Estimation of the Electromagnetic Field Radiated by a Microwave Circuit Encapsulated in a Rectangular Cavity

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AGENDA

✓ Introduction
✓ Cavity Resonance frequencies
✓ Influence of the cavity on the electromagnetic field distribution
✓ Estimation of the EM fields in a closed cavity from an open cavity EM cartographies
  • Proposed approach
  • Radiated Emission Model
  • Results
✓ Conclusion and prospects
The designers of the Rx/Tx modules attach particular importance to the electromagnetic compatibility problems of their products.

**Introduction (1/2)**

- RF Power modules
- Radiated Emission
- Radiated Immunity
- Electromagnetic Environment?
- Failure Mechanism
- Evaluation of the cavity effect on the circuit performances

- DC supply
- Control board
- Transmitter module
HPA (High Power Amplifier):

- Simplified circuits:
  - Microstrip line
  - Simple amplifier
Cavity Resonance Frequencies (1/2)

✓ Electromagnetic Field in Metallic Cavity

✓ Expression of the electric field

\[ E_x = A_1 \cos\left(\frac{m \pi}{a} x\right) \sin\left(\frac{n \pi}{b} y\right) \sin\left(\frac{p \pi}{c} z\right) \]
\[ E_y = A_2 \cos\left(\frac{n \pi}{b} y\right) \sin\left(\frac{p \pi}{c} z\right) \sin\left(\frac{m \pi}{a} x\right) \]
\[ E_z = A_3 \cos\left(\frac{p \pi}{c} z\right) \sin\left(\frac{n \pi}{b} y\right) \sin\left(\frac{m \pi}{a} x\right) \]

✓ Expression of the magnetic field

\[ H_x = B_1 \sin\left(\frac{m \pi}{a} x\right) \cos\left(\frac{n \pi}{b} y\right) \cos\left(\frac{p \pi}{c} z\right) \]
\[ H_y = B_2 \sin\left(\frac{n \pi}{b} y\right) \cos\left(\frac{p \pi}{c} z\right) \cos\left(\frac{m \pi}{a} x\right) \]
\[ H_z = B_3 \sin\left(\frac{p \pi}{c} z\right) \cos\left(\frac{m \pi}{a} x\right) \cos\left(\frac{n \pi}{b} y\right) \]

\[ f_{mnp} = \frac{c}{2\sqrt{\varepsilon_r}} \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{c}\right)^2} \]
Studied Case: a simple Microstrip line

Cavity Resonance Frequencies (2/2)

$S_{21}$ parameter decreases at two frequencies because a portion of the electromagnetic energy ends up being stored in the cavity.

These frequencies are two eigenmodes of the cavity which correspond to the mode $(1,1,0)$ and $(2,1,0)$. 
EM Field with and without cavity (1/2)

✓ Field cartographie at f = 3 GHz

No impact on the profiles except in the vicinity of the metal walls:

- EM fields shows only slight reduction along the line.
- Significant decrease next to the metal walls of the cavity (about 5 V/m for the $E_y$ component and 10 V/m for the $H_z$ component).
Total change of the electromagnetic field distribution.

A difference of 50 dBA/m is observed on the normal component of the electric field ($E_z$).

Presence of a stationary wave which represents the cavity mode with an index (2,1,0).
Estimation of the EM fields in a closed cavity from an open cavity EM cartographies

✓ Proposed approach

- EM field mapping with Cover Open
- Modeling by electric dipole
- Inserting the model in HFSS
- Encapsulate the model in a cavity
- Mapping of the EM field in closed cover
Radiated Emission Model

1- Model topography

Each dipole is represented by:
- its position,
- its orientation with respect to the x-axis ($\theta$),
- its length ($d\ell$),
- the current flowing through it ($I$).

In our model, we are pre-fixed:
- The length,
- Position.

And we extract:
- the orientation of each dipole,
- The current,
- the effective relative dielectric constant ($\varepsilon_{\text{reff}}$) of the DUT.

Estimation of the EM fields in a closed cavity from an open cavity EM cartographies

✓ Radiated Emission Model

1- Model topography

\[
\begin{align*}
[H_x] &= f_{Hx}([\alpha_x],[I],[\theta],[k],fr) \\
[H_y] &= f_{Hy}([\alpha_y],[I],[\theta],[k],fr) \\
[E_z] &= f_{Ez}([P_o],[P_d],[I],[\theta],[k],[\varepsilon],fr)
\end{align*}
\]

- \(fr\) is the modeling frequency,
- \([\alpha_x]\) and \([\alpha_y]\) are constants based on the dipole positions, their lengths and the observation point,
- \([\varepsilon]\) is the medium’s permittivity given by \([\varepsilon_0\varepsilon_{refff}], \varepsilon_0 = 8.85418e^{-12}\) F/m,
- \([k]\) is the wave number given by \([k] = (2\pi/\lambda) \times [\varepsilon_{refff}]^{0.5}\)
- \([P_d]\) is the dipole position vector,
- \([P_o]\) is the position vector of the observation point,
- \(f_{Hx}, f_{Hy}, \) and \(f_{Ez}\) are non-linear mathematical functions associating all the other parameters and variables.
Radiated Emission Model

2-Parametric Extraction

- The extraction is a two steps technique:
  - The initial parameter vector is first calculated
  - They are then passed through a two-level non-linear optimization procedure based on the Levenberg-Marquardt technique.

