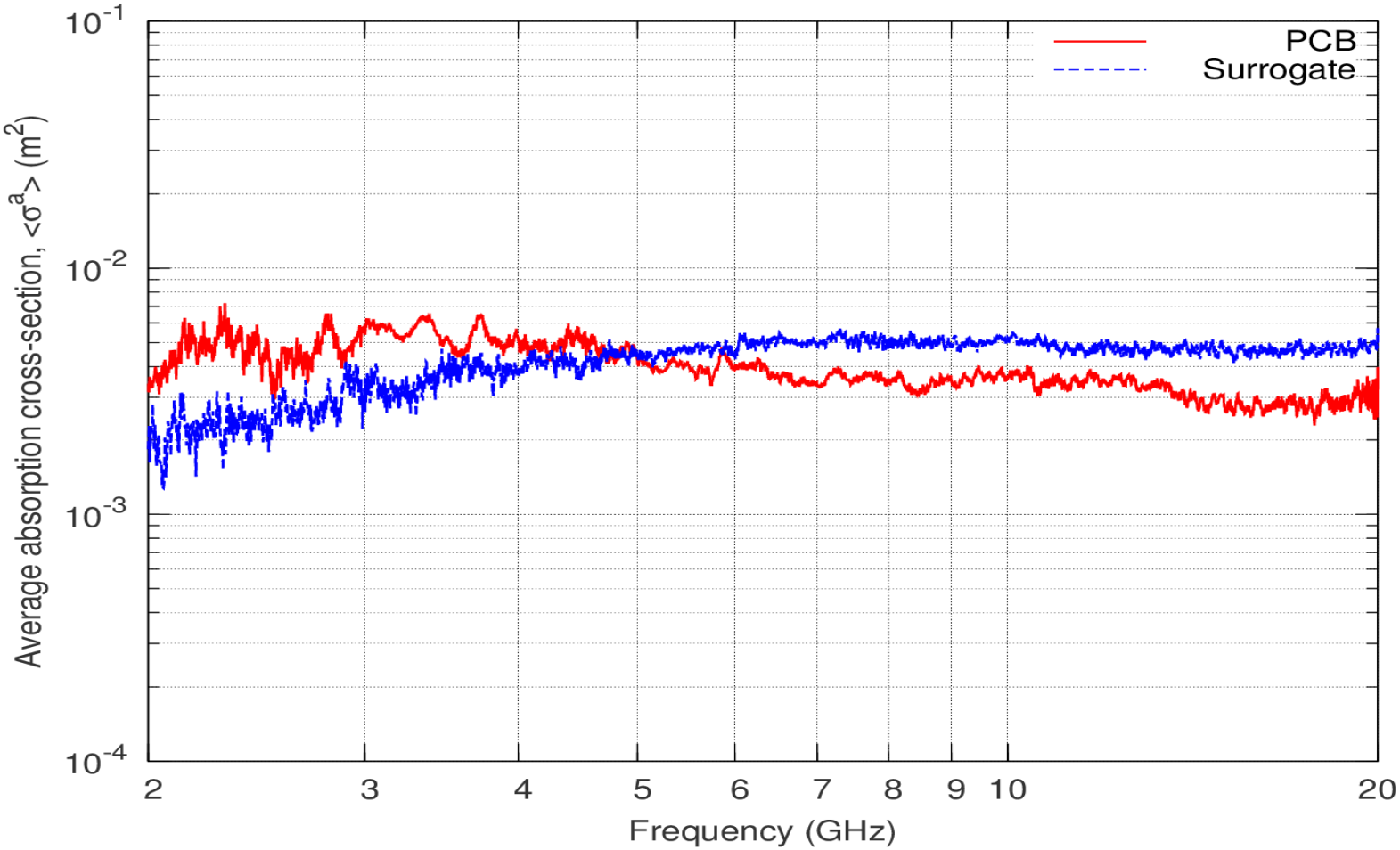


The ‘ReCo’

