Aperture Transmission Cross Section for Prediction of Shielding Effectiveness of Enclosures

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Objective:

- To calculate and to estimate the shielding effectiveness of realistic, electrically large enclosures.

Two approaches:

- The semi-empirical FDTD model (T Martin et al.).
- Simple analytical model for bounding estimates.

General background:

Define the Average Shielding Effectiveness, <SE>, as:

$$\langle SE \rangle = \frac{S_{inc}}{S_{scalar}}$$

S_{inc} is the power density of the incident external field

S_{scalar} is the so called scalar power density inside the enclosure

The average <> refers to different locations inside the enclosure.

General background (2):

Average Shielding Effectiveness, <SE>, depends on **both** aperture and cavity properties. For an electrically large cavity, with volume V and quality factor Q, we have:

$$\langle SE \rangle = \frac{2\pi V}{\sigma_a \lambda Q}$$

General background, cont.:

σ_a denotes the *transmission cross section* of the aperture:

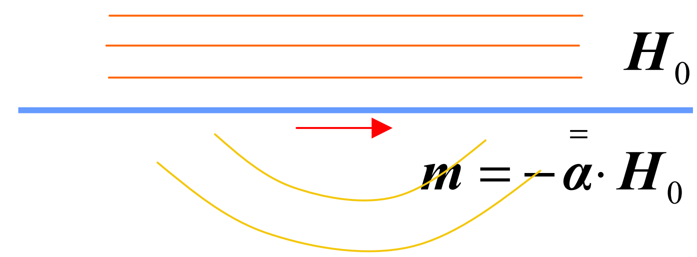
$$P_{trans} = \sigma_a S_{inc}$$

where P_{trans} is the power transmitted through the aperture and S_{inc} is the power density of the incident field.

Thus, σ_a is a very useful and appropriate way to characterize leakage through an aperture. Methods to measure and to calculate it have been developed.

Part one. Semi-empirical model

- Aperture model based on measured transmission cross section σ_a



- Aperture replaced by a magnetic dipole (Bethe dipole).

$$|\alpha(\omega)| = \frac{c^2 \sqrt{3\pi\sigma_a(\omega)}}{2\omega^2}$$

A comprehensive description of the FOI semi-empirical method has been accepted for publication in a special issue on electromagnetic modelling in IEEE Trans. on EMC, spring 2003.

Why semi-empirical modelling ?

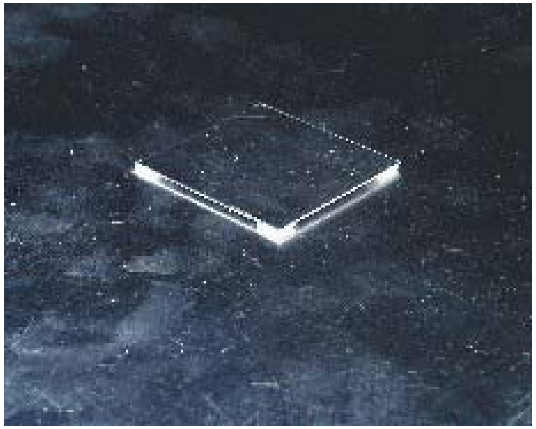
For real complex apertures it holds that:

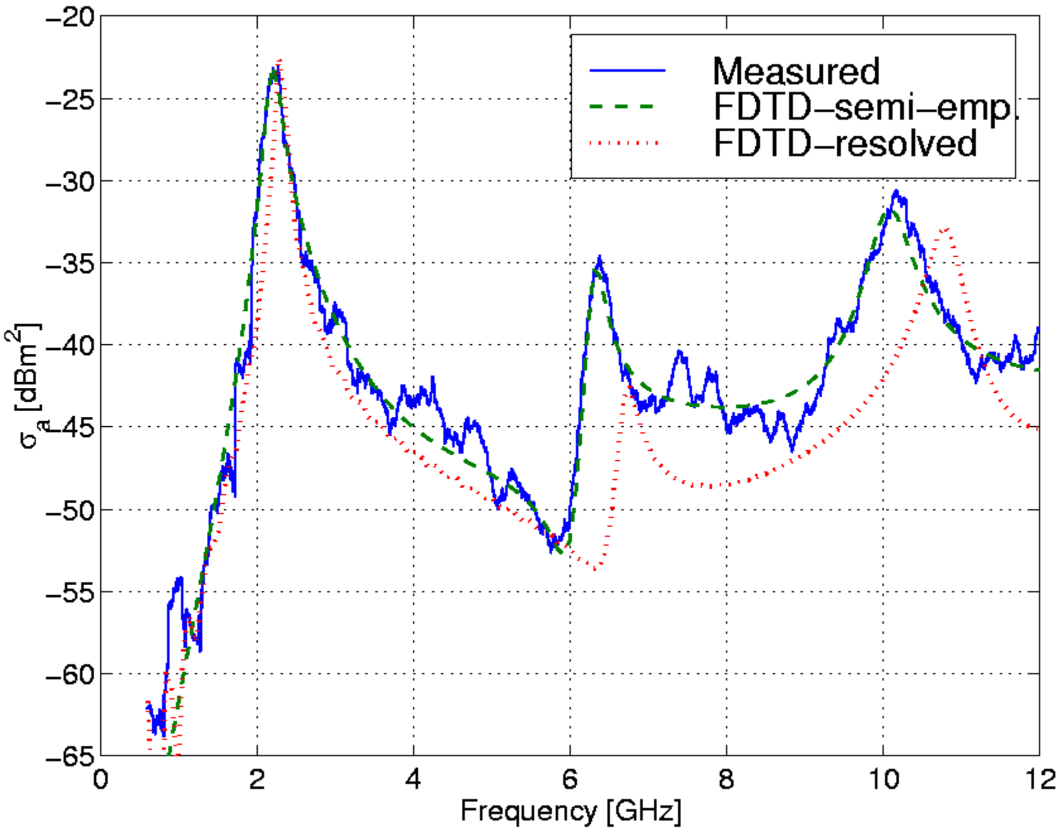
- Geometrical details are often unknown.
- Material properties are often unknown.