- The model is extracted based on the following imposed conditions:
  - Physically $1 < \varepsilon_{\text{reff}} < \varepsilon_r$ (of the substrate present in the DUT).
  - The effect of $\varepsilon_{\text{reff}}$ is negligible on the near-magnetic field very close to the DUT.

- The dipole orientations and currents are first extracted and subsequently the effective relative permittivity is determined.
Radiated Emission Model

3 - Obtaining initial vector of model parameters

The initial vector of the dipole orientations $[\theta_{init}]$ is estimated through the inverse method as shown:

\[
\begin{align*}
[H_x]_{mx1} &= [\alpha_x]_{mzp} \times [I_{init} \cdot \sin(\theta_{init})]_{px1} \\
\Rightarrow A_i &= [\alpha_x]_{mzp}^{-1} \times [H_x]_{mx1} = [I_{init} \cdot \sin(\theta_{init})]_{px1} \\
[H_y]_{mx1} &= [\alpha_y]_{mzp} \times [I_{init} \cdot \cos(\theta_{init})]_{px1} \\
\Rightarrow B_i &= [\alpha_y]_{mzp}^{-1} \times [H_y]_{mx1} = [I_{init} \cdot \cos(\theta_{init})]_{px1} \\
\therefore [\theta_{init}] &= \tan^{-1}(A_i/B_i) \in R, \text{ for } i = 1,2,\ldots,p
\end{align*}
\]

Where, $m$ is the number of measurement points, and $p$ is the number of dipoles used for modeling. The initial current vector $[I_{init}]$ is calculated by back-substituting the values of $[\theta_{init}]$. The initial $[\epsilon_{reff}]$ vector is a unity vector $[\epsilon_{reff\_init}] = 1$. 
Estimation of the EM fields in a closed cavity from an open cavity EM cartographies

✔ Radiated Emission Model

4 - Optimization of parameters

A two-level optimization technique based on the Levenberg-Marquardt non-linear least-squares method is deployed in order to extract the model parameters. The system is separated into real and imaginary parts and optimized simultaneously so that the error functions are minimum.

\[ f_1 = \begin{cases} \text{real}(H_{x,y}^{\text{meas}} - H_{x,y}^{\text{model}}) \\ \text{imag}(H_{x,y}^{\text{meas}} - H_{x,y}^{\text{model}}) \end{cases} \]

With

\[ H_x^{\text{model}} = f_{Hx}(\alpha_x, I_{\text{init}}, \theta_{\text{init}}, k, fr) \]
\[ H_y^{\text{model}} = f_{Hy}(\alpha_y, I_{\text{init}}, \theta_{\text{init}}, k, fr) \]

\[ E_z^{\text{model}} = f_{Ez}(P_o, P_d, I_{\text{sol}}, \theta_{\text{sol}}, k_{\text{init}}, \epsilon_{\text{init}}, fr) \]
Estimation of the EM fields in a closed cavity from an open cavity EM cartographies

✓ Radiated Emission Model

5 – Insertion of the model in HFSS

Electric dipoles

✓ Possibility to adapt the boundary condition to define a metallic cavity (PEC on the top of the box)
Estimation of the EM fields in a closed cavity from an open cavity EM cartographies

✓ Results

1– At a frequency of 3 GHz

Open cavity

Excellent agreement is found between both the results, with slight differences in certain field components
Estimation of the EM fields in a closed cavity from an open cavity EM cartographies

✓ Results

1– At a frequency of 3 GHz

Closed cavity

Excellent agreement is found between both the results, with slight differences in certain field components
Estimation of the EM fields in a closed cavity from an open cavity EM cartographies

✓ Results

1– At a frequency of 6,75 GHz

Closed cavity

Cavity’s modes are excited and it imposes its electromagnetic fields and therefore the model is not capable to reproduce this phenomenon.
Conclusions

✓ The developed approach gives a good estimation of electromagnetic field in the closed cavity at frequencies when the resonance modes are not excited,

✓ When the resonance modes are excited, the approach is not capable to estimate the closed cavity electromagnetic field:
  - Because the developed approach is based on a 2D emission model
  - The $\varepsilon_{\text{reff}}$ is different in the two cases (open and closed cavity)
Prospects

✓ Using the same approach with a 3D emission model (PhD of H. Shall – IRSEEM/E-CEMANR project)

![Diagram of 3D emission model](image)

![Graphs of simulated electric fields](image)
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