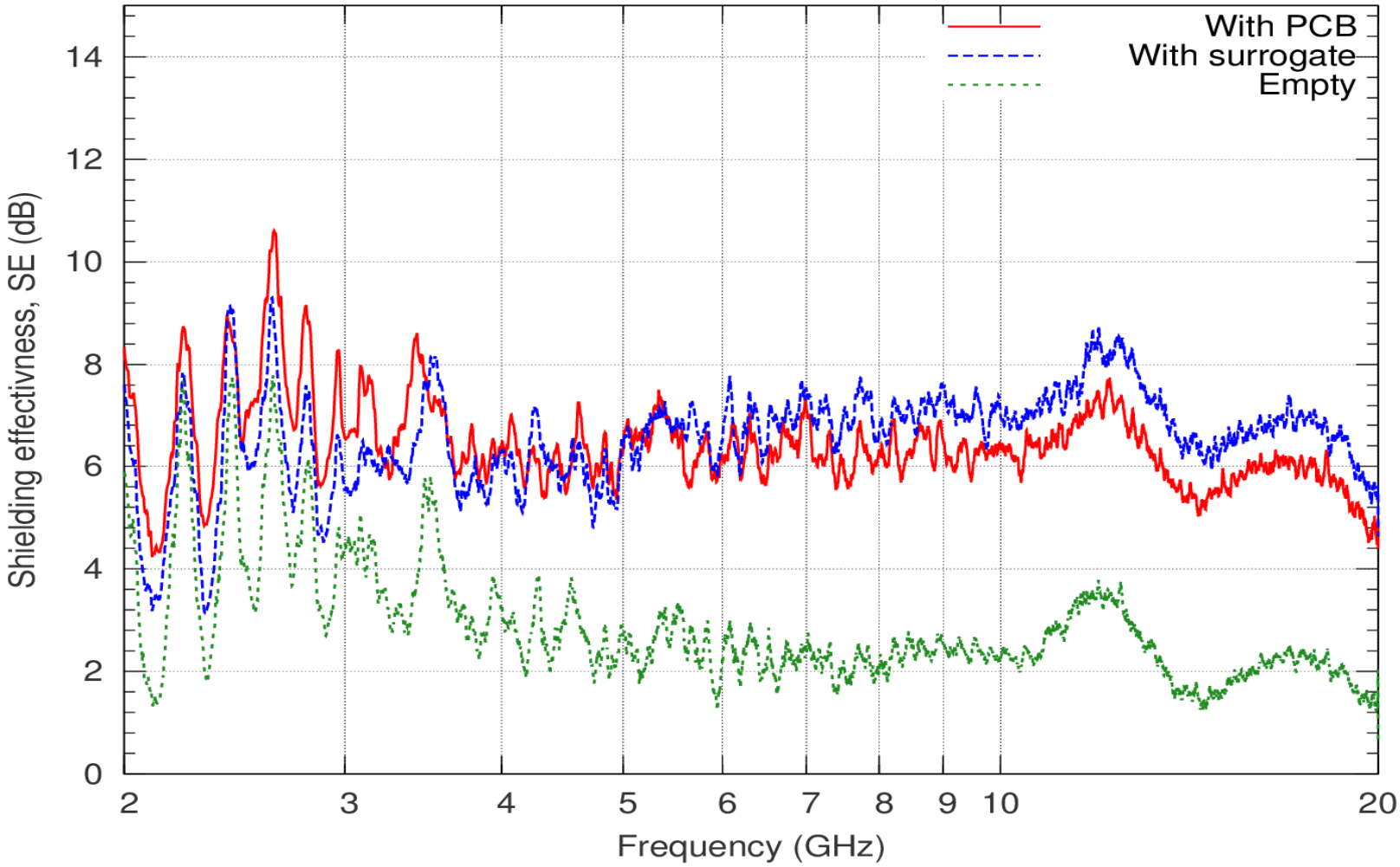
- Representative Contents made from absorber or from loaded transmission lines
- Want same ACS as real PCBs