Also:

- The necessary high resolution leads to far too large memory requirements.

Initial check: σ_a for covered aperture



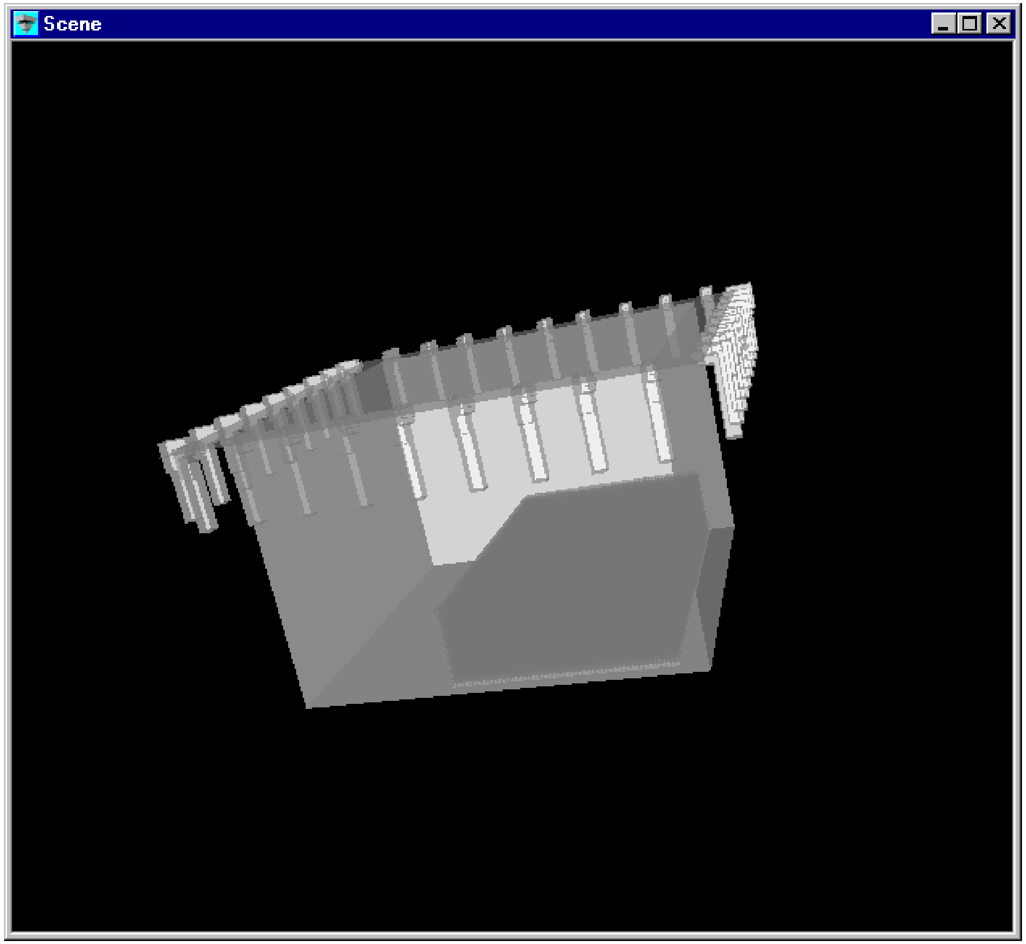


(Martin et al. IEEE EMC Symp Seattle 1999)

“Equipment” box:

- Metallic enclosure
- 7 monopole antennas terminated in 50 Ω
- Absorbing material
- Interchangeable aperture panel

