Estimating the Maximum Radiated Electromagnetic Emissions from Complex Systems

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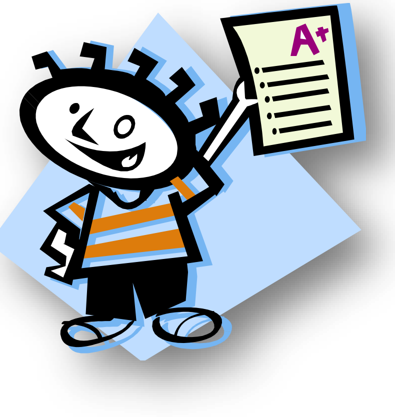
EMC Expert Systems



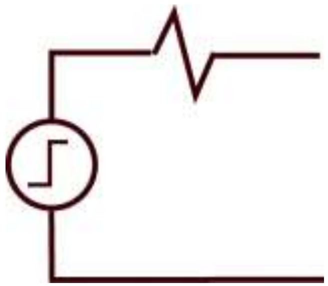
- The goal is to distinguish between a good design and a bad design and identify features of a design that are likely to result in emissions or susceptibility problems.
- Existing expert system tools are capable of finding many problems that would be difficult to locate manually.

EMC Expert Systems

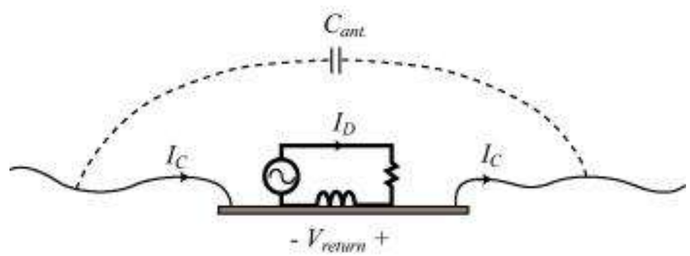
- Printed Circuit Board Layout
- Automotive EMC
- System-Level Extensions

