Estimating the Maximum Radiated Electromagnetic Emissions from Complex Systems

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The goal is to distinguish between a good design and a bad design and identify features of a design that are likely to result in emissions or susceptibility problems.

Existing expert system tools are capable of finding many problems that would be difficult to locate manually.
EMC Expert Systems

- Printed Circuit Board Layout
- Automotive EMC
- System-Level Extensions
PCB Expert System Method

Source Model

Coupling Path Model

Antenna Model
PCB Expert System Emissions Models

- Differential-Mode Radiation
- Coupling to I/O Radiation
- Voltage-Driven Common-Mode Radiation
- Current-Driven Common-Mode Radiation
- Power Bus Radiation
Algorithms Locate Hard-to-Find Problems
Expert System Algorithms are constantly asking the question,

What's the worst that could happen?
Effect of Extended Cable on Ground

![Diagram showing the effect of extended cable on ground]

- $l$ meters

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board analysis using expert system algorithms

- 8 clock buffers
- 28 load capacitors
- 32 decoupling capacitors
- Clocked at 50 MHz
- No heatsink
- Size: 3” by 2”, 6 layers
- Powered with one cable
Measurement vs. Calculation: 1-nF Load
Power Bus Radiation Model

\[
Q(f) = \left( \frac{1}{Q_d} + \frac{1}{Q_c} + \frac{1}{Q_{\text{comp}}} \right)^{-1}
\]

\[
|E| = \frac{120l_i}{\varepsilon_r \min(a,b) r} h \times Q(f)
\]

Maximum Power Bus Radiation

\[ |E| = f(r, \theta, \varphi, \varepsilon, h, L, W, \omega) \times V(0, 0) \]

\[
\text{board\_ size\_ factor} = \begin{cases} \sin \left( \frac{2\pi \ell_{\text{board}}}{\lambda} \right) & \text{when } \ell_{\text{board}} \leq \frac{\lambda}{4} \\ 1.0 & \text{otherwise} \end{cases}
\]

\[ |E|_{\text{max}} = f_{\text{max}} \times V(0, 0) \times \text{board\_ size\_ factor} \]
Maximum Power Bus Radiation

\[ |E|_{\text{max}} = f_{\text{max}} \times V(0,0) \times \text{board\_size\_factor} \]
Minimum Power Bus Voltage

Expert System Field Calculation Performed in Reverse

Minimum voltage required to generate fields exceeding the FCC Class B limit

\[ V(0.0)_{\text{min}} = \frac{|E|_{\text{FCC}}}{f_{\text{max}} \times \text{board\_size\_factor}} \]
Minimum Power Bus Voltage (Board w/Cable)

\[ |E| = 20 \times I_{0(max)} \times f_{max}(\theta,k) = 20 \times \frac{V(0,0)}{37 \text{ ohm}} \times 2.76 \]

\[
\text{cable\_ rad\_ factor} = \begin{cases} 
\sin \left( \frac{2\pi \ell_{\text{cable}}}{\lambda} \right) & \text{when } \ell_{\text{cable}} \leq \frac{\lambda}{4} \\
1.0 & \text{otherwise}
\end{cases}
\]

\[
\text{board\_ size\_ factor} = \begin{cases} 
\sin \left( \frac{2\pi \ell_{\text{board}}}{\lambda} \right) & \text{when } \ell_{\text{board}} \leq \frac{\lambda}{4} \\
1.0 & \text{otherwise}
\end{cases}
\]

\[ |E|_{\text{min}} = |E| \times \text{cable\_ rad\_ factor} \times \text{board\_ size\_ factor} \]
Minimum Power Bus Voltage (Board w/Cable)

\[ |E|_{\text{min}} = |E| \times \text{cable\_rad\_factor} \times \text{board\_size\_factor} \]
Minimum Power Bus Voltage (Board w/Cable)

\[ V_{\text{min}} = \frac{|E|_{\text{max}}}{\text{cable\_rad\_factor} \times \text{board\_size\_factor}} \times 37 \text{ ohm} / 20 \times 2.76 \]

Expert System Field Calculation Performed in Reverse

[Graph showing minimum voltage required to generate fields exceeding the FCC Class B limit vs. frequency (MHz)]

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IC-Heatsink to Cable Coupling

\[ V_{CM} = \frac{C_{heatsink}}{C_{board}} V_{DM} \]

\[ V_{DM} = 0.2234 \frac{C_{board}}{C_{heatsink}} \times \frac{r}{F_{board} F_{cable}} \times |E_{max}| \]
IC-Heatsink to Cable Coupling

Spacing between heatsink and board is 1 cm

$C_{\text{heatsink}} = 0.43 \text{ pF}$

$C_{\text{board}} = 5.14 \text{ pF}$
IC-Heatsink to Cable Coupling

Minimum voltage required to generate fields exceeding FCC Class B limit

Spacing between heatsink and board is 1 cm

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Conclusions

- EMC expert systems employ “maximum radiated emissions” algorithms that estimate the worst-case emission based on the information available about the system.

- These algorithms are useful for EMC design analysis, which is nearly always performed with incomplete or approximate data.

- These algorithms can be a useful for trouble shooting circuit boards because voltages and currents measured on the board can be related to possible emissions sources.