Measured ACS of ReCo Compared to Real PCB



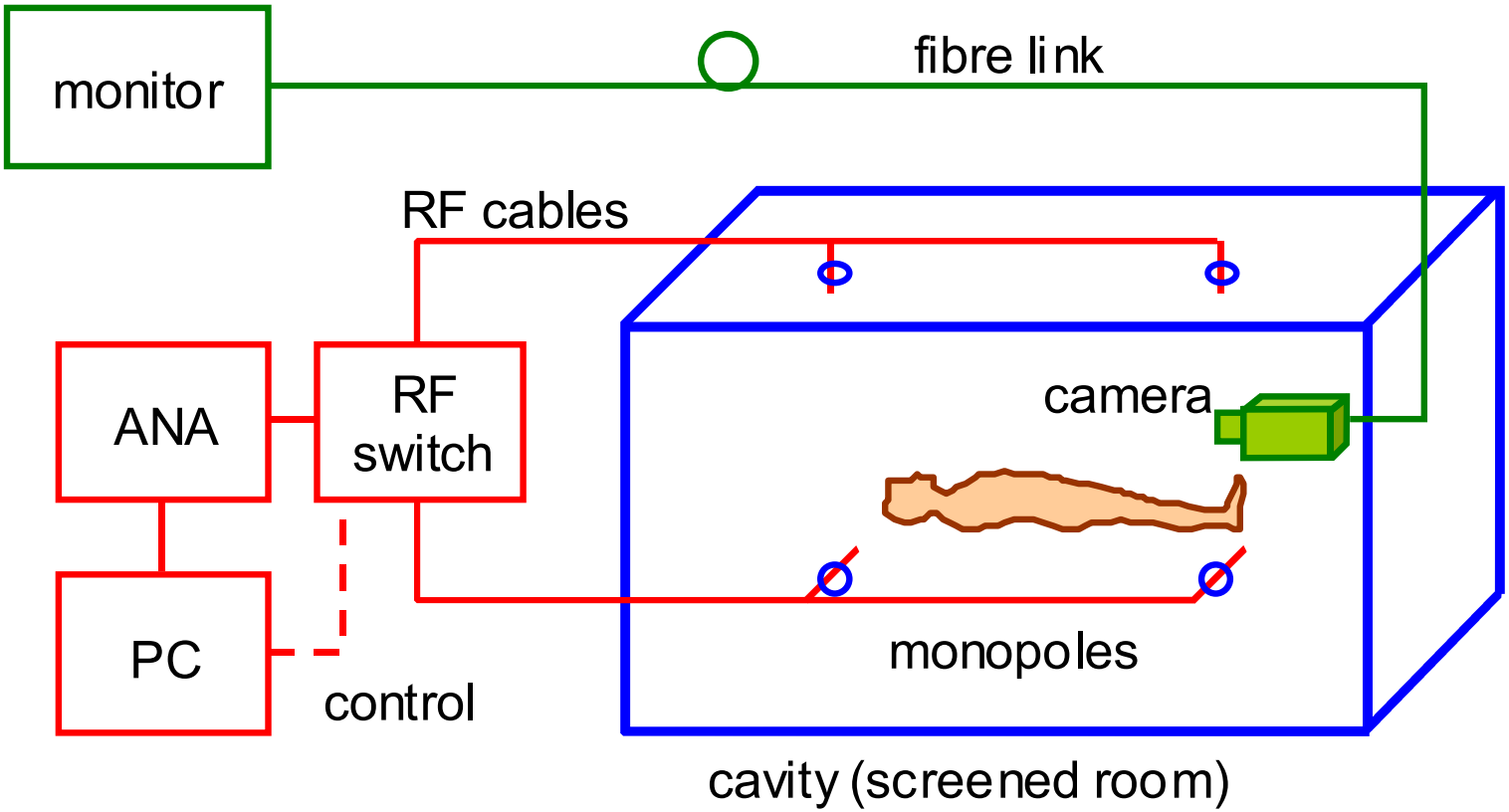
SE Measurement



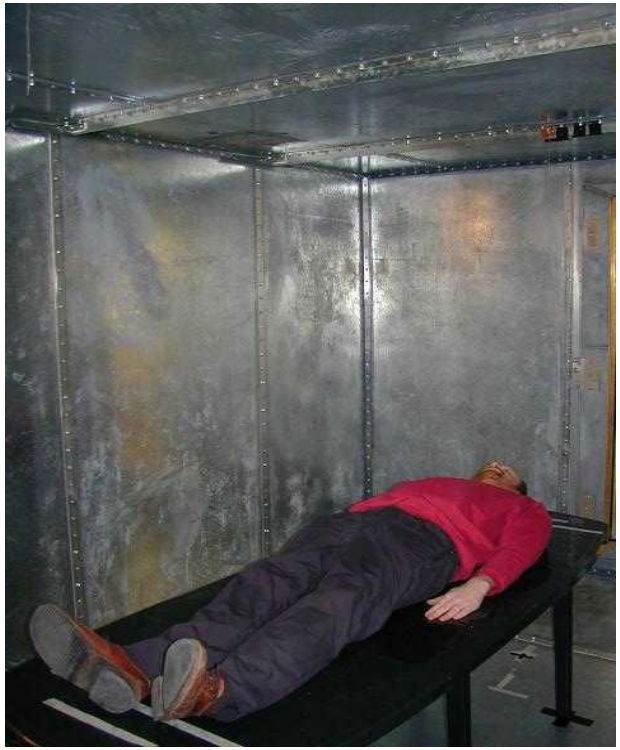
What if the ‘Absorber’ is a Person?

- Fundamental resonance of screened room, 60MHz
  - field penetrates whole body
  - non-invasive measurement of body water
- Higher-order resonances, 1-20GHz
  - field only reaches few cm at surface
  - gives absorption cross section in multi-path environment