PCB Expert System Method

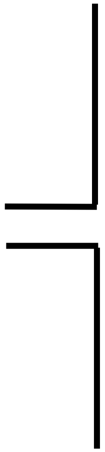
Source Model



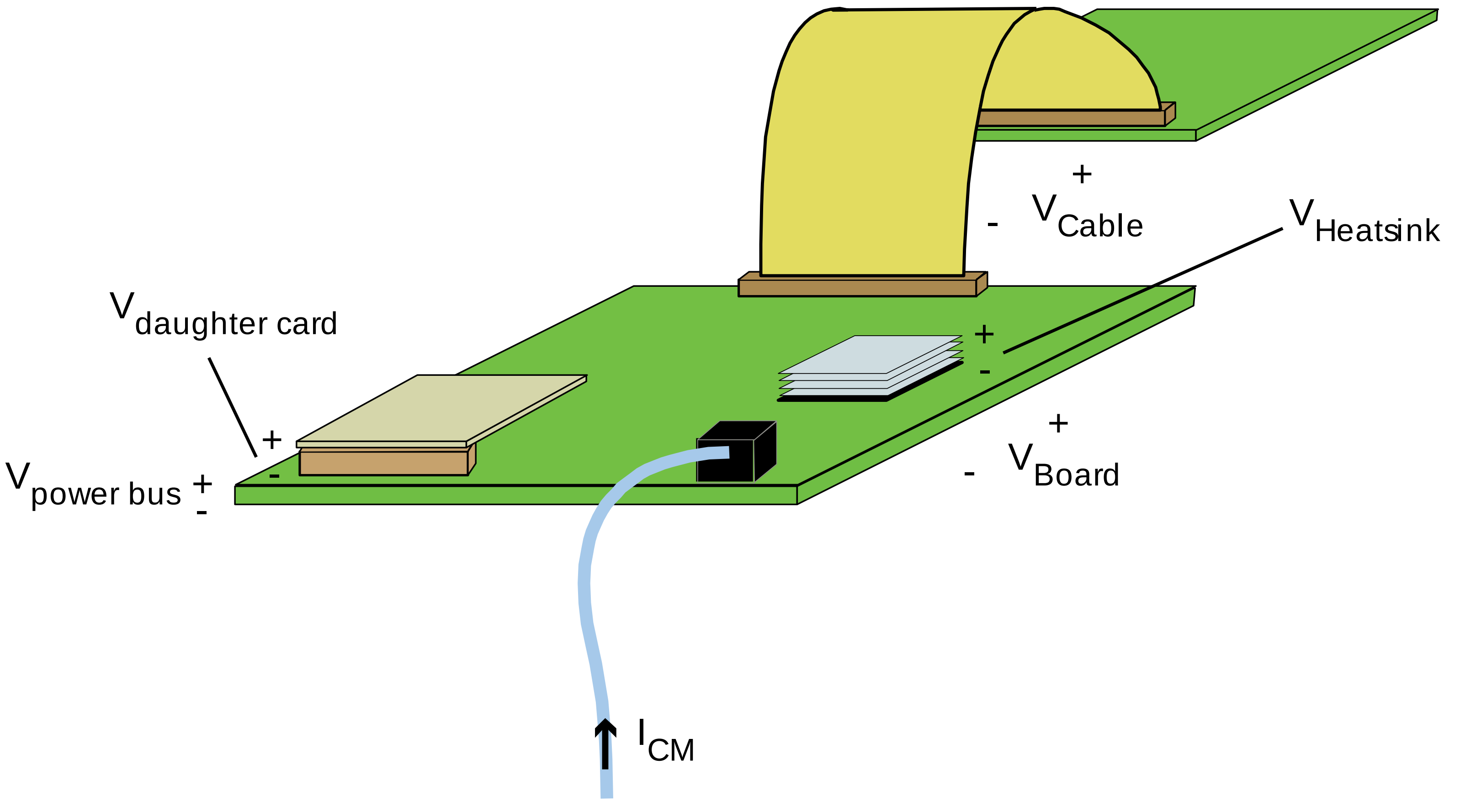
Coupling Path Model



Antenna Model



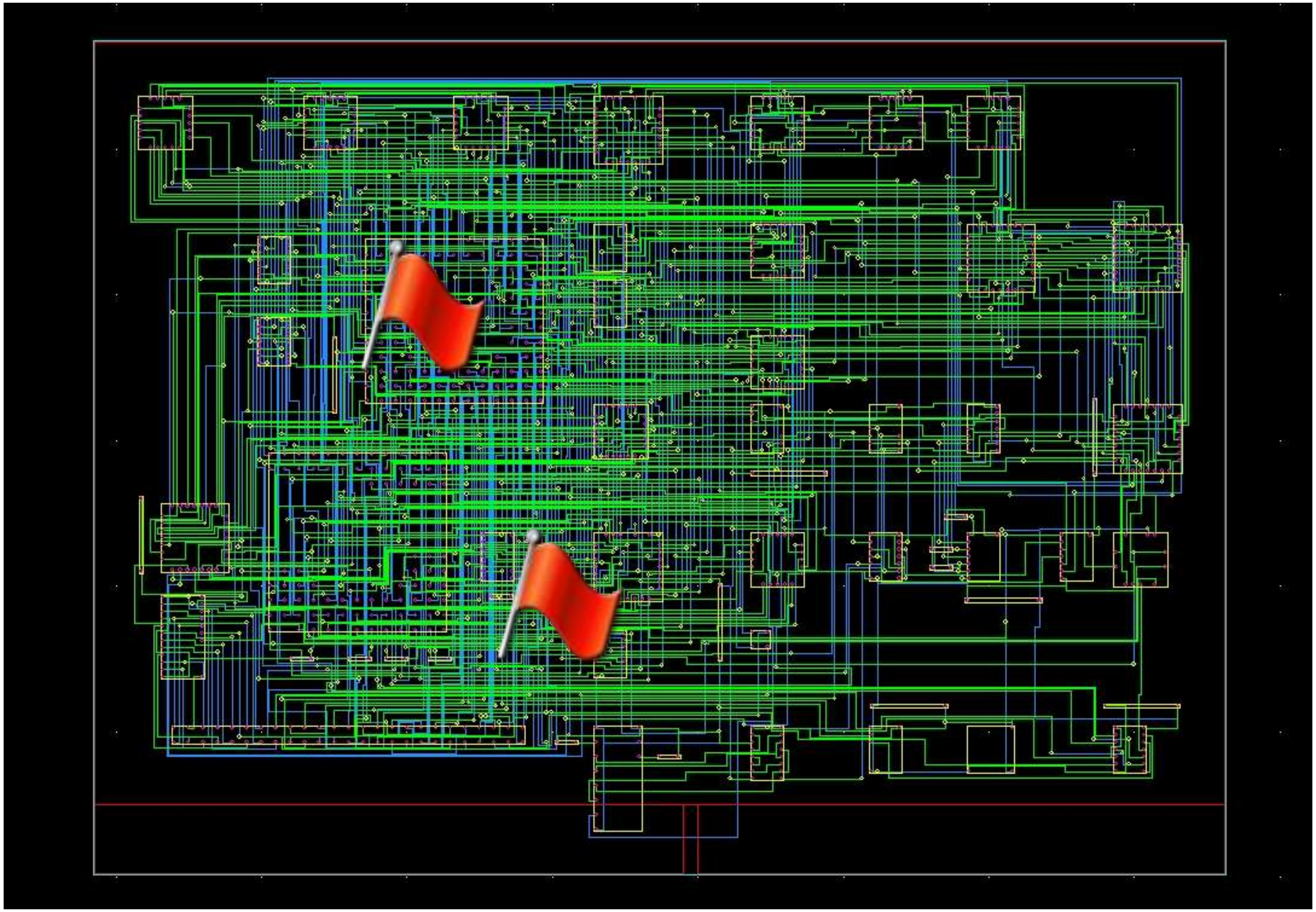
PCB Expert System Method



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