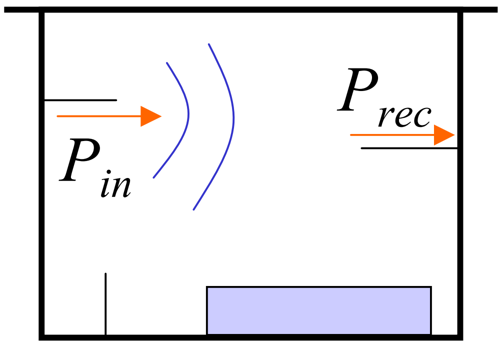
FDTD model

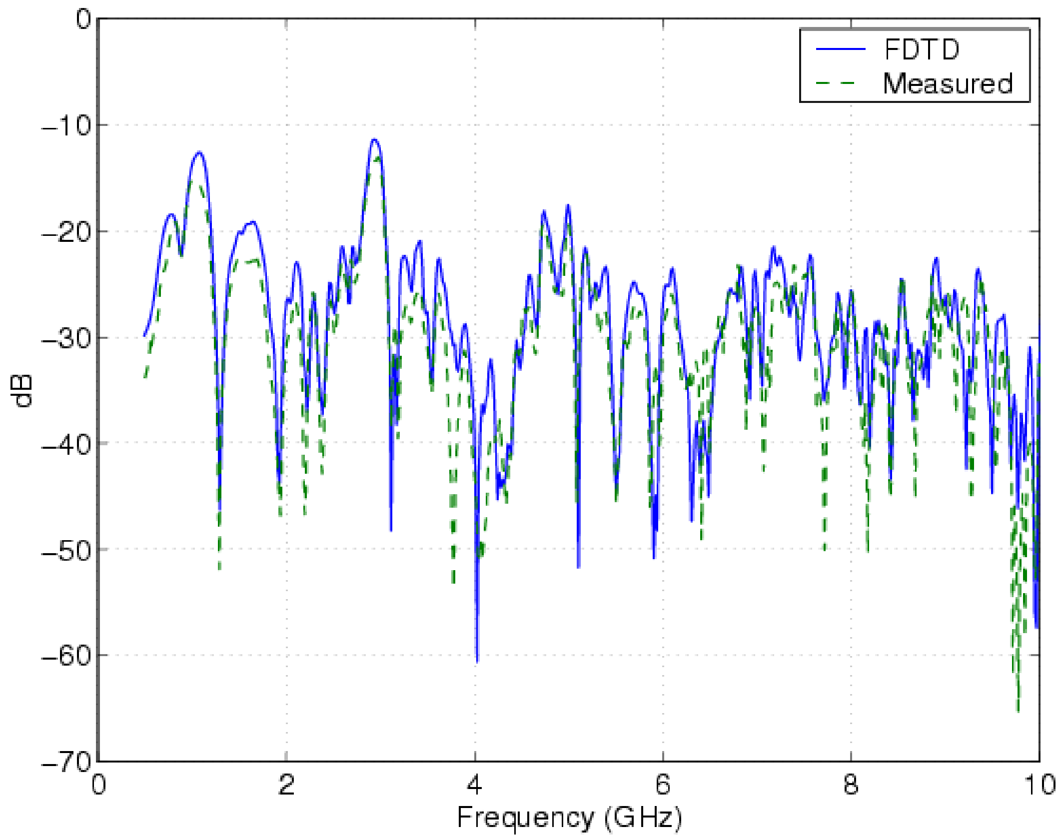


- Cell size 3mm
  (10 cells/λ at 10 GHz)
- $N_x \times N_y \times N_z =$
  150 × 150 × 100
- 20 000 time steps

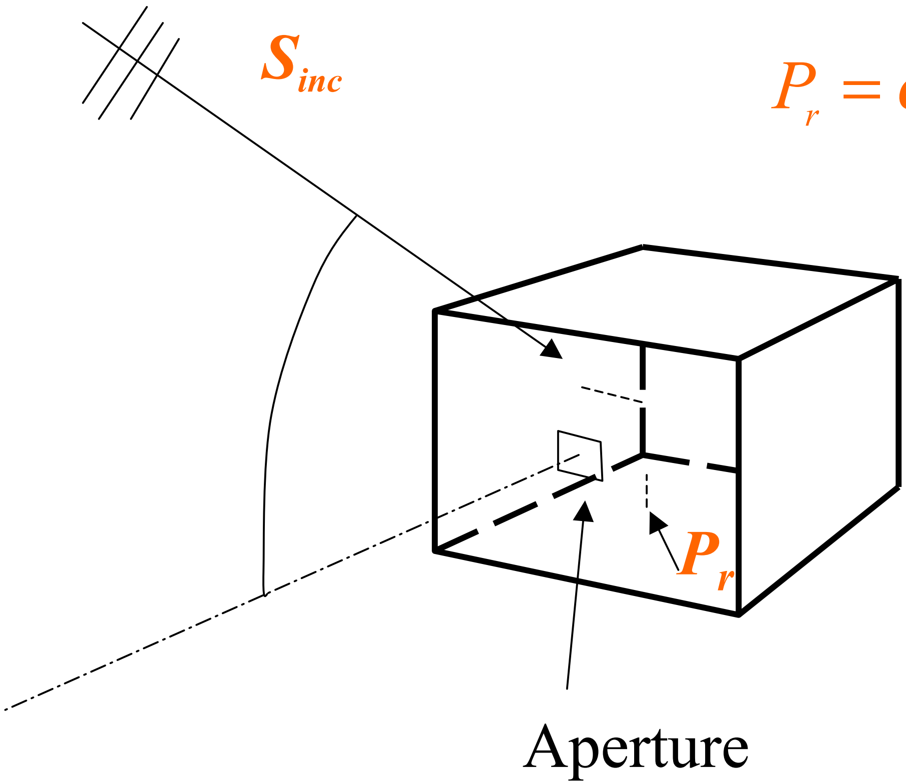
Validation of FDTD model of enclosure absorber (no aperture)

