Essential New Tools for EMC Diagnostics and Testing

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Where is Clemson University?

Clemson, South Carolina, USA


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Tools Required to Outfit an EMC Laboratory

Semi-anechoic test facility

Shielded room

Network analyzers

Spectrum analyzers

Impedance analyzers

Waveform generators

Oscilloscopes

Antennas, Probes

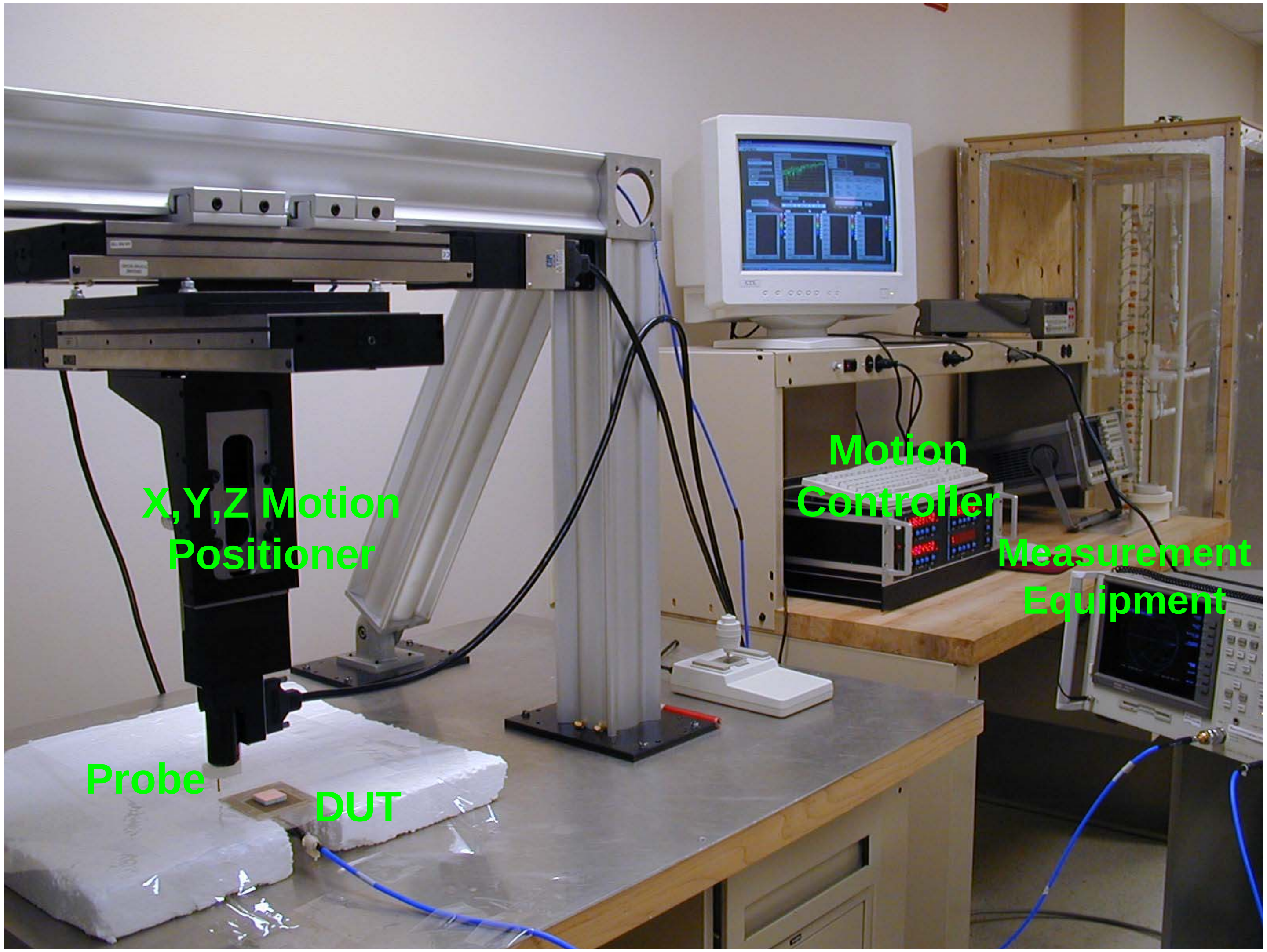
Power supplies

Prototyping facilities

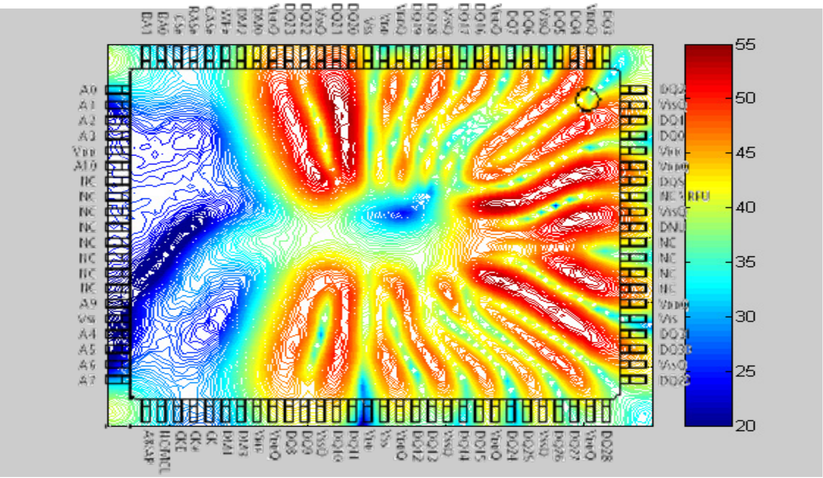
Amplifiers, Pre-amplifiers

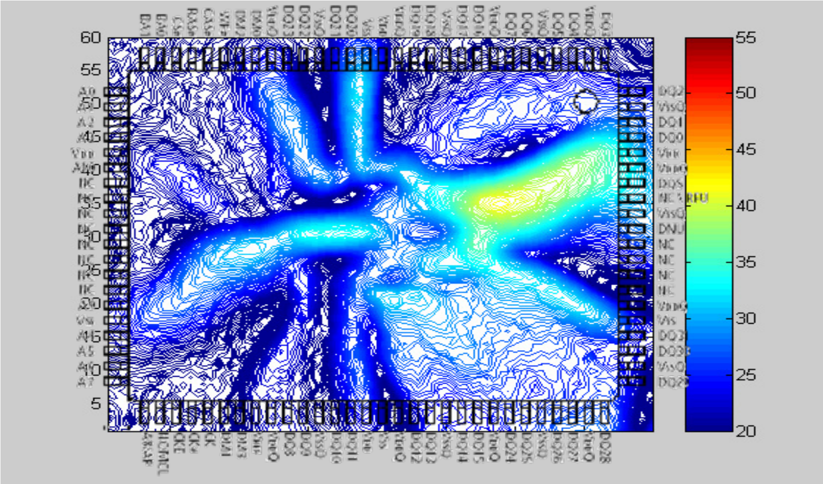
…

Near-Field Scanners