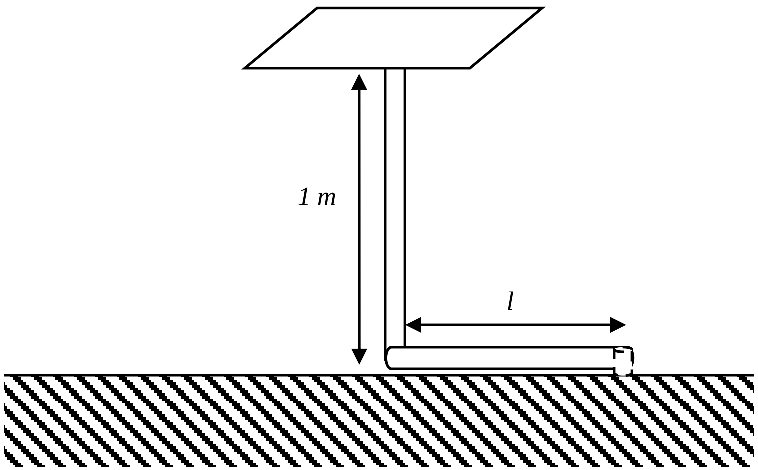
Algorithms Locate Hard-to-Find Problems

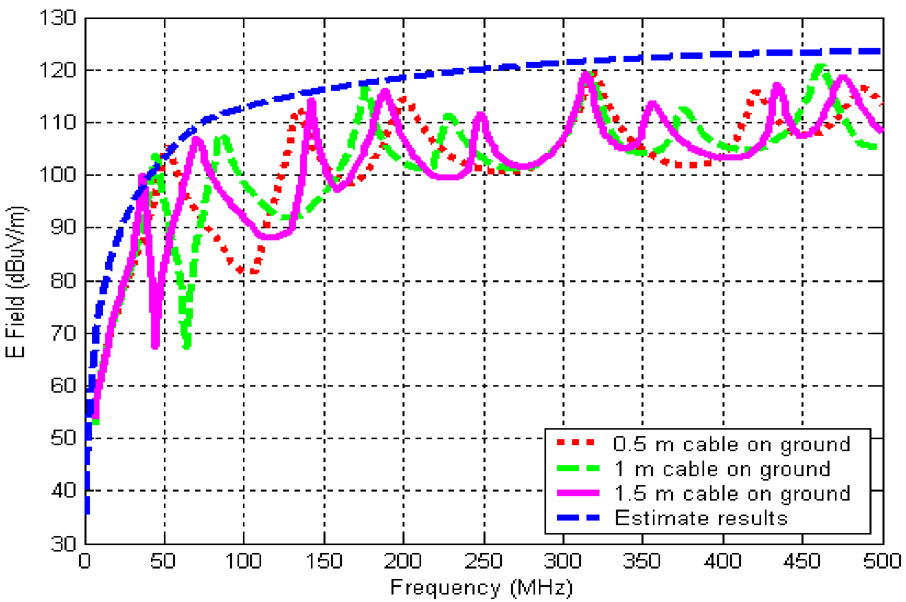


Expert System Algorithms are constantly asking the question,

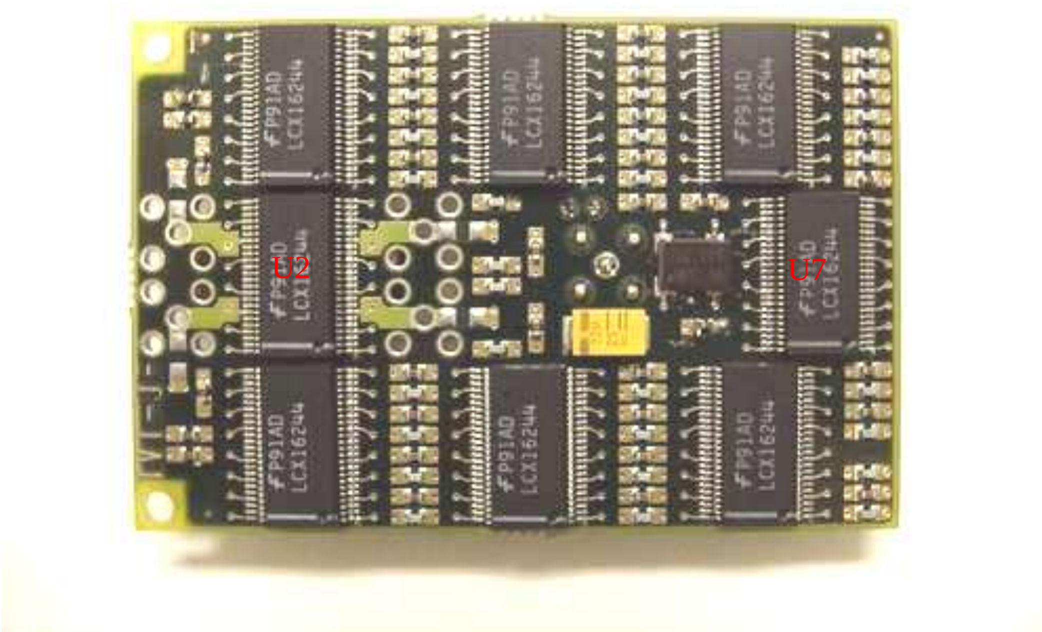
What's the worst that could happen?