Resonant Cavity Perturbation

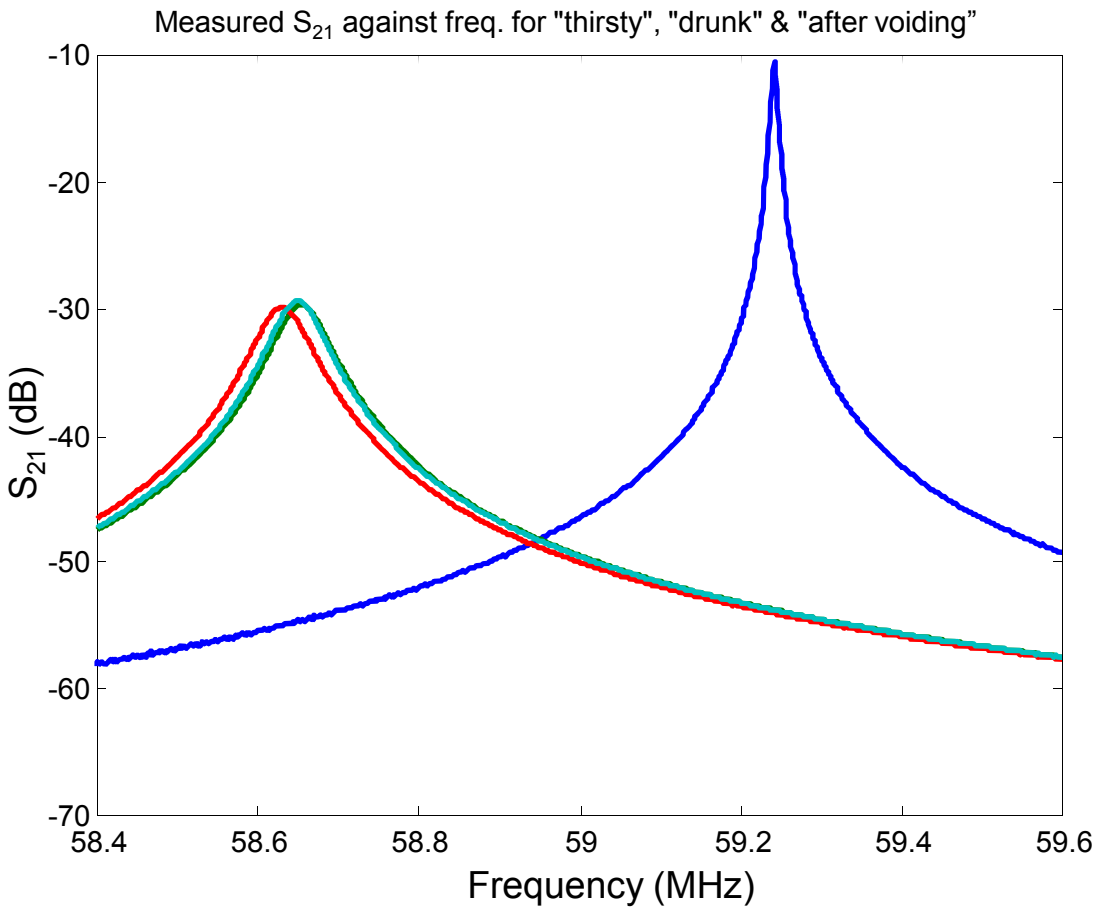


Screened Room used as Cavity

