Enclosure Shielding; Studies of the Effects of Circuit Cards in Enclosures and the use of Surrogate Circuit Cards for Shielding Measurement

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Shielding Effectiveness

- Shielding Effectiveness (SE) of an enclosure is conventionally defined as the ratio of the internal field in an enclosure to the external field.
- Modern SE measurement standards, e.g. IEEE299.1, allow for the statistical nature of the external and internal fields at microwave frequencies where the shielding enclosures are electrically large.
- Energy penetration into the enclosures is through a variety of aperture types.
- At microwave frequencies SE ratios of typical equipment enclosures are frequently low compared to those obtainable in shielded rooms.
Shielding Effectiveness

• The electromagnetic environment inside an equipment enclosure at microwave frequencies is strongly dependent on the absorption of energy by the enclosure’s contents.
• This effect is neglected by current shielding measurement standards.
• Here we extended the concept of shielding measurements using surrogate “representative contents” we first proposed at lower frequencies into the regime were the enclosure is electrically large.
Others do it!

It’s the same principle as using a crash dummy!
Surrogate Contents

• We demonstrate how a surrogate fabricated from radio absorbing material can be made to give comparable overall absorption to a real printed circuit board.

• The surrogate produces a comparable internal environment inside an enclosure to that of a real printed circuit card during a shielding measurement.

• A typical PCB is a complex structure. It has many different types of component. One thing that the components have in common is that their absorption characteristics microwave frequencies are not specified!
The typical PCB is a three dimensional structure. As well as the absorption of the circuit elements, the substrate absorbs energy with increasing efficiency as the frequency is increased in the microwave range. In many applications PCBs are stacked to form a complex periodic array within the enclosure.
Absorption Cross-Section

- The absorption cross-section (ACS) of an object is the total power it absorbs from an incident plane-wave per unit power density.
- Far-field quantity (could be limiting)
  - Depends on angle or arrival of the plane-wave \((\theta, \varphi)\) and its polarisation angle \(\psi\).
  - Many absorption process in PCBs: trace loads (including devices), substrate, packaging,…

\[
\sigma^a(\theta, \varphi, \psi) = \frac{P^a(\theta, \varphi, \psi)}{S_{inc}}
\]

\[
S_{inc} = \frac{|E_{inc}|^2}{\eta_0}
\]
Average ACS Measurement

- Reverberation Chamber (RC) is most efficient environment for high frequency SE measurement
- Good RC – uniform and isotropic plane-wave spectrum (Hill)
- Measure average ACS of enclosure contents in RC
- Use to predict SE in loaded enclosures

\[
\langle \sigma^a \rangle = \frac{1}{2 \cdot 4\pi} \left\{ \int_{4\pi} \sigma^a(\theta, \varphi, 0^\circ) d\Omega + \int_{4\pi} \sigma^a(\theta, \varphi, 90^\circ) d\Omega \right\}
\]
Measurement Setup

- Average ACS determined by difference in insertion loss between loaded and unloaded chamber

**Insertion loss**

\[ IL = \frac{1}{|S_{21}|^2} \]

**Total efficiency of antennas**

\[ \eta_i^T = \eta_i^\text{rad} (1 - |S_{ii}|^2) \]

\[ \langle \sigma_{\text{EUT}}^a \rangle = \frac{\lambda^2}{8\pi} \eta_1^T \eta_2^T (IL_{\text{loaded}} - IL_{\text{unloaded}}) \]
Measurement Implementation

- Broadband monopole antenna

Lower part of RC with stirrer
RC dimensions 600mm x 700mm x 800mm

- 100 stirrer positions
- 50/100 MHz frequency stirring bandwidth

Expanded polystyrene support with FPGA PCB
ACS Measurement Limits

For a given size of RC there is a minimum and a maximum ACS that can be measured. The ACS range that can be measured with a given uncertainty, \( \alpha \), depends on relationship between the number of independent samples, the chamber unloaded Q-factor and the chamber loading – see;