Effect of Extended Cable on Ground



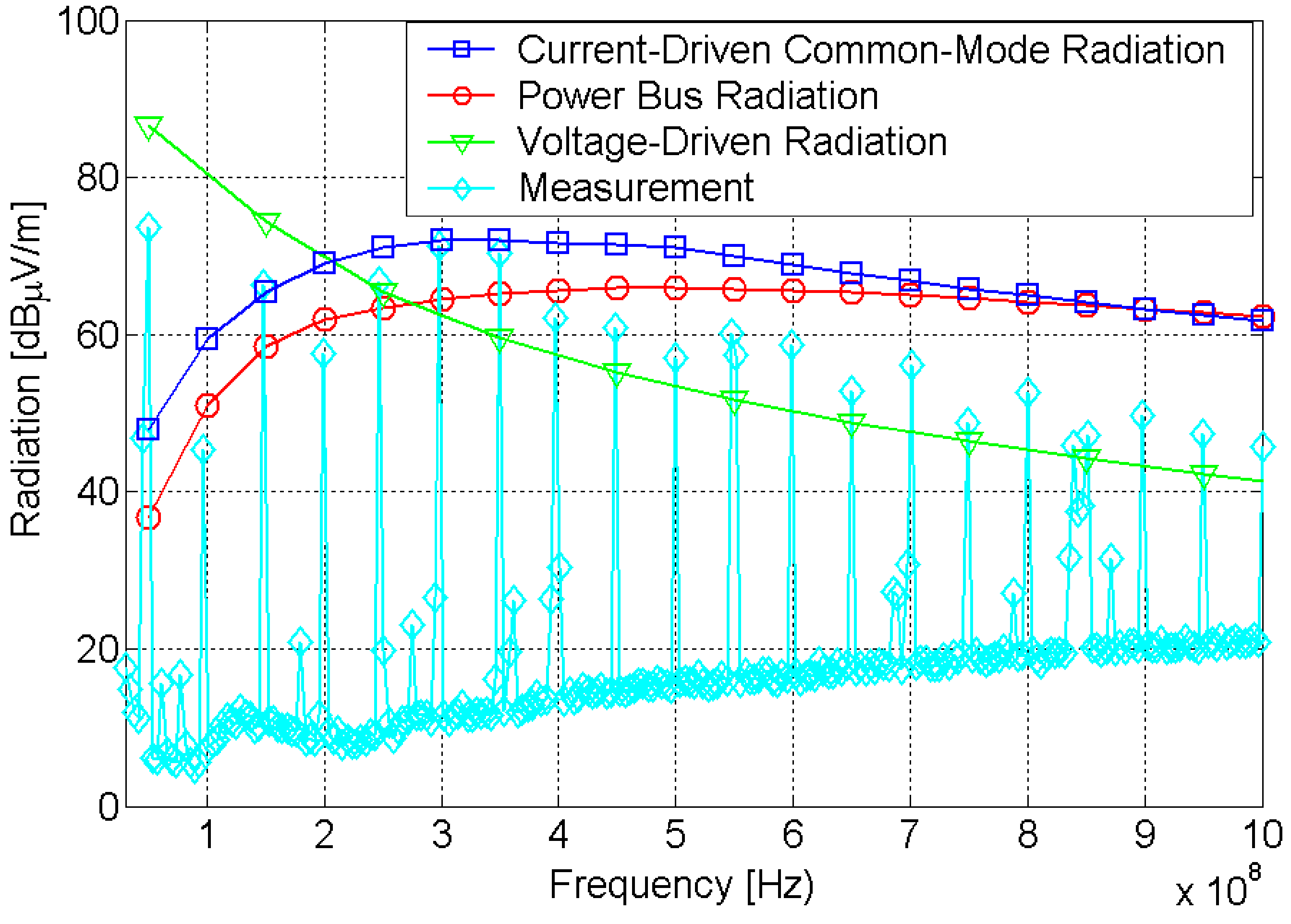


Board Analysis using Expert System Algorithms



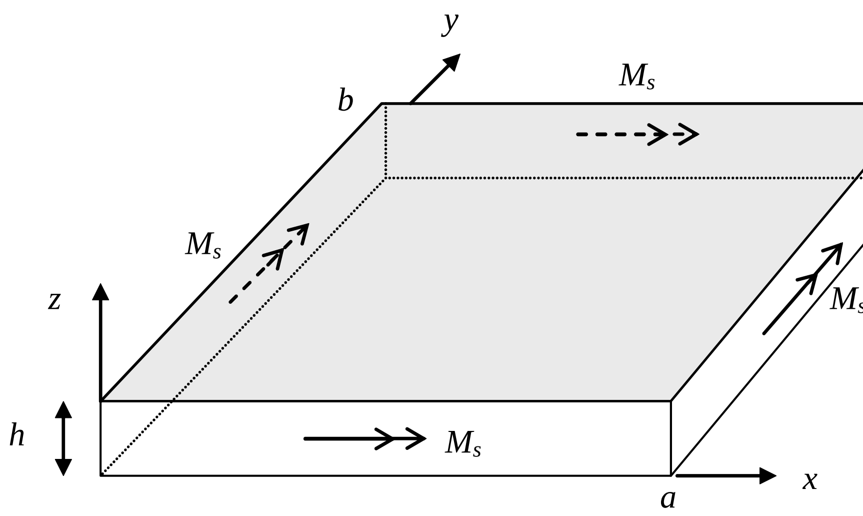
- 8 clock buffers
- 28 load capacitors
- 32 decoupling capacitors
- Clocked at 50 MHz
- No heatsink
- Size: 3” by 2”, 6 layers
- Powered with one cable

Measurement vs. Calculation: 1-nF Load



Power Bus Radiation Model

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



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

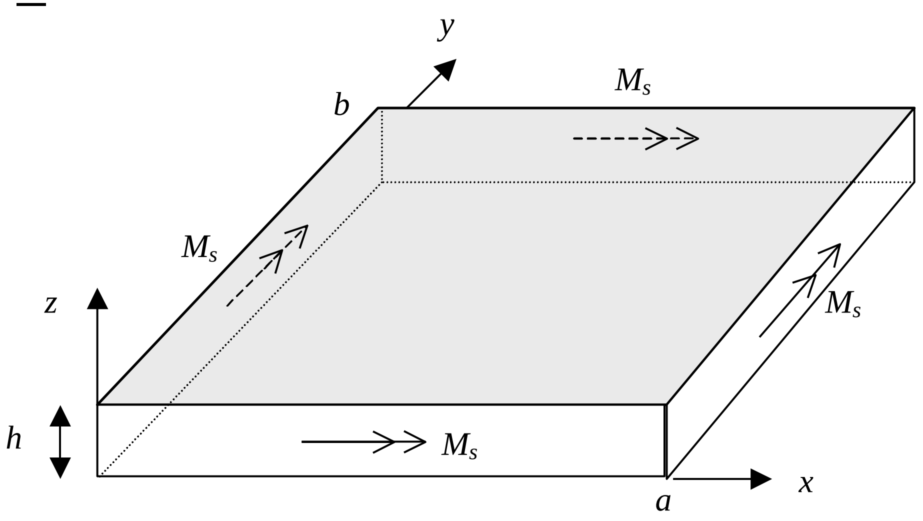
H. Shim and T. Hubing, “Estimating radiated emissions from the power planes in a populated printed circuit board,” *IEEE Trans. on Electromagnetic Compatibility*, vol. 48, no. 1, Feb. 2006.

Maximum Power Bus Radiation

$$\left|E\right| = f(r,\theta,\varphi,\varepsilon_r,h,L,W,\omega) \times V(0,0)$$

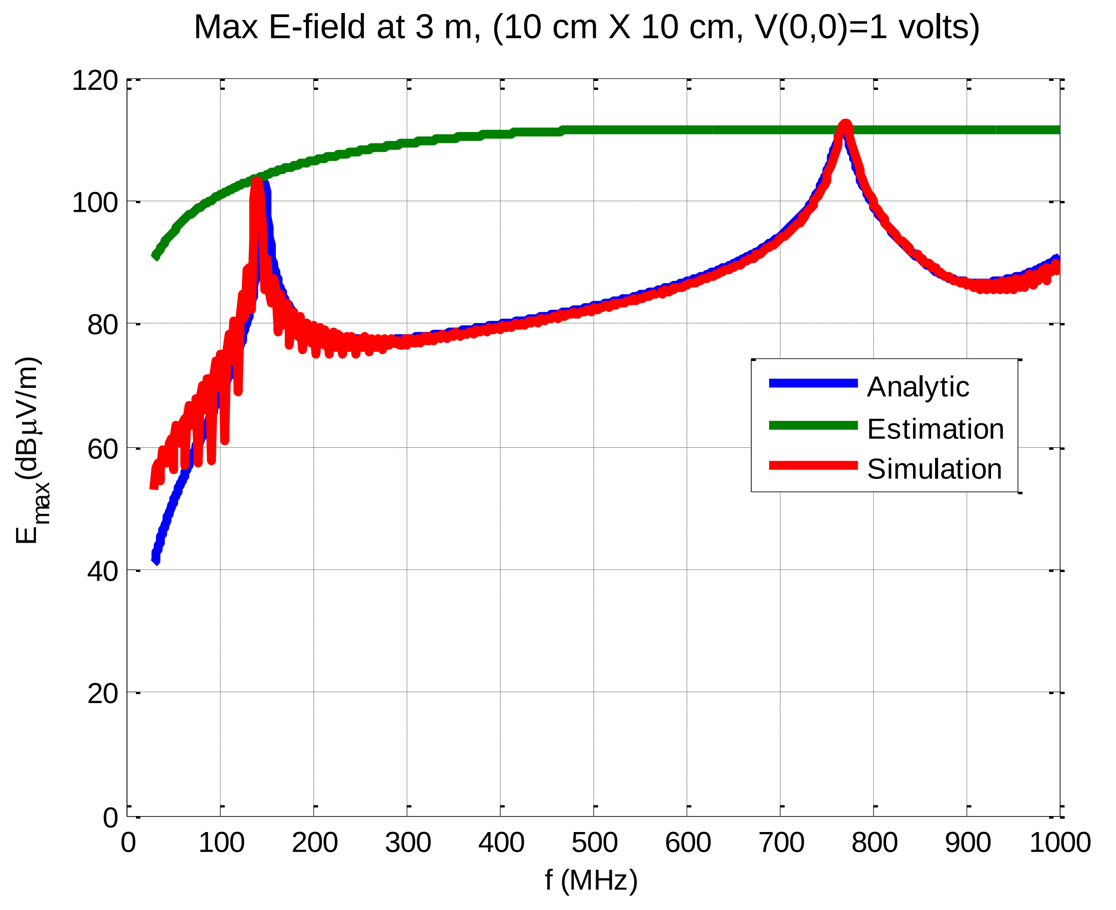
$$\text{board\_ size\_ factor} \equiv \begin{cases} \sin\left(2\pi \ell_{board} / \lambda \right) & \text{when } \ell_{board} \le \dfrac{\lambda}{4} \\ 1.0 & \text{otherwise} \end{cases}$$