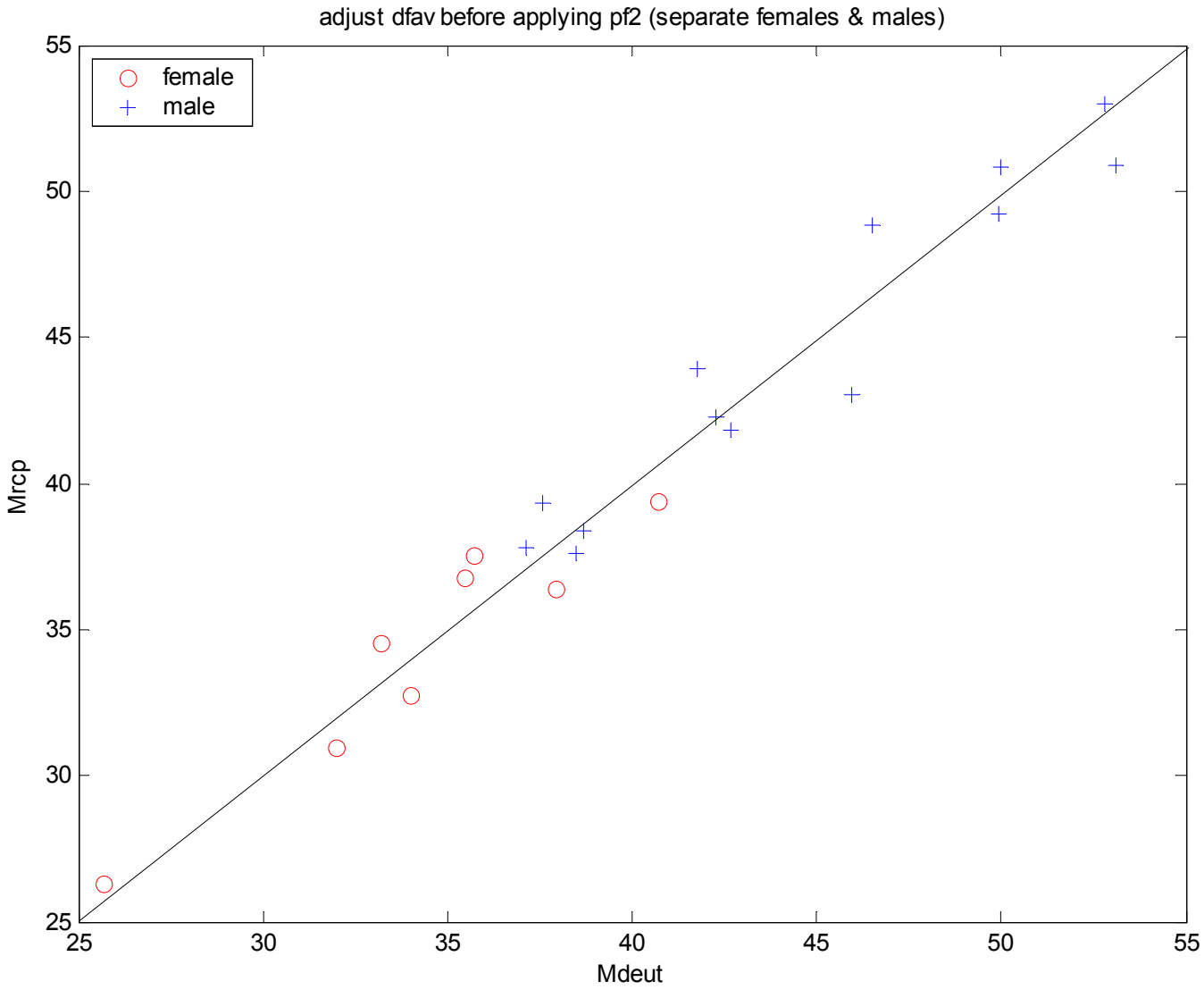


- Resonant shift due to dielectric properties of body, which depend on tissue water