We used a series of absorbing cubes made from commercial absorber (LS22). Each cube was measured and compared to a theoretical estimate of the ACS of a sphere of the same surface area.
Cube ACS measurements compared to MIE series models of spheres with the same surface area and material properties.
The measured ACS of an FPGA board is shown here in the frequency range 1GHz to 20GHz. Note the surprising result that the ACS appears independent of whether the board is powered and running a programme or unpowered.
• Moving a PCB within the RC even to the wall does not change the ACS significantly
Vertical vs Horizontal PCB

Average Absorption Cross Section (m²)

Frequency (GHz)

Horiz
Vert

10⁻³

IC 1407 ACCREDIT
When the components close to chamber wall:

- The ACS is reduced by 10% to 50%
Enclosure SE Measurement

\[ SE = -10 \log_{10} \left( \frac{P_{\text{in}}}{P_{\text{out}}} \right) \]

\[ SE = \frac{\left| S_{31} \right|^2}{\left| S_{21} \right|^2} \frac{1 - \left| S_{22} \right|^2}{1 - \left| S_{33} \right|^2} \]

SE is measured according to the procedure detailed in IEEE Std™ 299.1
The PC enclosure SE is measured as detailed in the previous slide with and without its contents. The number of frequency points is 10001 and averaging is with a 50MHz frequency stirring window combined with 100 mechanical stirrer positions.
The SE of the PC enclosure depends on whether it has contents or not. Note the higher SE of the loaded enclosure resulting from the internal field reduction caused by energy absorption into the enclosure contents. See the paper _Predicting Shielding Effectiveness of Populated Enclosures Using Absorption Cross Section of PCBs_ at this conference.
Surrogate PCB Design

The surrogate PCB is fabricated from a conducting sheet with tailored blocks of carbon loaded polyurethane foam to replicate the absorption of the PCB components. The conducting sheet replicates the PCB ground plane structure. This prototype is single sided.
Surrogate – PCB ACS Comparison

Average absorption cross-section, $<\sigma^a>$ (m$^2$)

Frequency (GHz)

PCB
Surrogate

$10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$

2 3 4 5 6 7 8 9 10 20
Enclosure SE Measurement

![Graph showing shielding effectiveness (SE) in dB across different frequencies with and without PCB and surrogate.](image)
Conclusions 1

• Average ACS is a useful metric for quantifying high frequency absorption of enclosure contents
• It can be measured efficiently and accurately in a reverberation chamber
• Role in development standardised SE measurement of enclosure with contents
• Initial results indicate that the ACS of a PCB is almost independent of whether it is energised or not. Requires further investigation!
Conclusions 2

• The SE of an enclosure with absorbing contents is observed to be higher than that of an empty enclosure as the energy absorption lowers the internal field strength.
• We have demonstrated that surrogate contents based on resistively loaded blocks can replicate the real PCBs.
• The surrogates can be tuned to replicate any wanted PCB performance and offer a standard for measurements.
• Currently surrogates based on circuit cards with resistively loaded traces fitted with field and power probes are under development.
Future work

• Implications for immunity
  – Where does the absorbed energy go?
  – How does this affect immunity?

• Standardisation
  – Inclusion of the effect of absorption in shielding standards?
Published Papers

**Measured average absorption cross-sections of printed circuit boards from 2 to 20 GHz**
DOI: 10.1109/TEMC.2015.2499841

**Predicting Shielding Effectiveness of Populated Enclosures Using Absorption Cross Section of PCBs**

**Changes in a Printed Circuit Board's Absorption Cross Section Due to Proximity to Walls in a Reverberant Environment**

**On the measureable range of absorption cross-section in a reverberation chamber**

**Absorption cross section measurement of stacked PCBs in a reverberation chamber**

**Enclosure shielding assessment using surrogate contents fabricated from radio absorbing material**