$$\left|E\right|_{max} = f_{max} \times V(0,0) \times \text{board\_ size\_ factor}$$



Maximum Power Bus Radiation

$$|E|_{max} = f_{max} \times V(0,0) \times board\_\ size\_\ factor$$

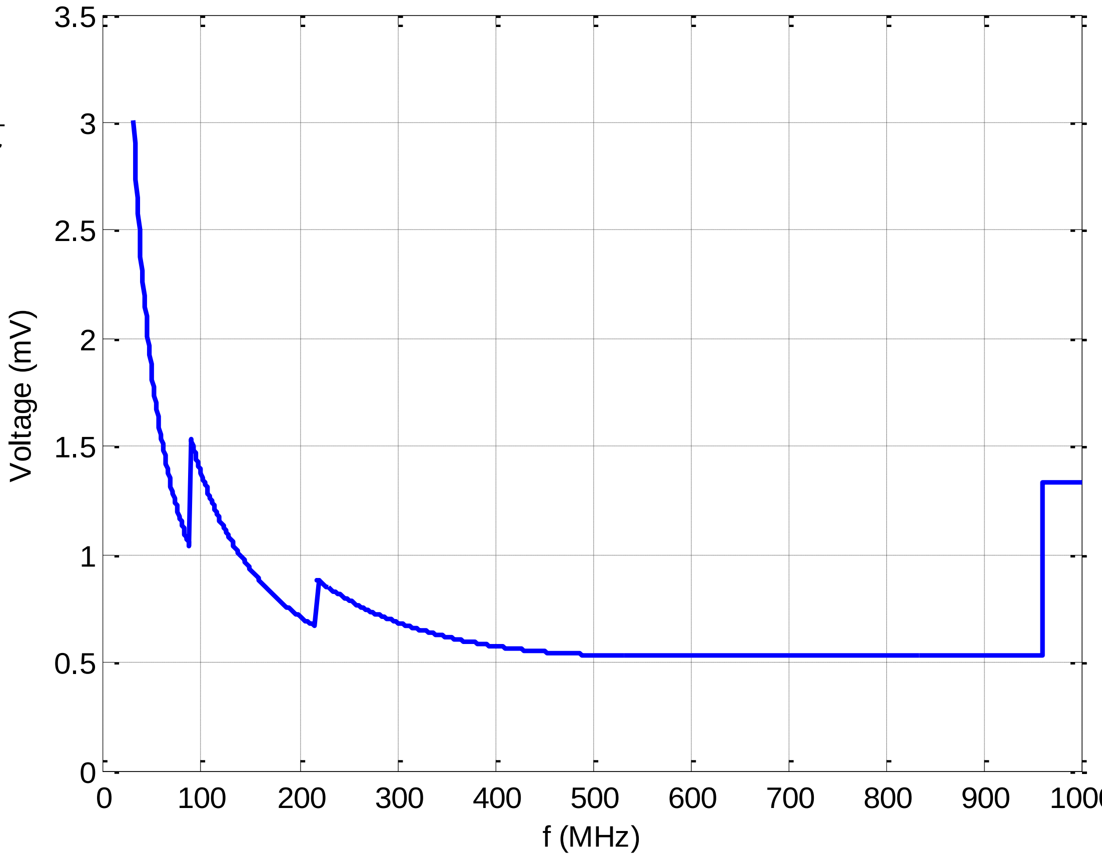


Minimum Power Bus Voltage

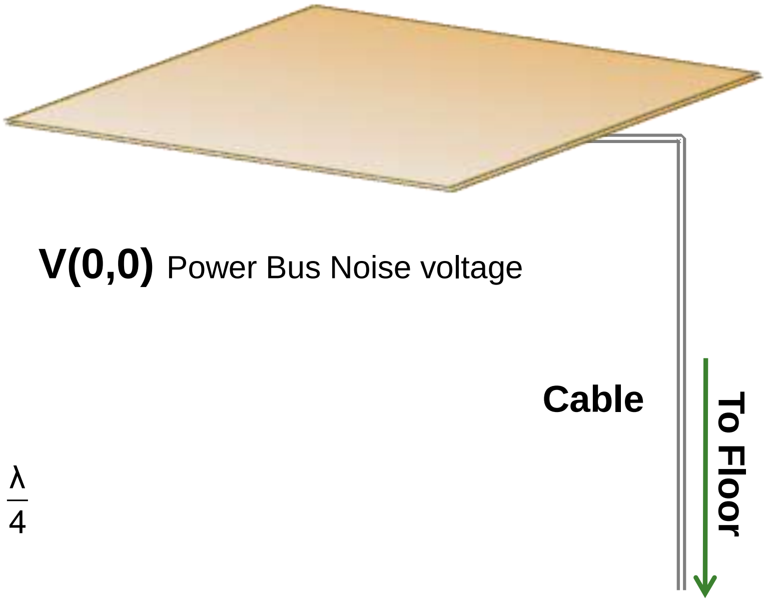
Expert System Field Calculation Performed in Reverse

$$V(0.0)_{min} = \frac{|E|_{FCC}}{f_{max} \times board\_size\_factor}$$

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



Minimum Power Bus Voltage (Board w/Cable)



