EMI Troubleshooting Using Maximum Radiated Emissions Calculators

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Oh no! My product is failing!
Troubleshooting Step #1: Identify possible culprits

Possible Antenna?

Possible Source?
(Processor with 200-MHz clock)
Troubleshooting Step #2: Evaluate possible culprits

Maximum Emissions Calculation Performed in Reverse

\[ V_{\text{min}} = \frac{|E|_{\text{max}}}{\text{cable_rad_factor} \times \text{board_size_factor}} \times 37 \, \text{ohm} / (20 \times 2.76) \]

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

- Could be the culprit!
- Not the culprit!
What is the maximum 3-meter radiated field strength at 315 MHz?

a. impossible to predict without knowing what antenna is connected
b. impossible to predict even if the antenna is known
c. 15 V/m
d. none of the above
What is the maximum 3-meter radiated field strength at 315 MHz?

\[
P_{\text{rec}} = \frac{P_{\text{rad}}}{4\pi r^2} D_0 = \frac{1}{2} \frac{|E|^2}{\eta} \quad |E_{\text{max}}| = \sqrt{\frac{\eta P_{\text{rad}}}{2\pi r^2} D_0}
\]
What is the maximum 3-meter radiated field strength at 315 MHz?

\[ |E_{\text{max}}| = \sqrt{\frac{\eta P_{\text{rad}}}{2\pi r^2}} D_0 = \sqrt{\frac{(377\Omega)(5\text{ W})}{2\pi(3\text{ m})^2}}(6.4) = 1.46\text{ V/m} \]
What is the maximum 3-meter radiated field strength at 200 MHz?

We can put an upper bound on the radiated emissions at any given frequency!

The more we know about the product design, the lower this upper bound becomes.
Maximum Radiated Emissions Concept

What is the maximum 3-meter radiated field strength at 200 MHz (due to the voltage on the heatsink)?

Below 500 MHz, the heatsink voltage can induce common-mode currents on the attached cables.
Maximum Radiated Emissions Calculation

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

\[ V_{DM} = 0.2234 \left( \frac{C_{\text{board}}}{C_{\text{heatsink}}} \right) \frac{r}{F_{\text{board}} F_{\text{cable}}} \left| E_{\text{max}} \right| \]

References


Maximum Radiated Emissions Calculation

Spacing between heatsink and board is 1 cm

\[ C_{\text{heatsink}} = 0.43 \text{ pF} \]
\[ C_{\text{board}} = 5.14 \text{ pF} \]
Maximum Radiated Emission Calculator Example

Voltage-Driven Common-Mode EMI Calculator

The electric fields that couple directly to attached cables from a trace can induce common-mode currents on these cables resulting in radiated emissions. This source mechanism is referred to as voltage-driven, since the magnitude of the common-mode current is proportional to the signal voltage and independent of the signal current. For a given board geometry, a closed-form expression for the maximum emissions due to this coupling mechanism was developed in [1,2]. The number of cables attached to the board and the location of these cables does not affect the maximum emissions calculation.

Assumptions:
- The board is not within a shielding enclosure. (There’s a different calculator for this case.)
- There is at least one cable attached to the board and the cable length is much greater than the board dimensions.

Geometry:
- Return plane
- PCB
- Trace

Voltage Source
- Digital Signal - Trapezoidal Waveform
  Amplitude of the signal (4): 3.3 V
  Rise time (t_r): 5 ns
  Fall time (t_f): 5 ns
  Duty Cycle: 50 %
  Data Rate: 5 Mbps
- Swept Frequency - Constant Voltage
  Amplitude of the voltage signal (4):
  Lower frequency (f_l): MHz
  Upper frequency (f_u): MHz

References
Radiation Mechanisms

- **Differential-Mode Radiation**
  - from electrically small structures
  - from resonant structures

- **Coupling to I/O Radiation**
  - crosstalk on circuit board
  - near-field coupling to connector

- **Voltage-Driven Common-Mode Radiation**
  - from cables (coupled from traces or heatsinks)
  - from shielded enclosures

- **Current-Driven Common-Mode Radiation**
  - from cables
  - from shielded enclosures

- **Power Bus Radiation**
  - directly from power bus
  - coupled to shielded enclosure
How do we analyze an entire system?

- One calculator for each possible radiation mechanism
  - about a dozen calculators (so far)
  - each calculator applied to 1 – 100 structures typically

- Most calculations result in maximum emissions below limit
  - (at least in a well designed and well-defined system).

- Structures potentially causing excessive emissions deserve further attention.
  - demonstrate that they cannot be the culprit, or
  - take measures to ensure that they will not be the culprit.

- It’s possible to analyze systems with undefined parameters
  - let the calculator assume the worst case
Conclusions

- We can always put an upper bound on the radiated emissions from an electronic device.

- The more we know about the device design and test parameters, the closer the upper bound comes to estimating the actual emissions.

- Maximum radiated emissions calculators identify the circuits/structures in a product that are capable of generating emissions above a given limit.