$$\frac{P_{rec}}{P_{in}}$$



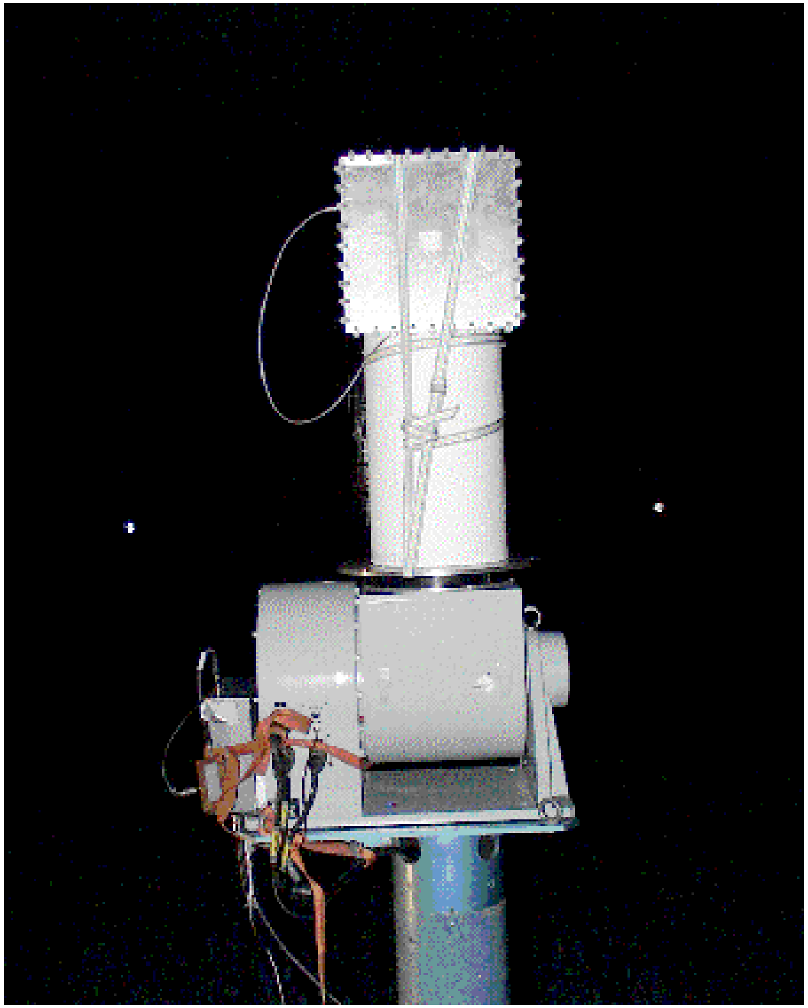


Cross-section, σ, of antennas inside box

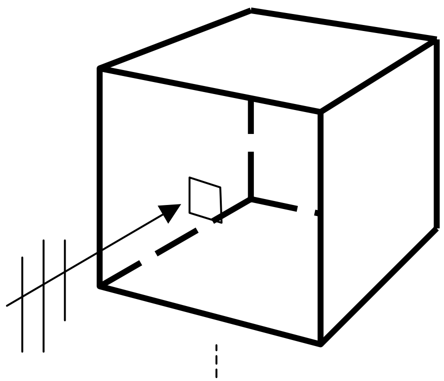


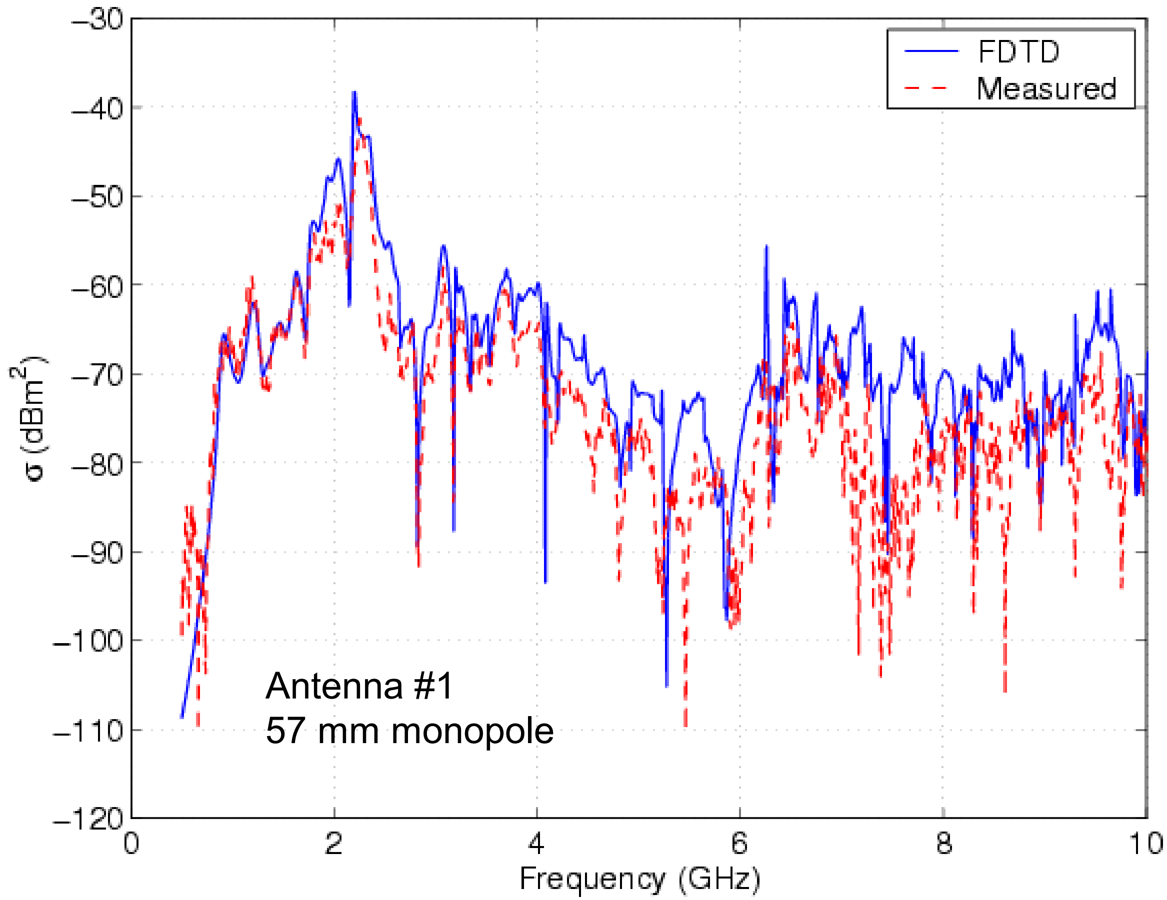
$$P_r = \sigma \cdot S_{inc}$$

Test box in FOI anechoic chamber

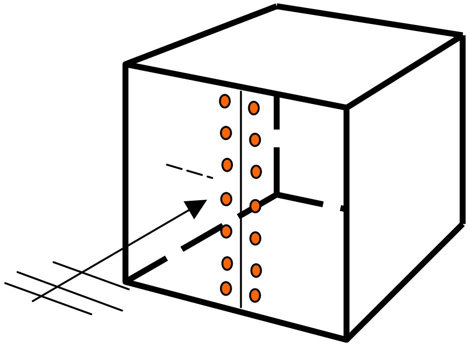


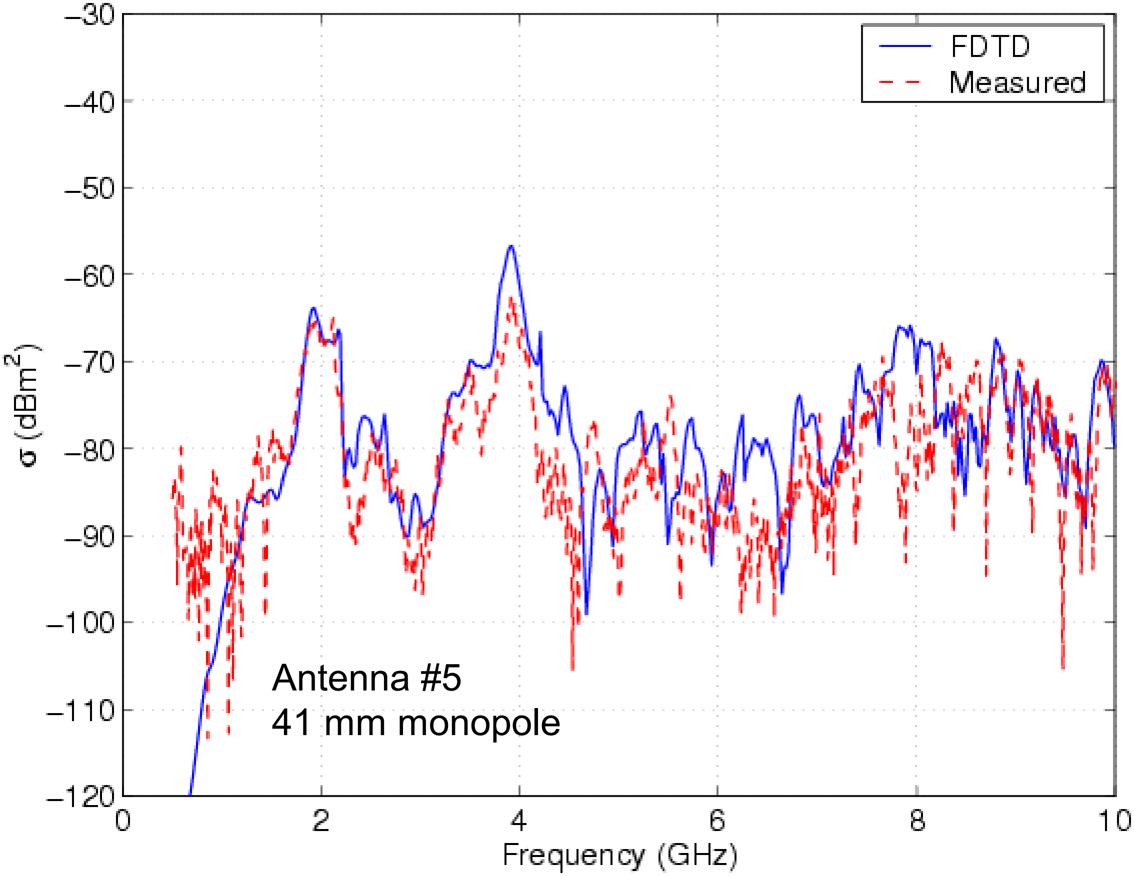
Covered Aperture.
Normal incidence. Vertical polarization





Riveted seam (modelled as an array of 9 magnetic dipoles). Normal incidence. Horizontal polarization.