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

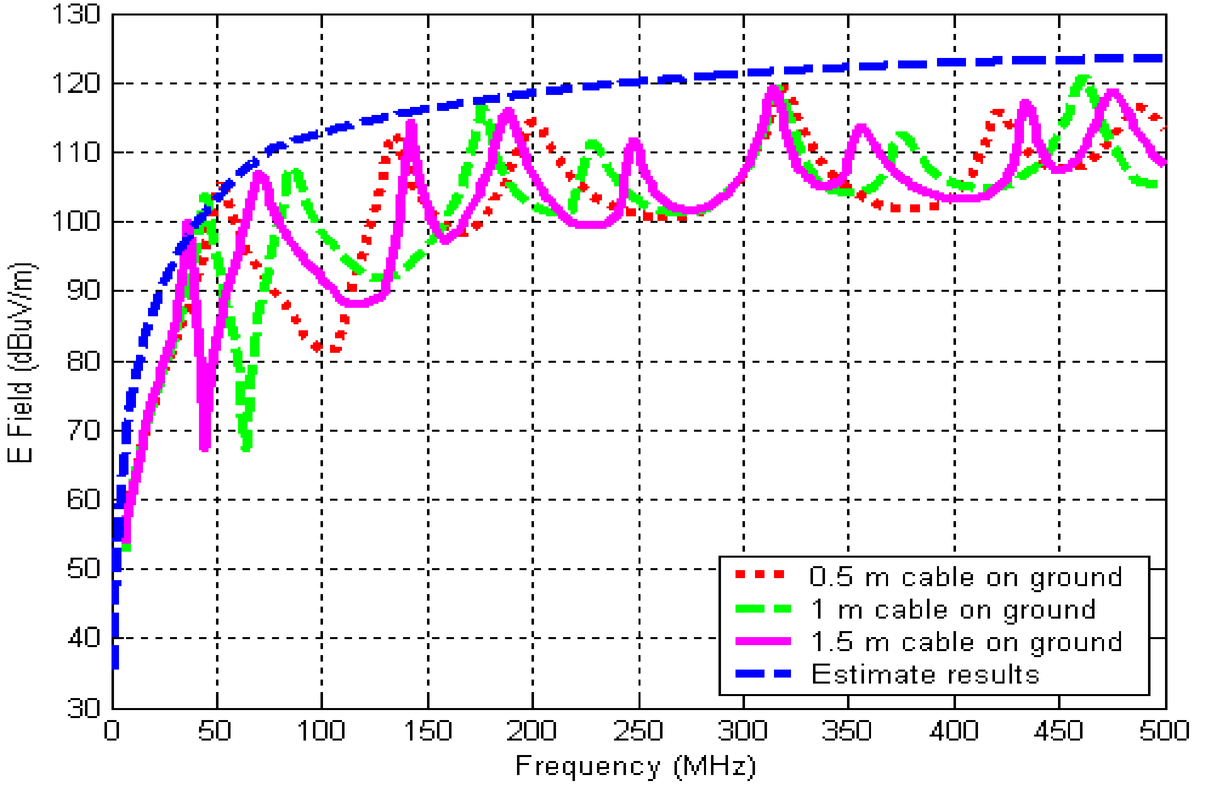
$$\text{cable\_ rad\_ factor} \equiv \begin{cases} \sin\left(2\pi\ell_{cable} / \lambda \right) & \text{when } \ell_{cable} \le \frac{\lambda}{4} \\ 1.0 & \text{otherwise} \end{cases}$$

$$\text{board\_ size\_ factor} \equiv \begin{cases} \sin\left(2\pi\ell_{board} / \lambda \right) & \text{when } \ell_{board} \le \frac{\lambda}{4} \\ 1.0 & \text{otherwise} \end{cases}$$

$$|E|_{min} = |E| \times \text{cable\_ rad\_ factor} \times \text{board\_ size\_ factor}$$

Minimum Power Bus Voltage (Board w/Cable)

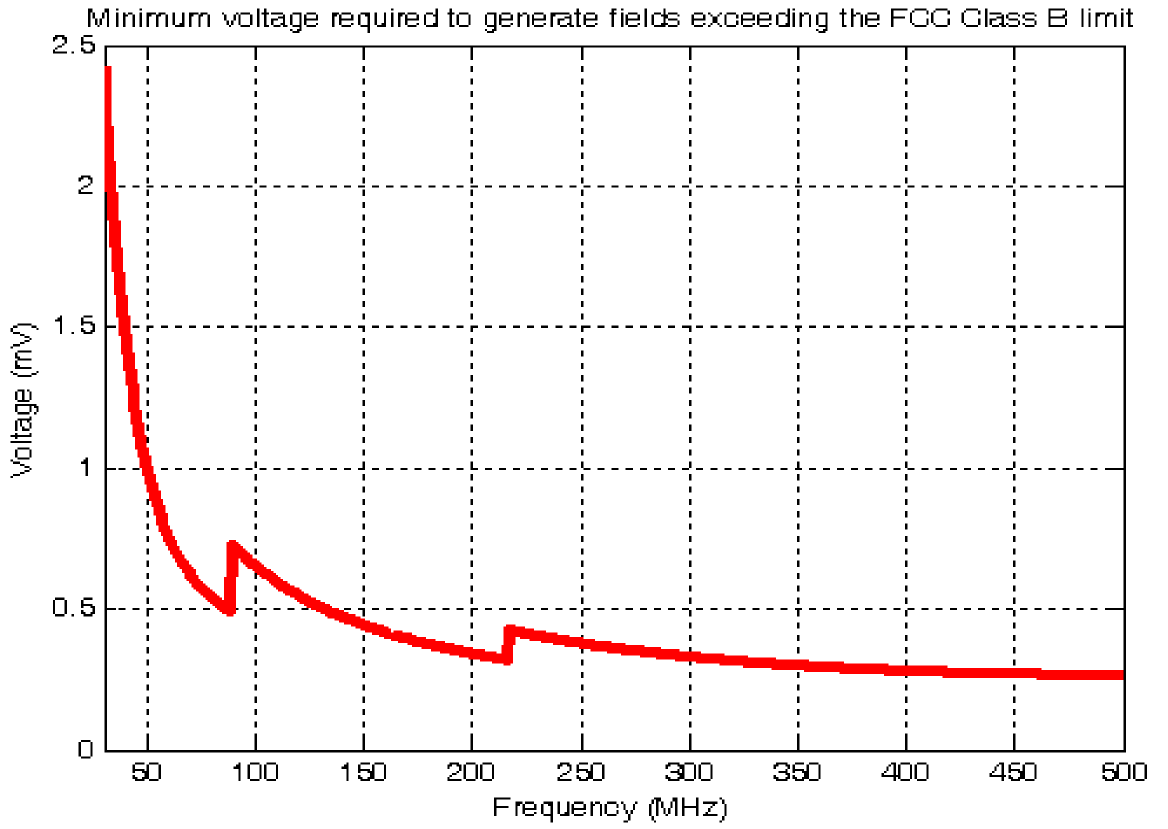
$$|E|_{min} = |E| \times cable\_rad\_factor \times board\_size\_factor$$



