Simple Statistical Model to Quantify Maximum Expected EMC in Spacecraft and Avionics Boxes

Workshop Session FR-AM-2
“EMC for Space Applications”

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**NASA Requirement**
Need to know RF environment in large fairings

**Challenges:**

1. Interior and exterior sources
   - C- S- and X-band transmitters
   - Lightning strike
   - External RF, interference

2. Electrically large
   - Sensitive to details

3. Details only known approximately
   - Fairing lining dimensions
   - Payload dimensions
   - Payload surface impedances
Model scale fairing EM field tests at KSC

- Fiber optic sensors to on a fiberglass mount used in 56 location within the fairing to measure the distribution.
- Spatial and frequency variation used.

Inner probe placement

Composite fairing half test set-up with fiberglass mount - outer probe positions
Field distribution of lossless fairing model at 5.65 GHz of small composite model MLFMM (FEKO) and MoM (WIPL-D)

Rotational model of a typical large fairing with size of lab model fields shown for comparison
Models have not correlated well with test.

Magnitude of 3 axis E-field comparison for composite three layer model

With fiberglass mount

Without fiberglass mount

Robust Physics
However, both model AND test show EM field collapses to 2 parameter PDF

C-Band composite fairing position and frequency stirring test and model data following Chi distribution.
An electronic enclosure of volume $V$ has EM modal density

$$n = \frac{8\pi V f^2}{c^3}$$

The asymptotic statistical mean EM field energy in the enclosure is governed by the excitation source power and enclosure Q factor

$$E[U] = \frac{\text{Source power}}{\omega \eta}$$

Hill (2009) has shown that:

$$Q = \frac{3V}{2\mu_r \delta S}, \quad \delta = \sqrt{\frac{1}{\pi f \mu_w \sigma_w}}$$

where $S$ is the surface area of the cavity walls $\mu_r$, $\mu_w$, and $\sigma_w$ are respectively the relative permeability, the permeability, and the conductivity of the cavity walls.

Langley [2004] has shown the asymptotic relative variance of the cavity energy is:

$$\text{RelVar}[U] = \frac{1}{\pi m} \left\{ \alpha - 1 + \frac{1}{2\pi m} \left[ 1 - e^{-2\pi m} \right] + E_1(\pi m) \left[ \cosh(\pi m) - \frac{1}{\pi m} \sinh(\pi m) \right] \right\}$$

where $m$ is the EM modal overlap factor:

$$m = f \eta n = \eta n / Q,$$

The relative variance of a field component at a point is:

$$1 + 2 \text{RelVar}[U]$$
New Variance & Max Expected
checked on modes of rectangular cavity

Blue curves: SEA mean and 95% confidence bands based on Rayleigh distribution
Black curve: simulated mean

Blue curves: SEA mean and 95% confidence bands based on lognormal distribution
Black curve: simulated mean
EM field Mean & Max Expected Measured
EM field Mean & Max Expected Predicted with simple PWB statistical model
Conclusions

- **Statistical PWB models look promising**
  - Ideal for complex payloads in fairings when EM design parameters are only ever known approximately
  - Statistical model predicts:
    - *Mean*
    - *Standard deviation*
    - *Max expected (eg 97.5% quartile)*
  - No time wasted meshing details
  - PWB model solves in seconds on laptop computer
  - Can also predict induced current & voltages in wiring harnesses