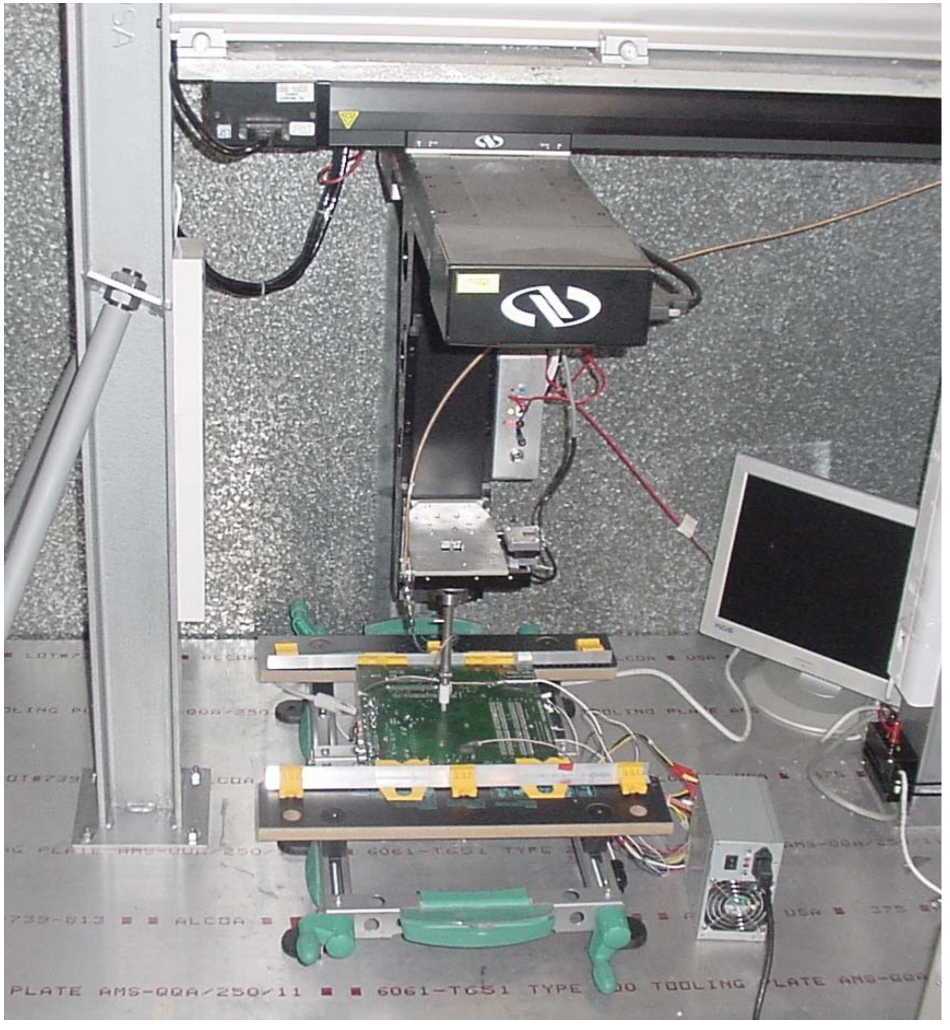


Near-Field Scanners





Near-Field ESD Scanners



ESD Scanner

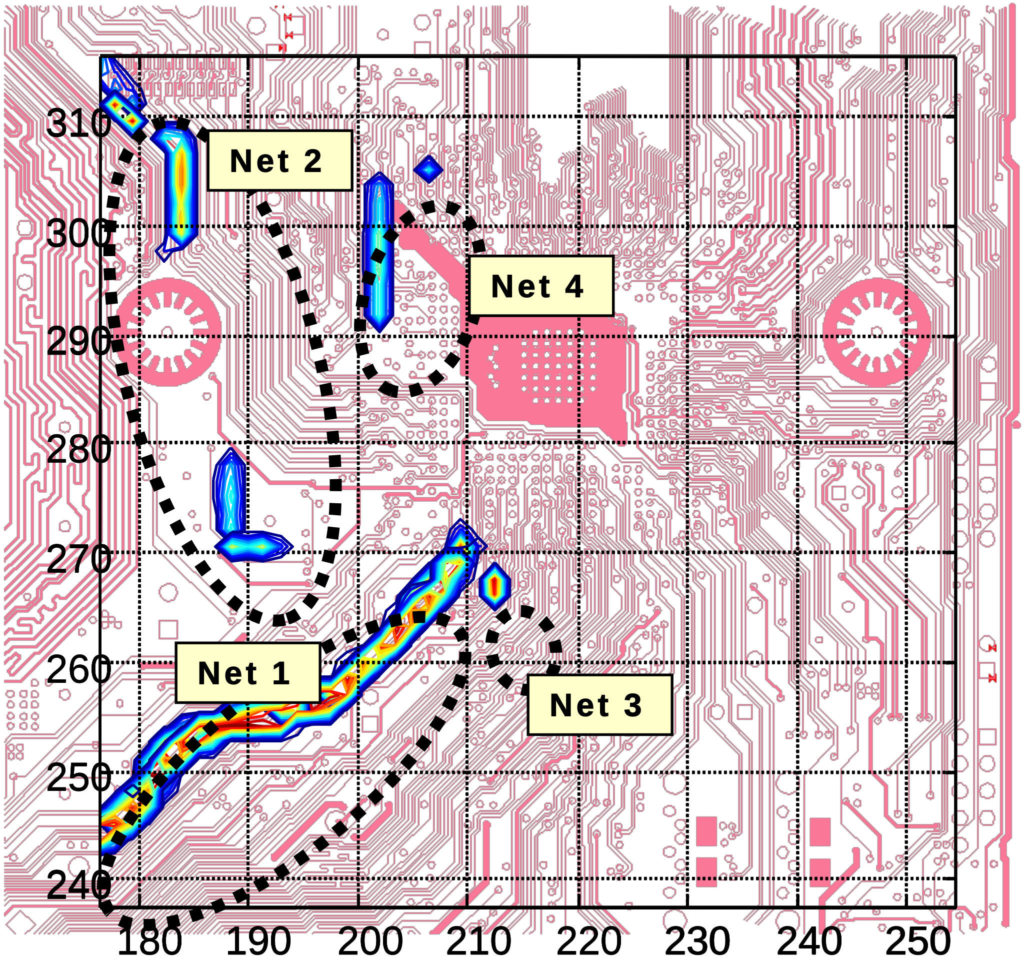
The system moves injection probes to predefined locations, injects pulses and observes the system response.

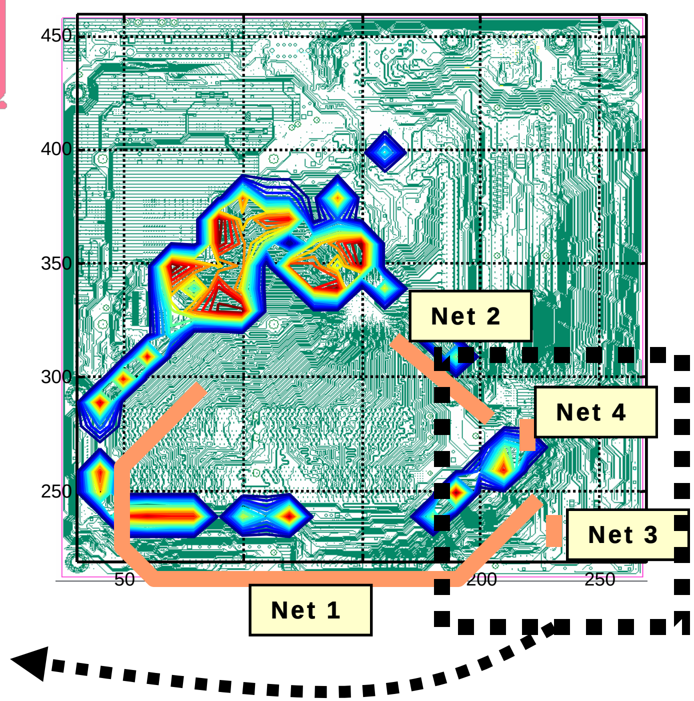
In most cases, pulses are “ESD-like”, e.g., having rise times 0.1 - 2 ns.

Injection is done using different injection probes for testing direct coupling, E and H-field coupling.

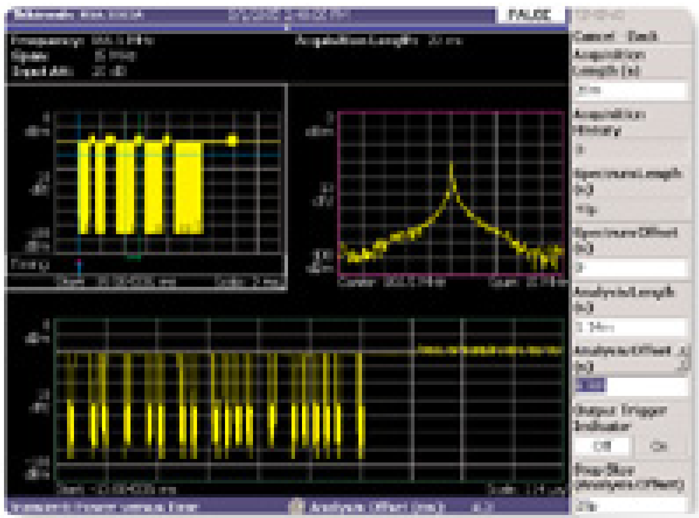
To determine the voltage at an input of an IC at a level that leads to a mal-function, the voltages are measured.