Shift in 60MHz Resonance



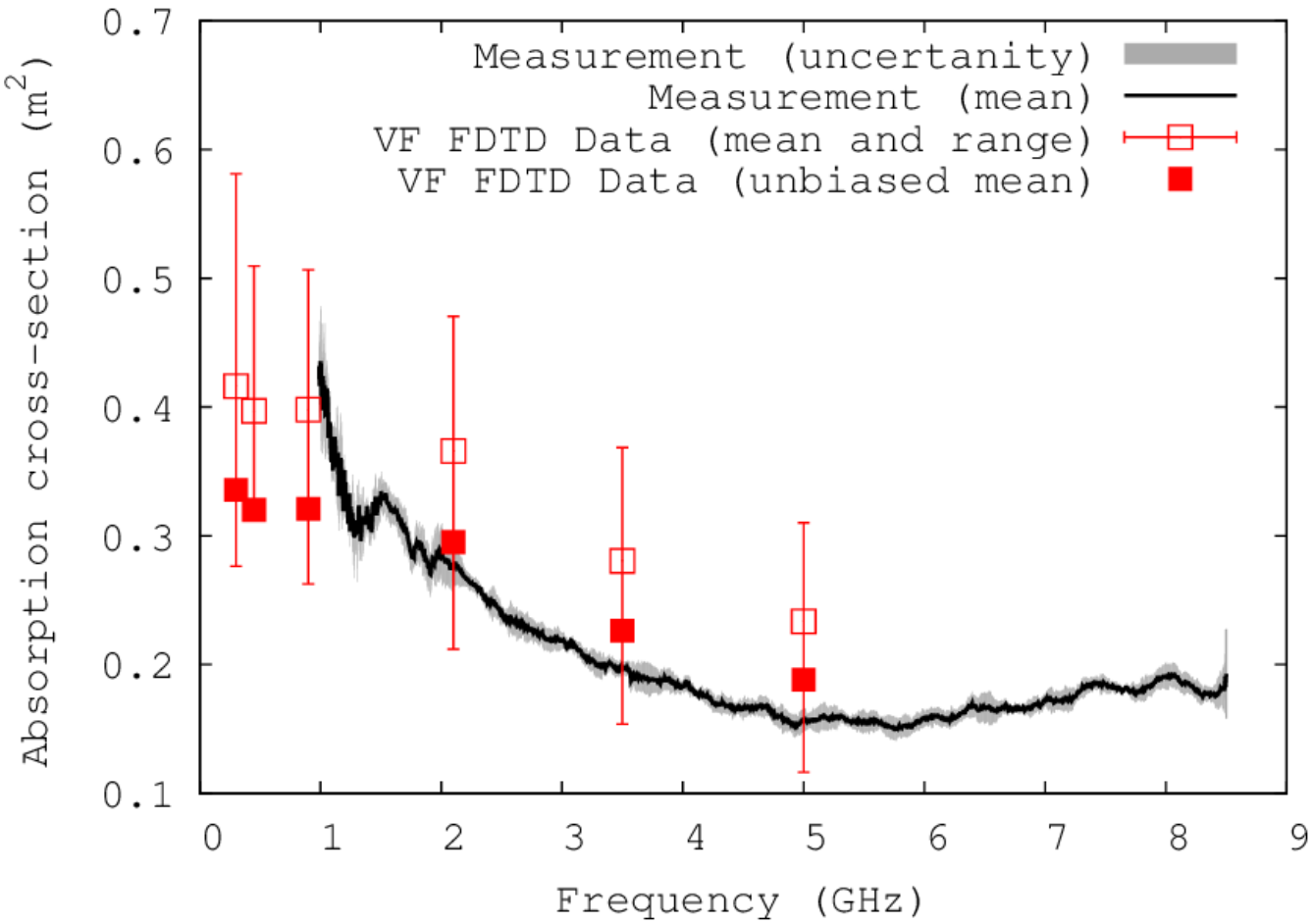
RCP vs Deuterium Dilution (TBW in kg)