Part two.

Simple estimate of upper bound for the receiving cross section of the internal wires.

Preliminary results were presented at AMEREM2002, Annapolis, USA, 2002.

The shielding effectiveness can be estimated by:

$$\langle SE \rangle = \frac{S_{inc}}{S_{scalar}} = \frac{2\pi V}{\sigma_a \lambda Q}$$

Inside the box we have a near-isotropic environment. Thus, an upper bound "internal" receiving cross-section, $\hat{\sigma}_{cavity}$, can be approximated by:

$$\hat{\sigma}_{cavity} \approx \frac{\lambda^2}{8\pi}$$

Combining the two equations yields:

$$\langle\hat{\sigma}\rangle = \frac{\langle\hat{P}_{rec}\rangle}{S_{inc}} \approx \frac{\lambda^2}{8\pi}\cdot\frac{S_{scalar}}{S_{inc}} = \frac{\lambda^2}{8\pi}\cdot\frac{\sigma_a\lambda Q}{2\pi V} = \frac{\sigma_a\lambda^3 Q}{16\pi^2 V}$$

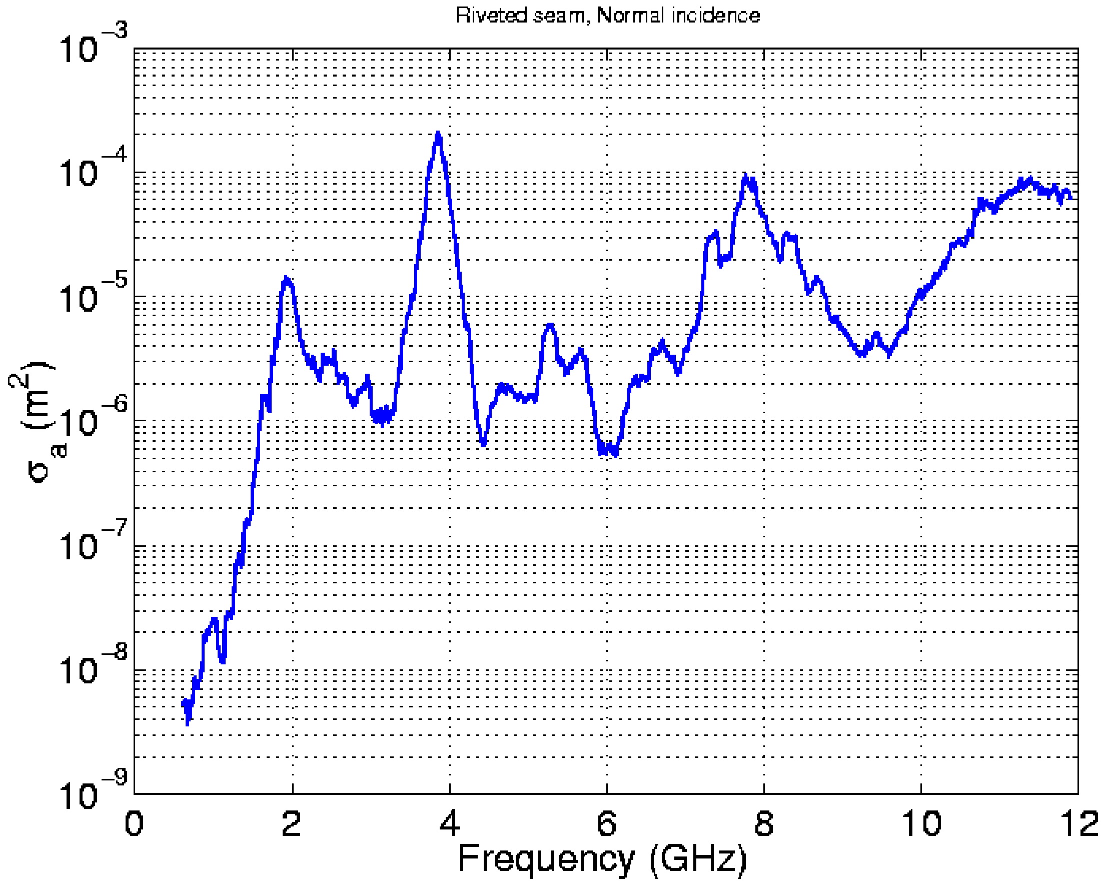
Again, the average <> refers to different locations inside the enclosure. Max values can be estimated (χ_2^2-distr.). For a 95% confidence level we get:

$$\mathbf{\mathit{UpperBound}} = 3\cdot\langle\hat{\sigma}\rangle$$

In the equation, V and λ are trivial to determine, σ_a is measured, and Q is estimated as for reverberation chambers:

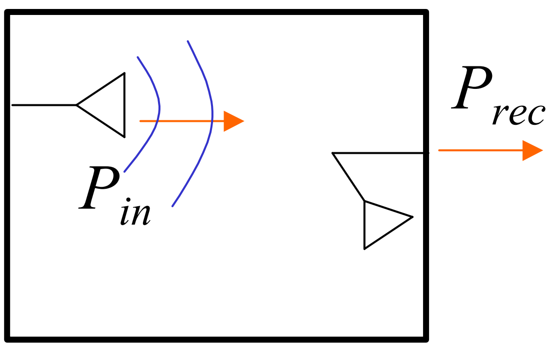
The model has been evaluated using different apertures and different angles of incidence. Since we plan to publish the results we here only show the results (which are typical) for the riveted seam.

Measured Transmission Cross Section for riveted seam (measured in FOI large Anechoic Chamber):



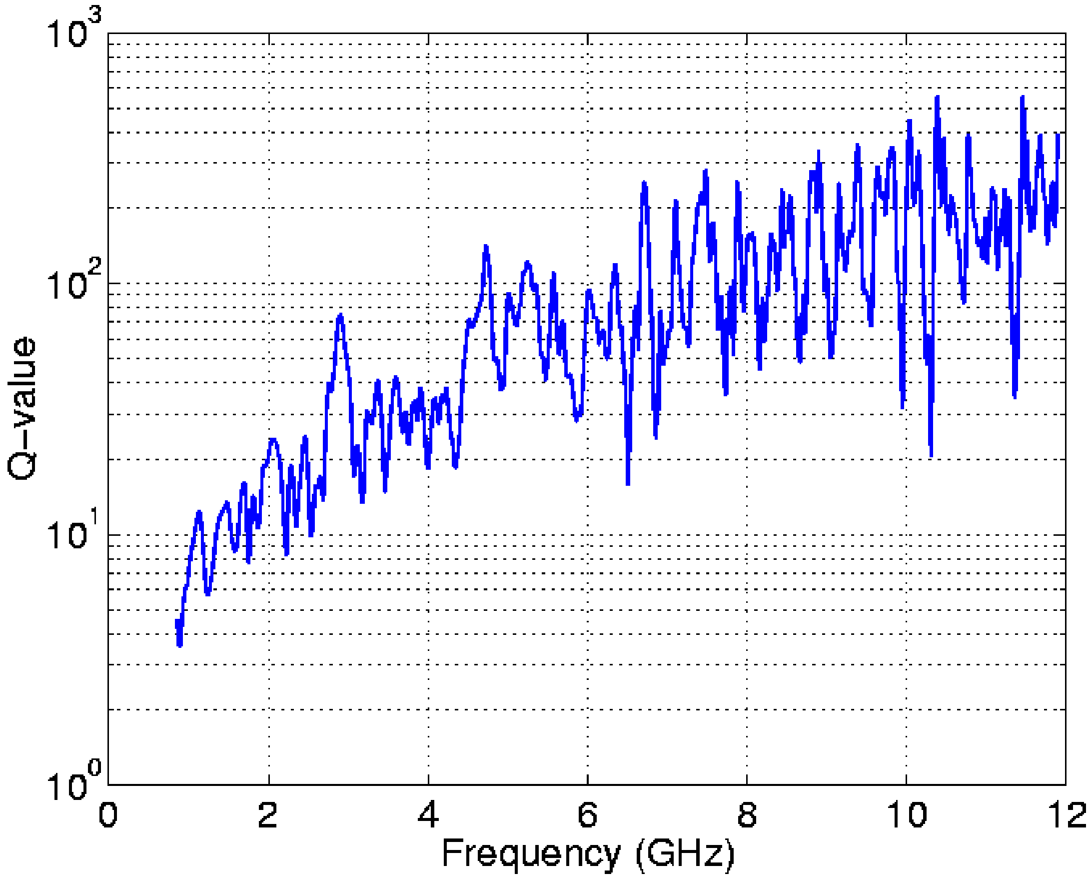
Q is estimated by measurements of the transmission loss between internal wires according to:

$$Q = \frac{16\pi^2 V}{\lambda^3} \cdot \left\langle \frac{P_{rec}}{P_{in}} \right\rangle$$

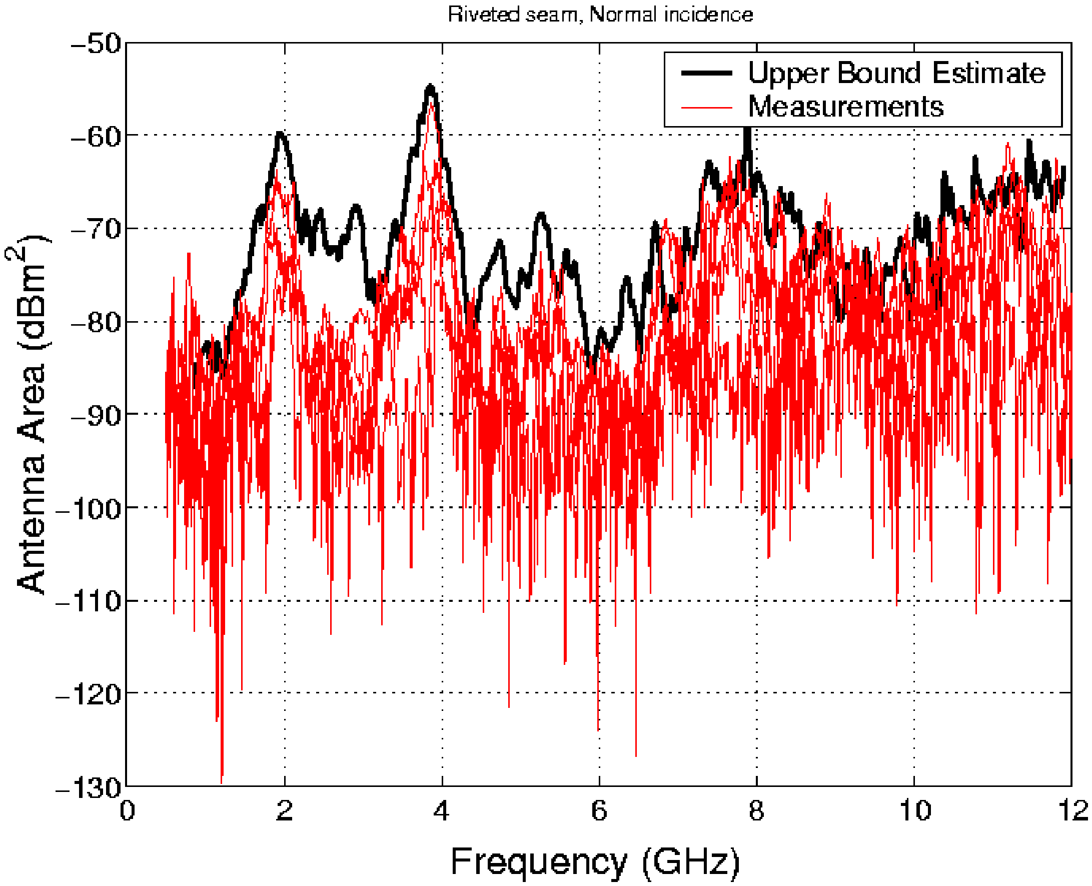


Where P_{in} is the net power transmitted into the enclosure and P_{rec} is the power measured by an (ideal) receiving antenna.

Measured Quality Factor, *Q*, for the enclosure:



Measured antenna cross section (“antenna area”) for the seven internal wires (red) and the *upper bound estimate* (black). Riveted Seam.



Summary and conclusions

- A semi-empirical model based on measured aperture transmission cross section has been developed.
- Complex apertures can be represented by short magnetic dipoles.
- The model has been evaluated using a metallic enclosure with 7 antennas mounted inside.
- Good agreement between measurements and FDTD simulations.
- The simple analytical expression gives a good upper bound estimate of the coupling.
- The shape of the upper bound is mainly determined by $\boldsymbol{\sigma}_a$