Near-Field ESD Scanners

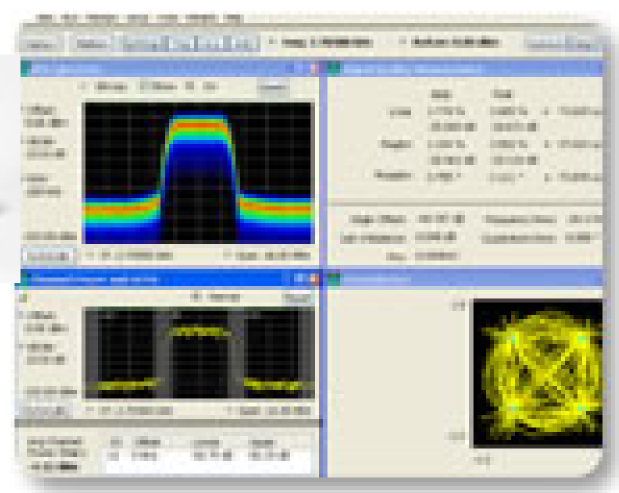




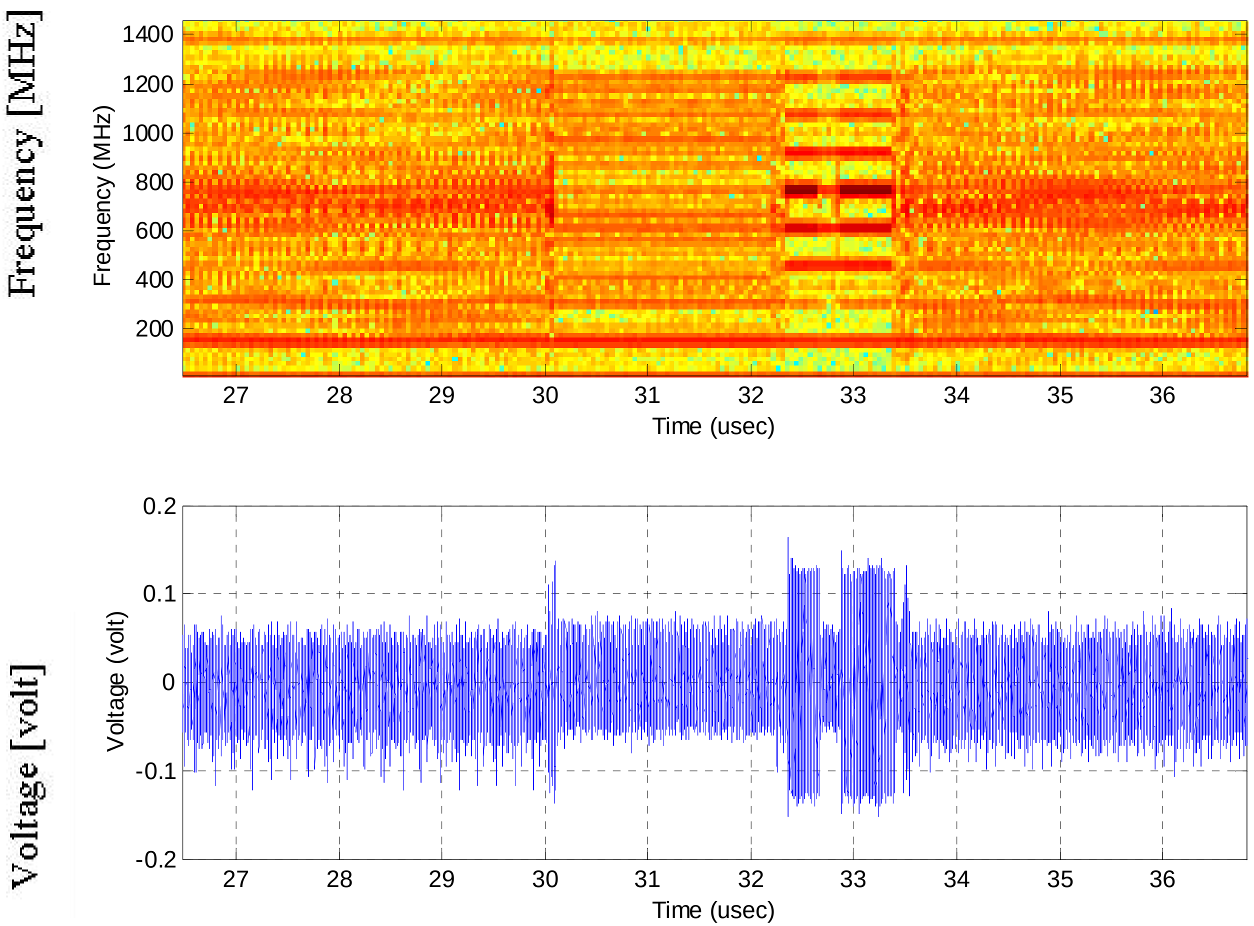
Time/Frequency Domain Analyzers



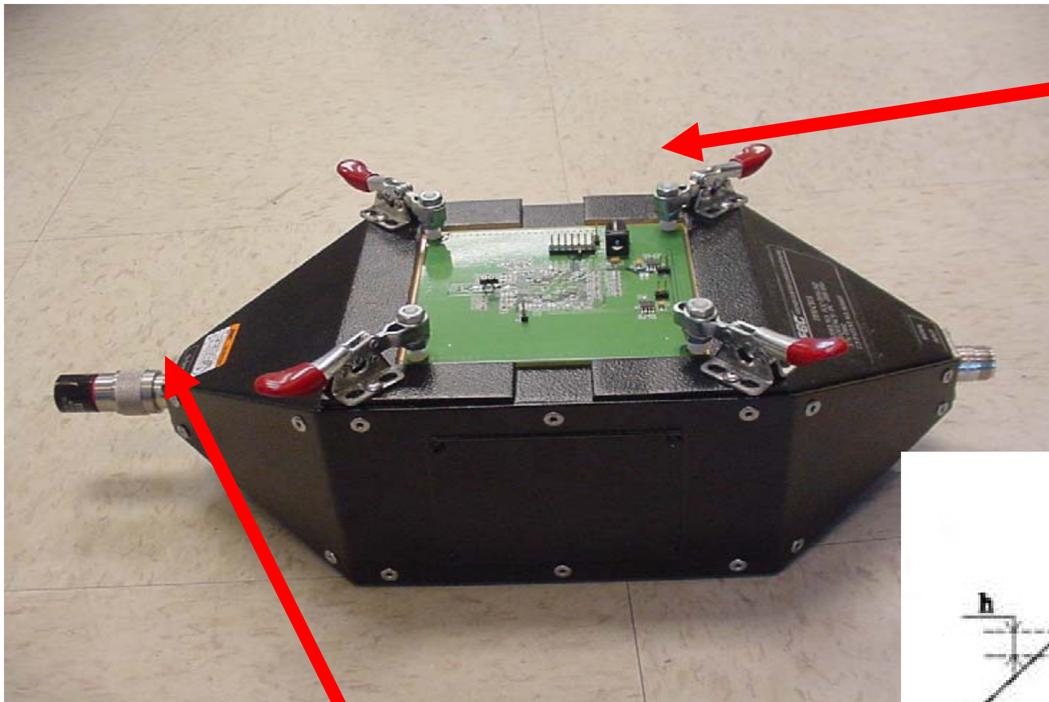
- Source Identification
- Source Characterization
- Narrow-Band Transient Capture



Time/Frequency Domain Analyzers

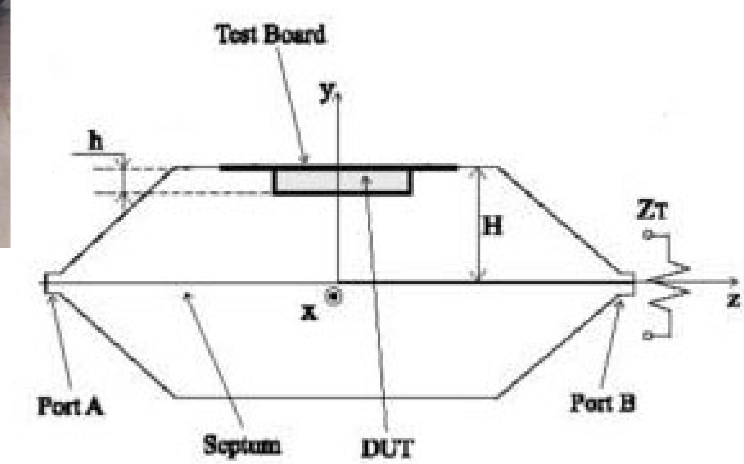


Mini-TEM Cells



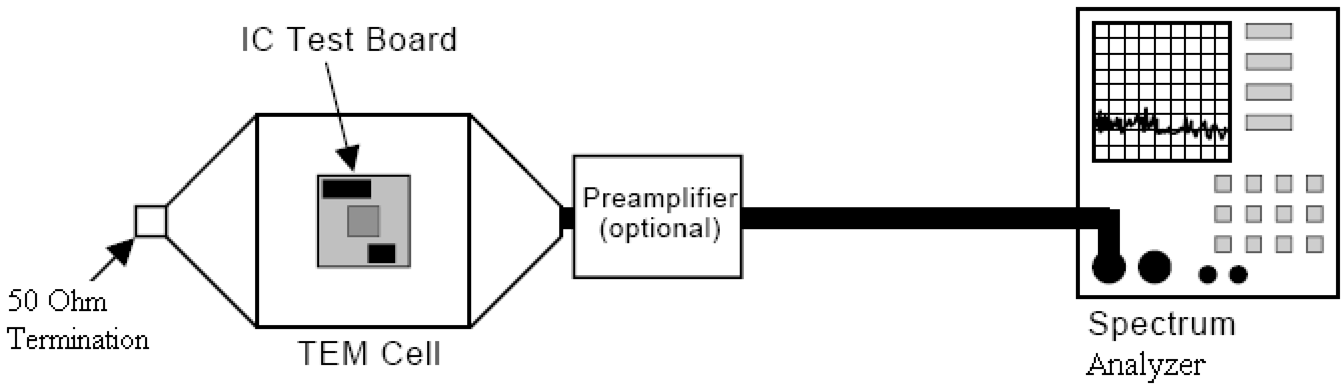
DUT (IC chips) mounted at the inner side of the test board (within TEM cell)