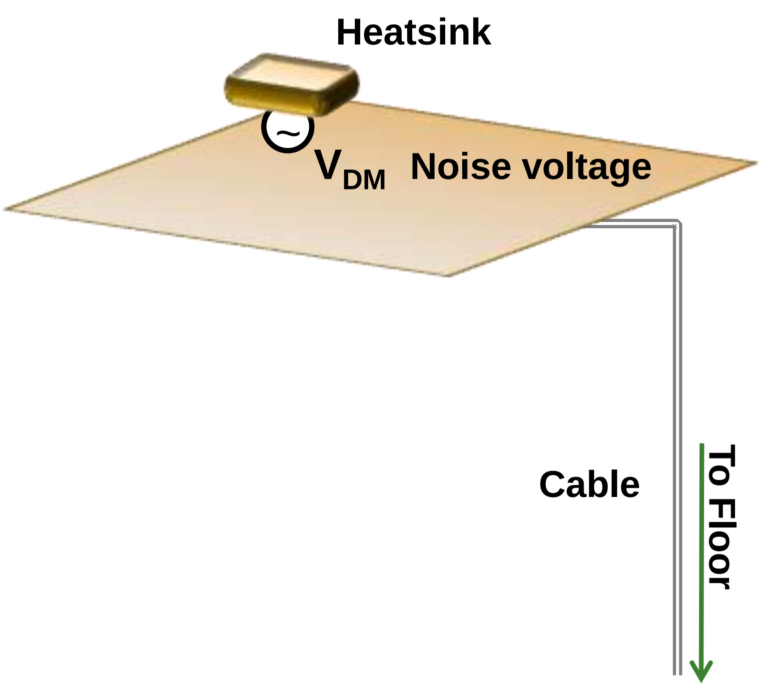
Minimum Power Bus Voltage (Board w/Cable)

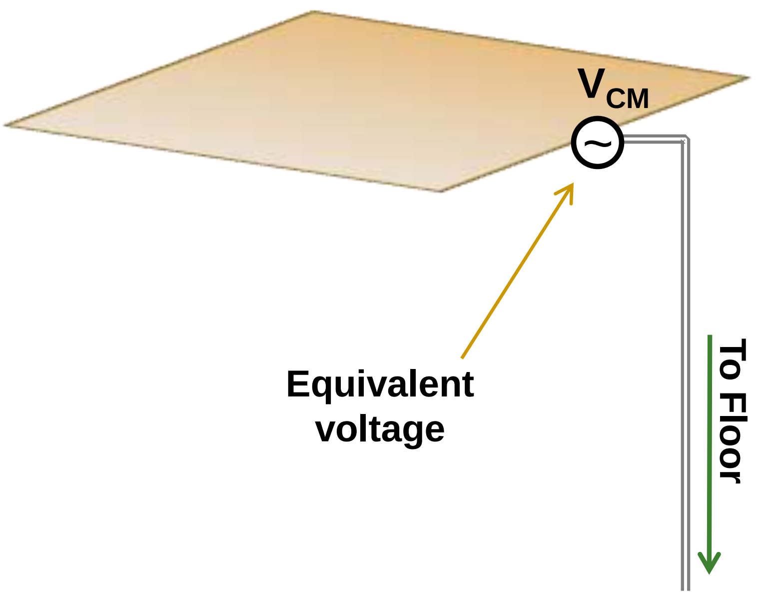
Expert System Field Calculation
Performed in Reverse

$$V_{min} = \frac{|E|_{max}}{cable\_rad\_factor \times board\_size\_factor} \times 37\,ohm \Big/ 20 \times 2.76$$