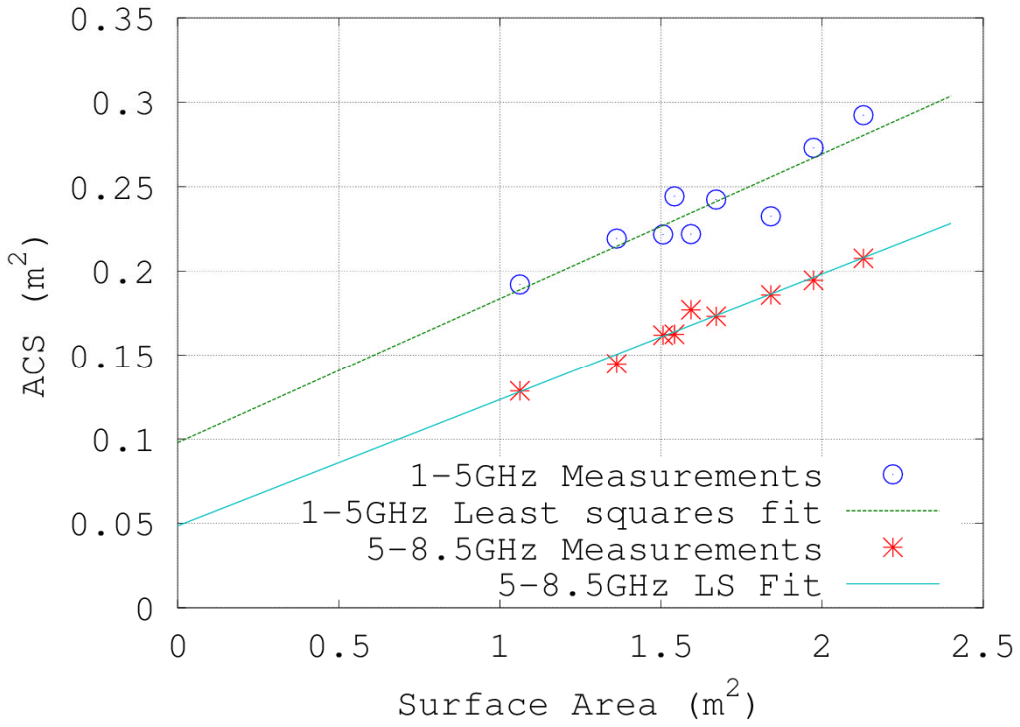
Microwave Absorption

- We are measuring human absorption from 1-20GHz in an environment where the waves are coming towards the body from all directions at once

Human ACS measurements



ACS vs Surface Area



- We are investigating relationships between ACS , surface area and subcutaneous body fat
- Measurement takes a few minutes

Conclusions

- Shielding at 1-20GHz is hard to calculate owing to density of modes
- Statistical power balance approach works well
- Need to account for PCB absorption and shadowing effects
- Shielding technology useful for studying body composition and exposure to microwaves

Many thanks to…

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Image on Slide 9 from IEEE Trans. EMC vol. 36 p. 169

The End