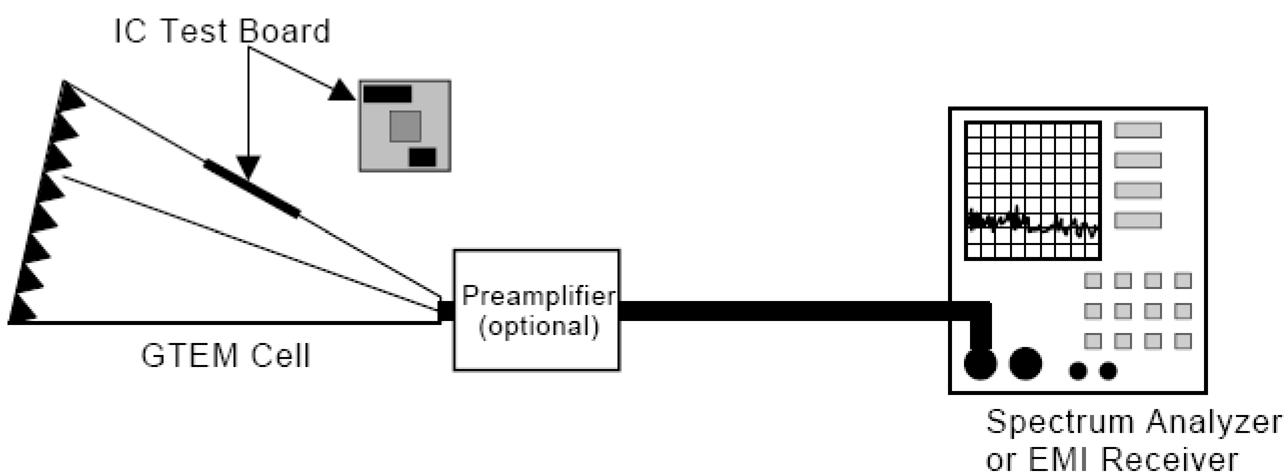
50 Ohm load



Mini-TEM Cells

Standards SAE J1752/3 and IEC 61967-2





Mini-TEM Cells

- More attention is being focused on the EMC design of ICs, MCMs and other electrically small sources.
- These devices generally don't radiate directly themselves. They couple to larger objects (e.g. cables and enclosures) that serve as the antennas.

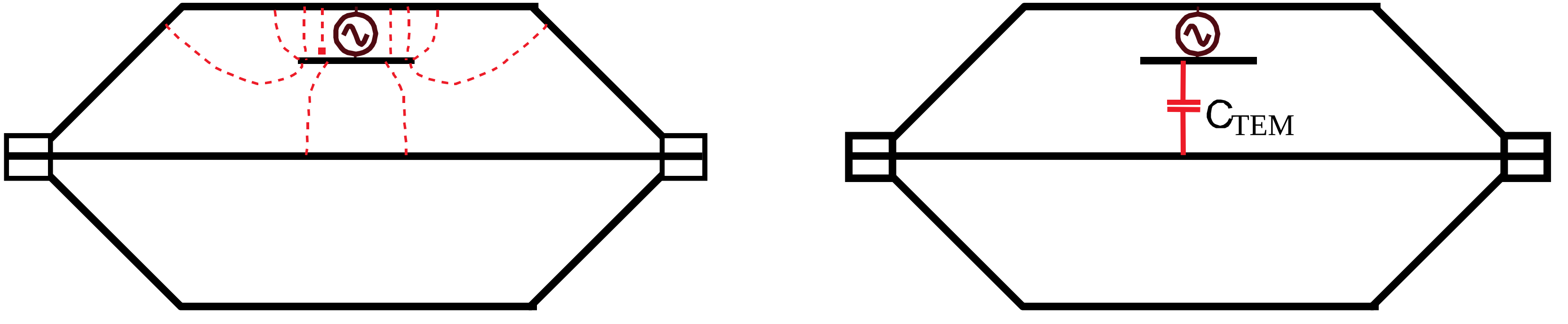
Mini-TEM Cells

There are only three possible coupling mechanisms from an electrically small source.

- Conducted
- Electric-Field Coupling
- Magnetic-Field Coupling

Mini-TEM Cells

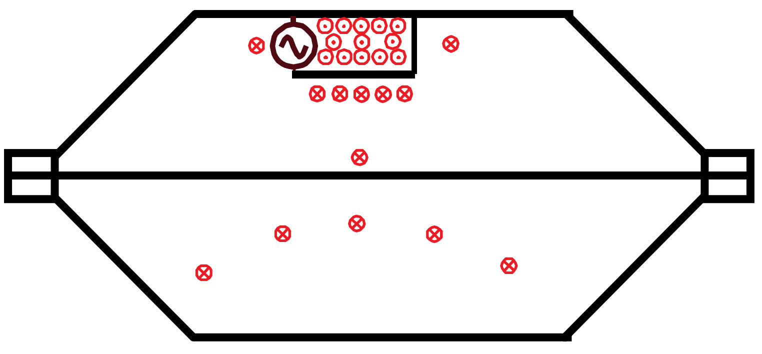
Electric field coupling can be represented with a mutual capacitance, $C_{TEM.}$ The voltage coupled to either end of the TEM cell will be identical.



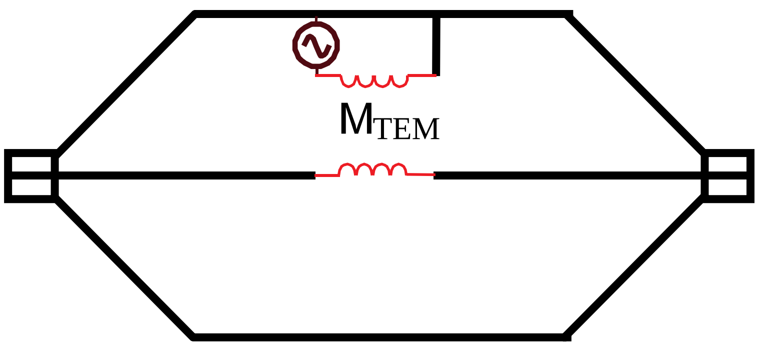
(a) (b)

Mini-TEM Cells

Magnetic field coupling can be represented with a mutual inductance, $M_{TEM.}$ Voltage appears across both terminations with opposite phase.



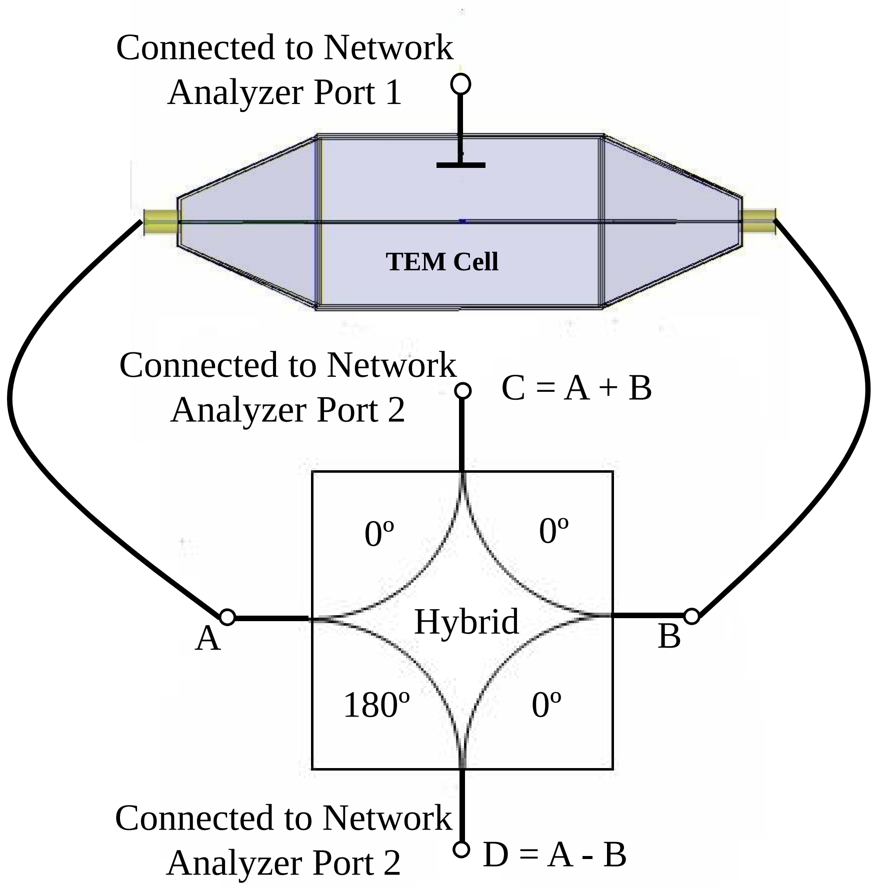
(a)