IC-Heatsink to Cable Coupling

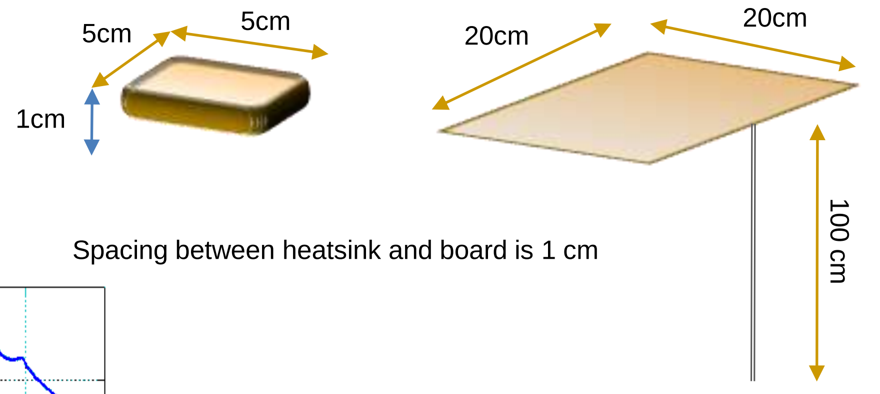




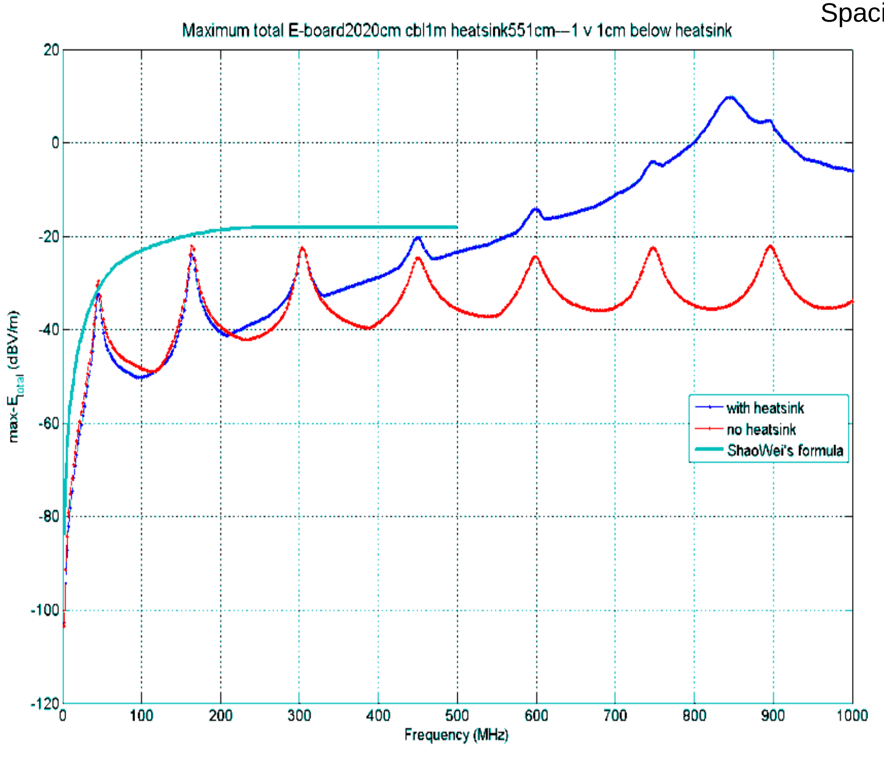
$$V_{CM} = \frac{C_{heatsink}}{C_{board}} V_{DM}$$

$$V_{DM} = 0.2234 \frac{C_{board}}{C_{heatsink}} \times \frac{r}{F_{board} F_{cable}} \times |E_{max}|$$

IC-Heatsink to Cable Coupling



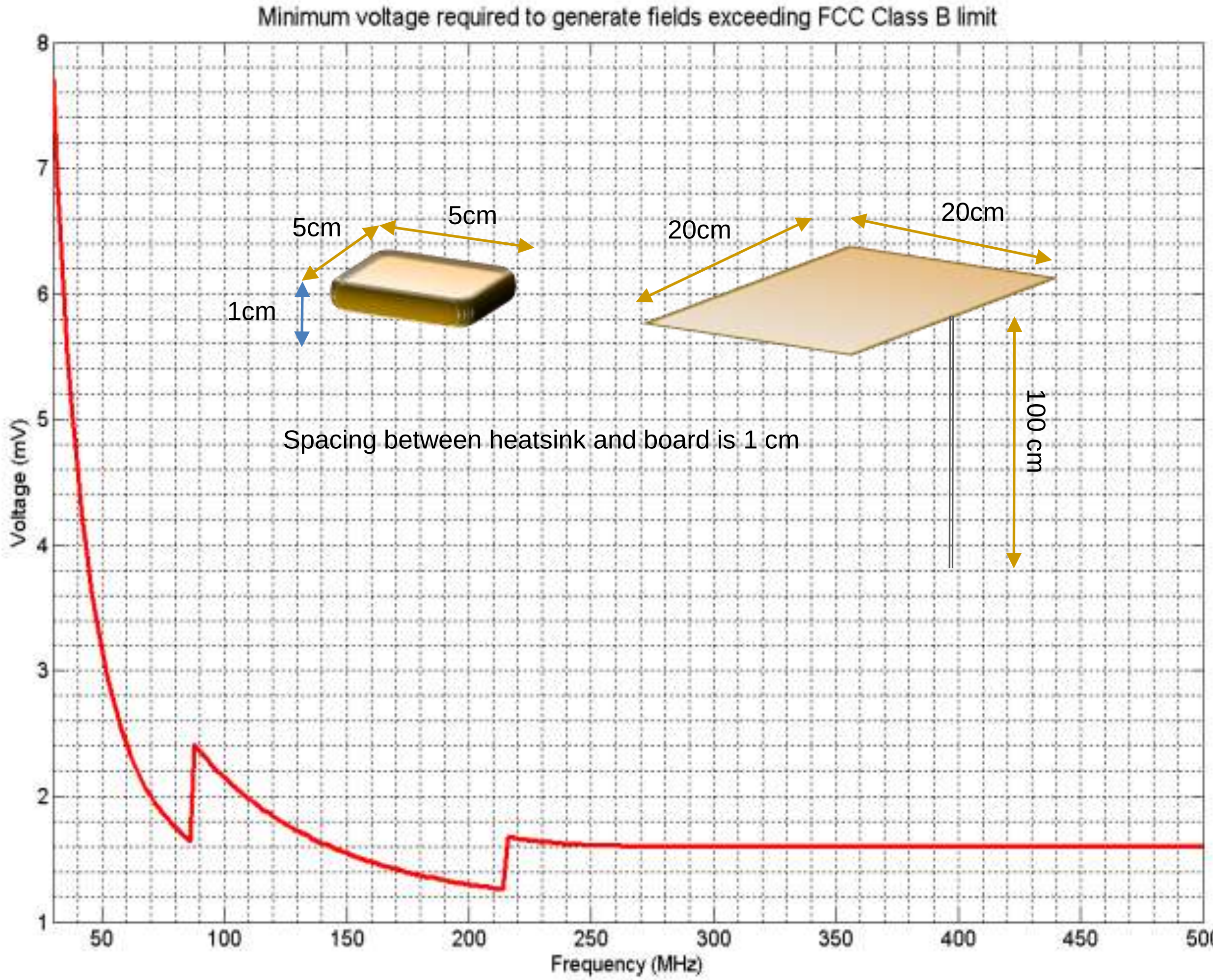
Spacing between heatsink and board is 1 cm



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

$$C_{board} = 5.14\,\text{pF}$$

IC-Heatsink to Cable Coupling



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.