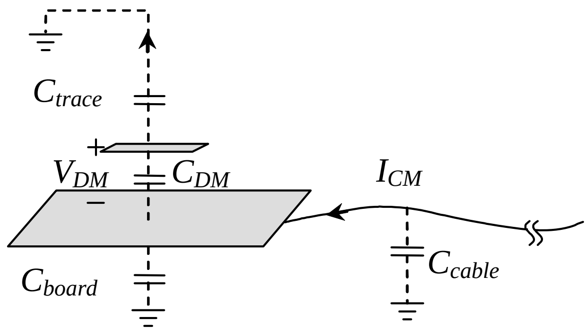
(b)

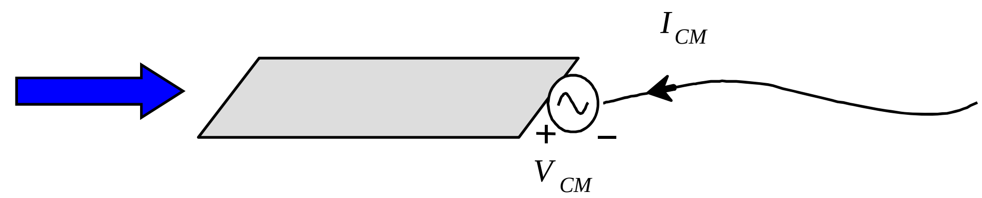
Mini-TEM Cells

- A hybrid can be used to differentiate electric and magnetic field coupling.
- The A-B output indicates the amount of magnetic field coupling.
- The A+B output indicates the amount of electric field coupling.

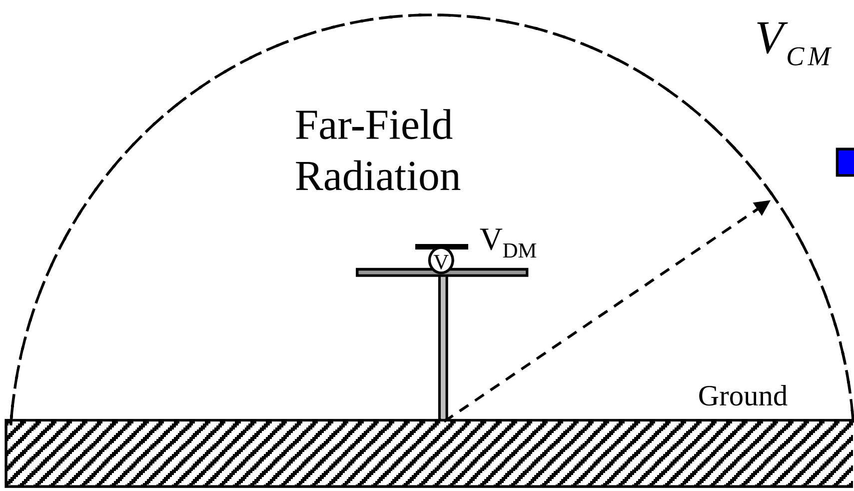


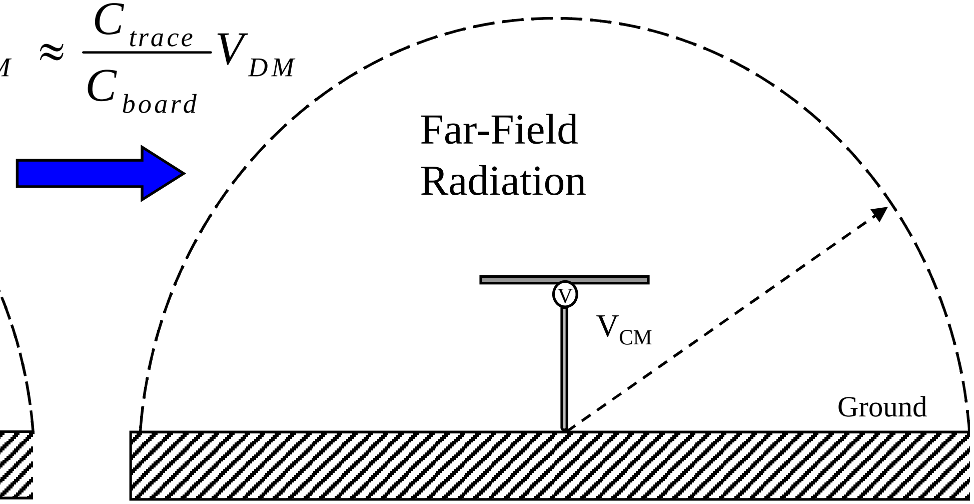
Voltage-Driven Radiation Mechanism



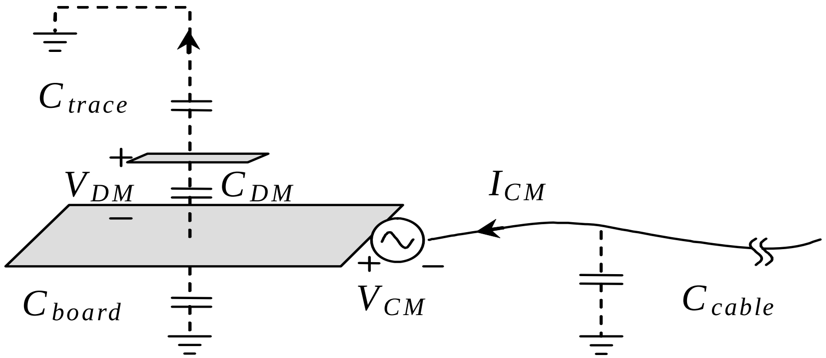


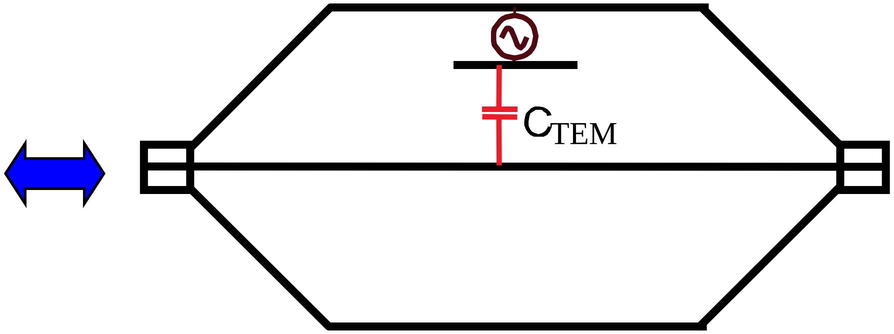
$$V_{CM} \approx \frac{C_{trace}}{C_{board}} V_{DM}$$





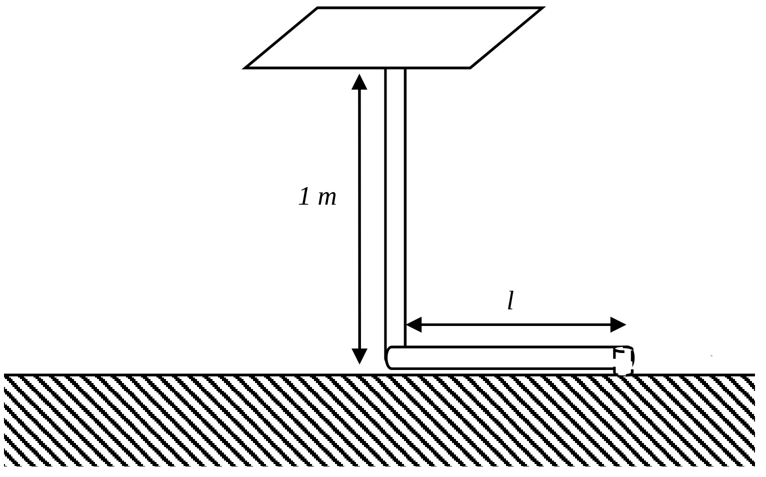
Correlating C_{trace} to C_{TEM}

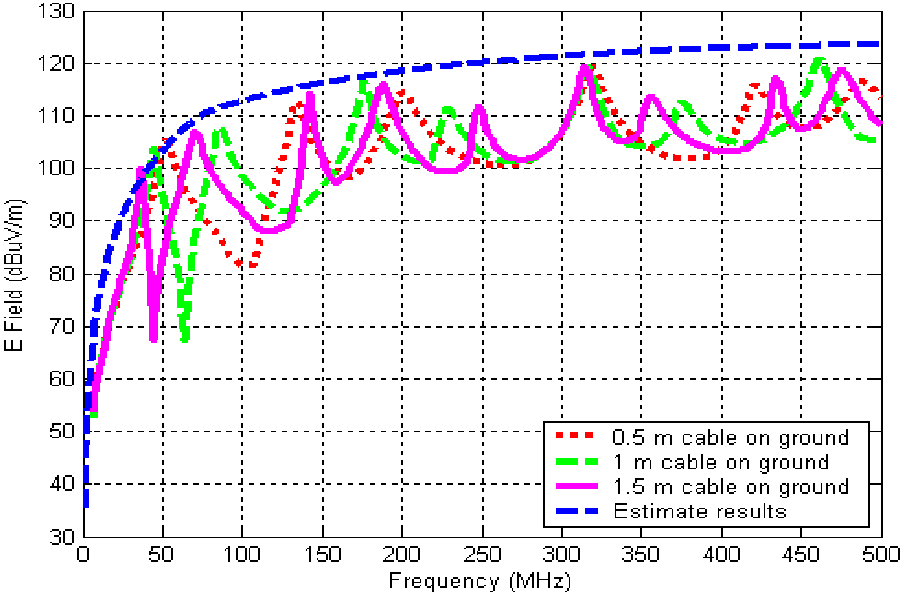




$$C_{trace} \approx C_{TEM} / 2.1$$

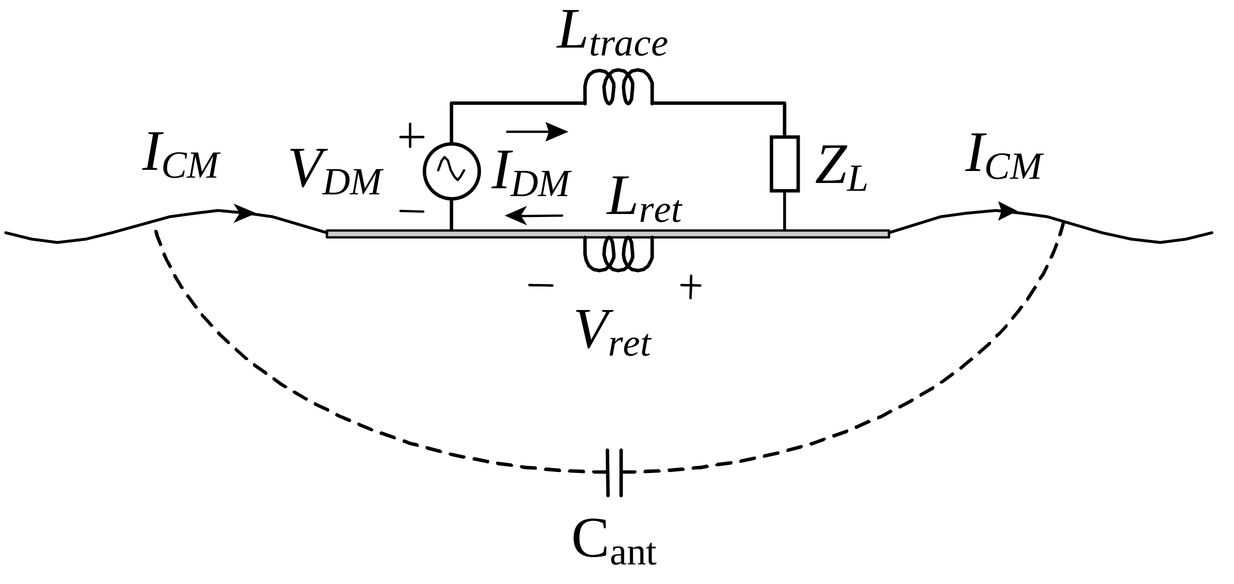
Effect of Extended Cable on Ground





Mini-TEM Cells

Current-Driven Common-Mode (Magnetic-Field) Coupling

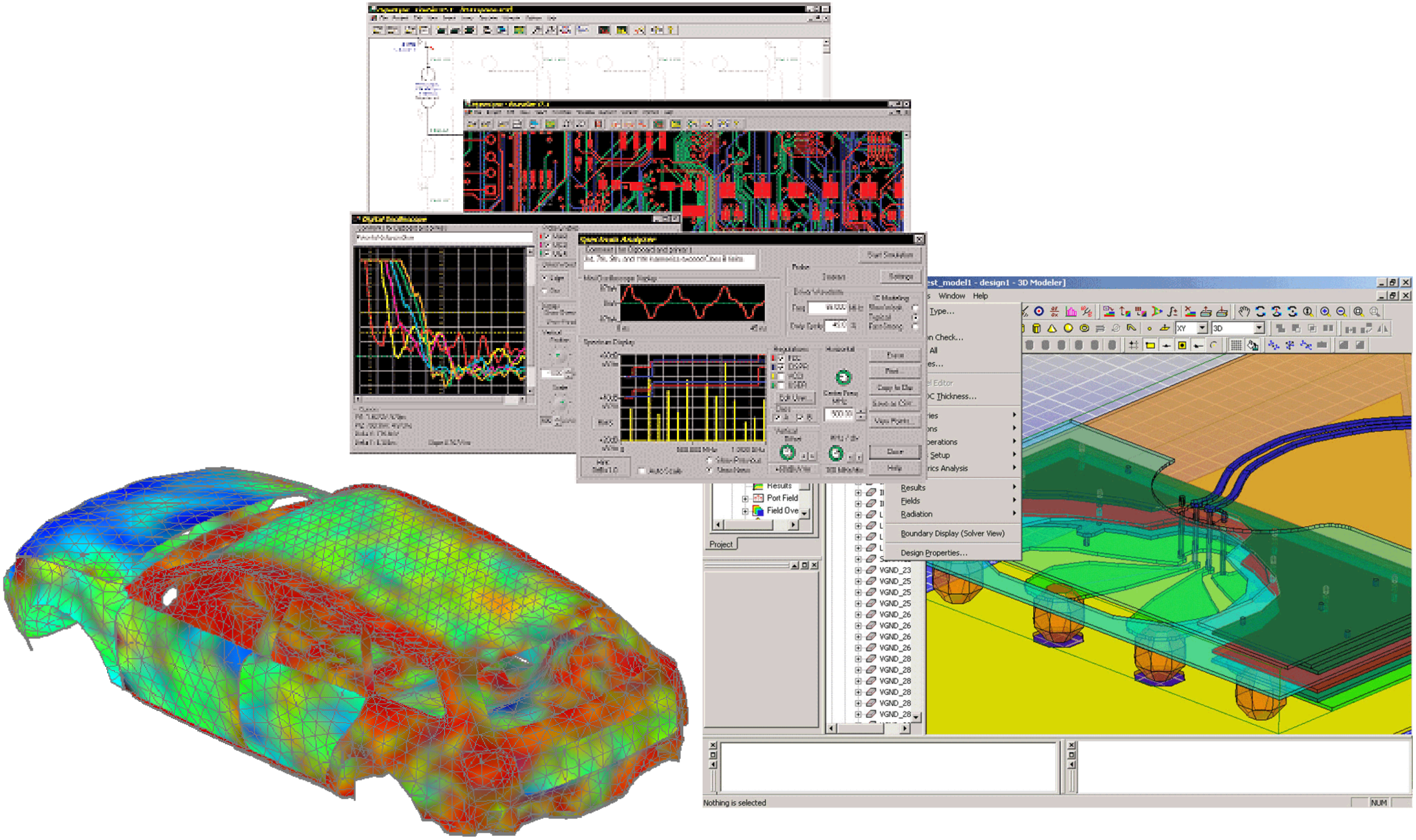


Source can be fully characterized by the current I_{DM} and the mutual inductance (source loop to antenna loop).

Mini-TEM Cell

- By connecting both outputs of the TEM cell to a hybrid, it is possible to separate the electric field coupling from the magnetic field coupling.
- Magnetic-Field coupling is fully characterized by the source current and mutual inductance to the radiating structure. These are both determined by the TEM cell measurement.
- Electric-Field coupling is fully characterized by the source voltage and the capacitance of the device being driven to infinity. These can both be determined by the TEM cell measurement.
- Therefore, a TEM cell measurement can be used to extract the parameters required to predict maximum radiated emissions due to coupling from an electrically small source.

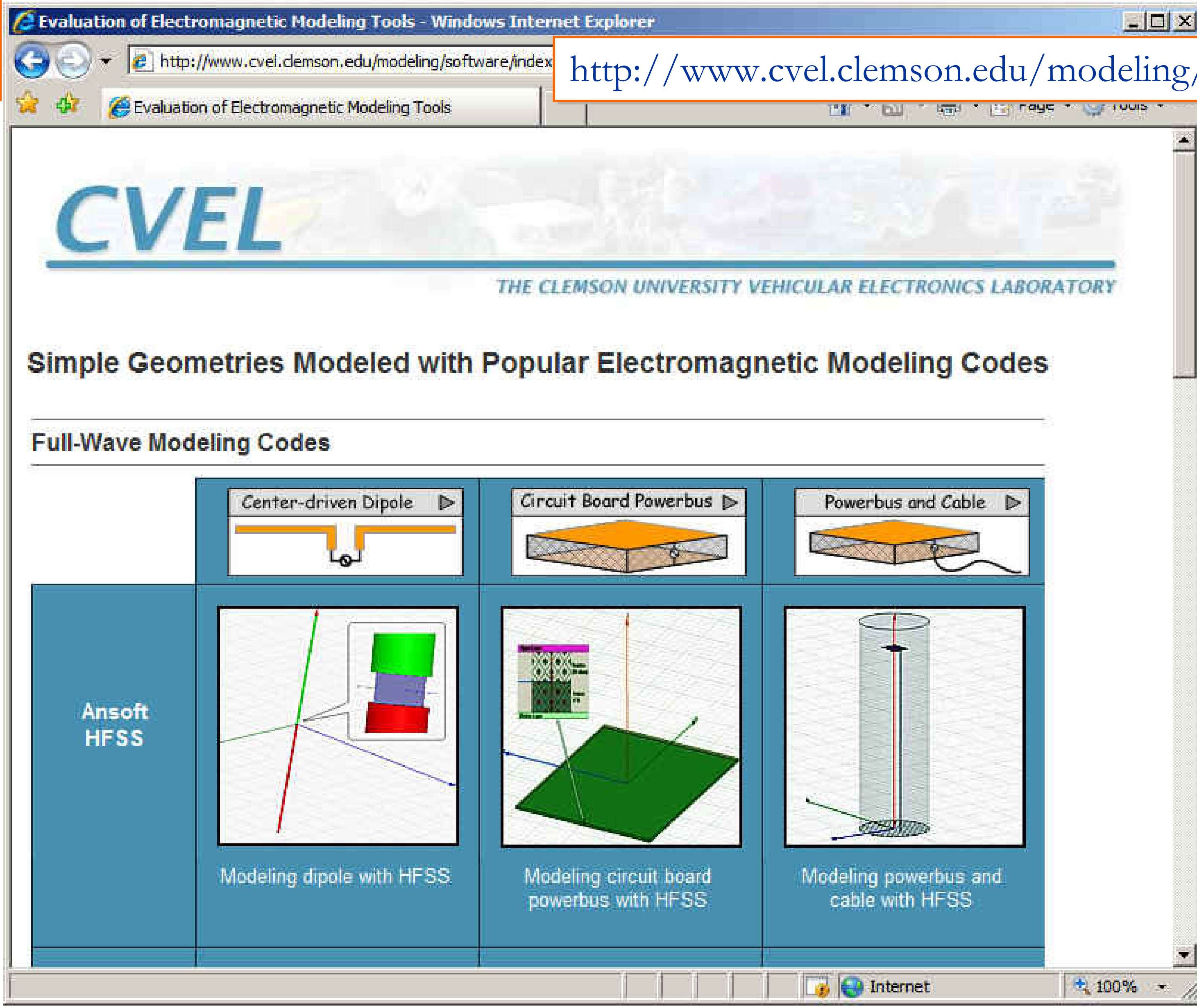
Numerical Electromagnetic Modeling Tools



Numerical Electromagnetic Modeling Tools

COMPLIANCE FIDELITY COMSOL Multiphysics
Fastcap EMA3D Fasthenry SINGULA
GEMACS SuperNEC FEKO Quickfield
VISULA EZ-FDTD FLO/EMC
MaxSIM-F Accufield EMC Workbench
MagNet EMAG Fastlap
Microwave Explorer
Maxwell 3D SPEED2000 EMAP
XFDTD Flux3D MSC EMAS COULOMB
Microwave Studio PAM-CEM NEC
Q3D MAGNETO EM IE3D MiniNEC HFSS

http://www.cvel.clemson.edu/modeling/software/



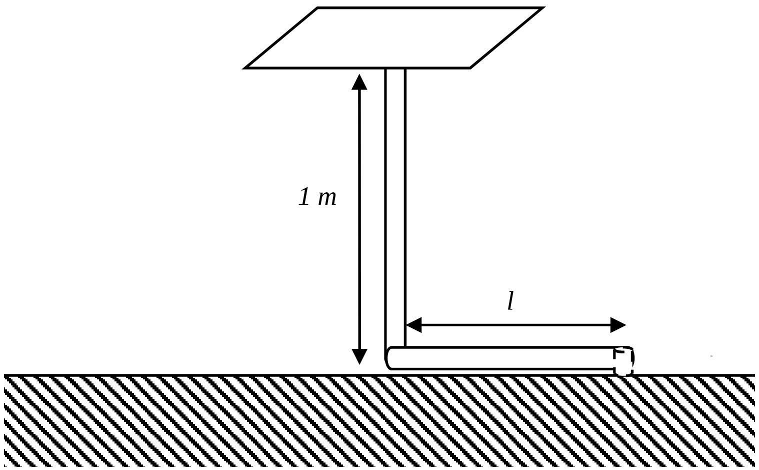
EMC Expert Systems

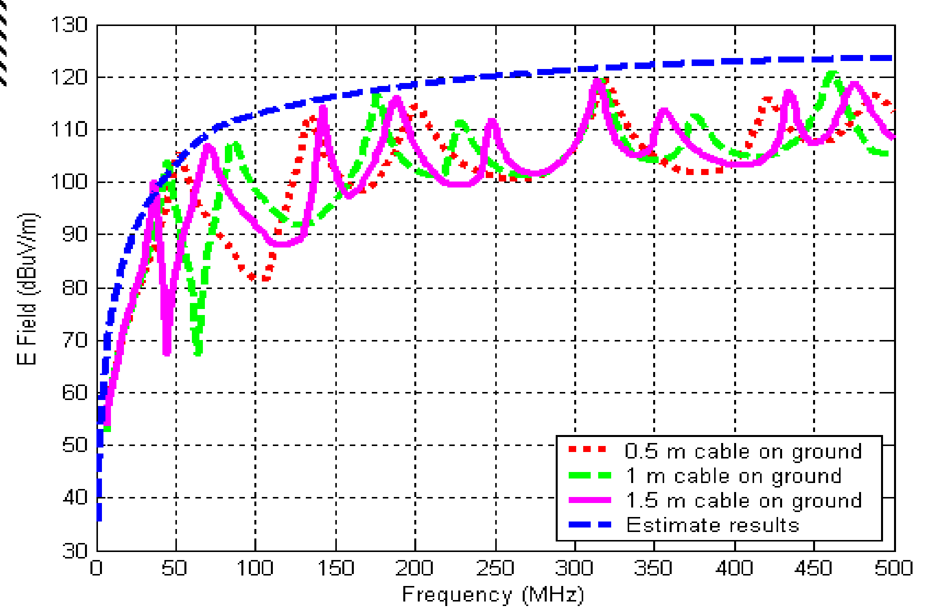
- Printed Circuit Board Layout
- Automotive EMC
- System-Level Extensions

Expert System Algorithms are constantly answering the question,

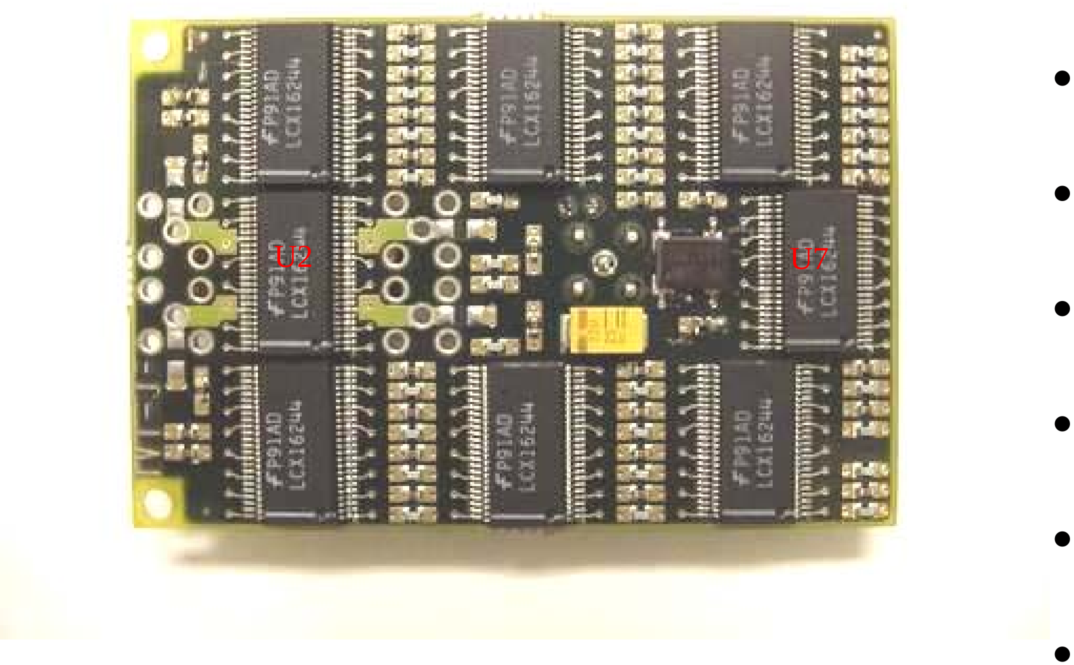
How bad could it be?

Effect of Extended Cable on Ground



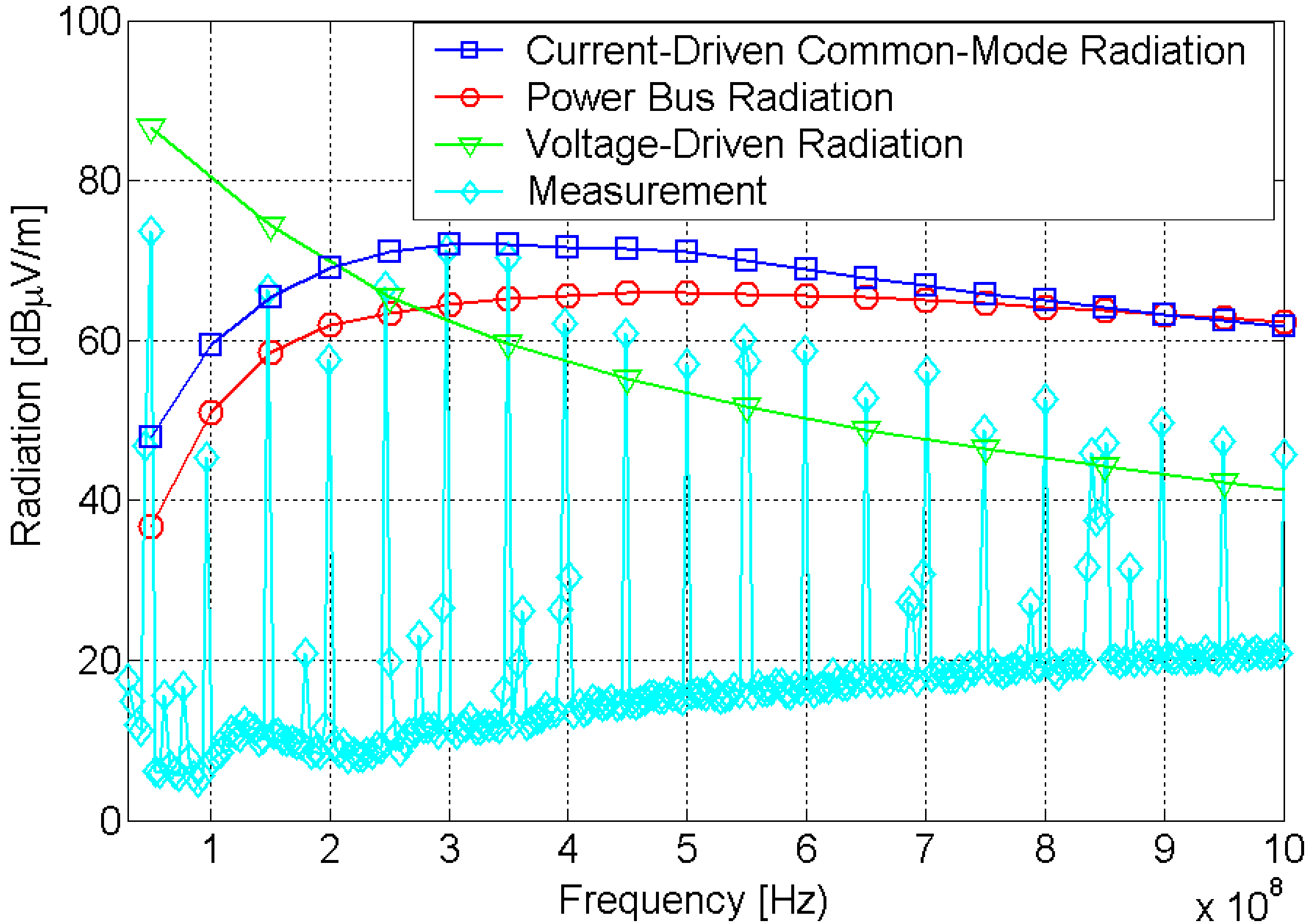


NCMS Board Analysis using Expert System Algorithms



- 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

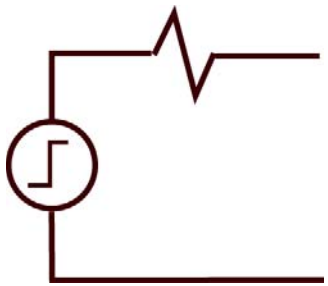


PCB Expert System Structure

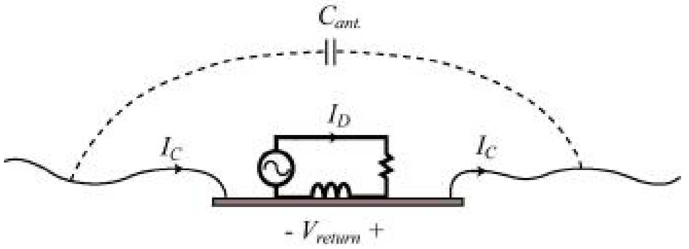
- Identify Sources
- Identify Antennas
- Evaluate Coupling

PCB Expert System Structure

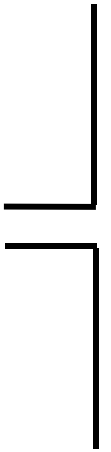
Source Model



Coupling Path Model



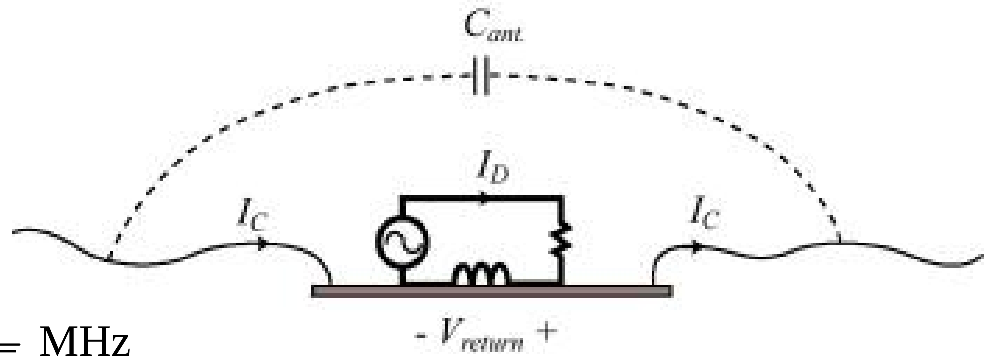
Antenna Model



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

Current-Driven Radiation Model



$$V_{ret,i} = \begin{cases} \omega L_{p,i} I_{DM,i}, & f \le \dfrac{75}{a\sqrt{\varepsilon_r}} \text{ MHz} \\ \dfrac{4.71\times 10^8 \times L_{p,i} I_{DM,i}}{a\sqrt{\varepsilon_r}}, & f \ge \dfrac{75}{a\sqrt{\varepsilon_r}} \text{ MHz} \end{cases}$$

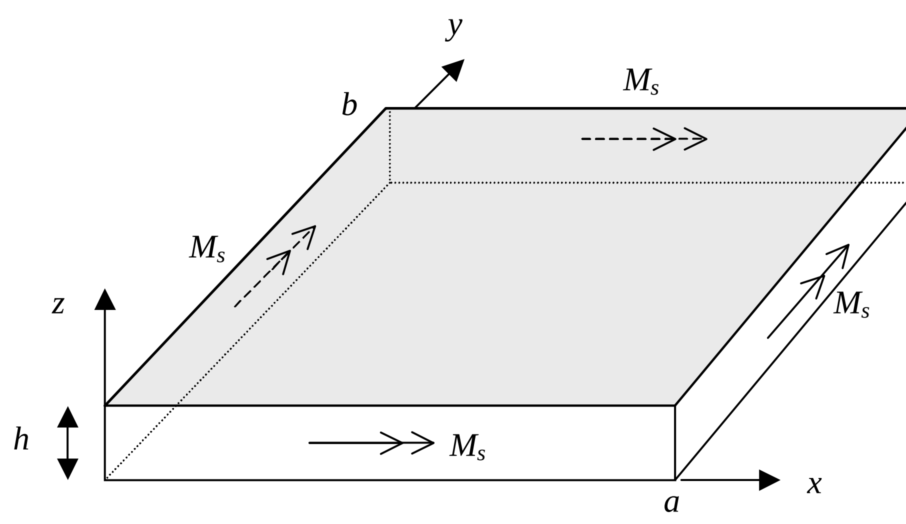
$$\left|E_{\text{cable-to-board}}\right| \approx 0.365 \times \frac{100 \times V_{ret}}{\sqrt{100^2 + 1/(\omega C_B)^2}}$$

D. M. Hockanson et. al., "Quantifying EMI resulting from finite-impedance reference planes," *IEEE Trans. on EMC*, vol. 39, no. 4, Nov. 1997, pp. 286-297.

H. Shim et. al., “Expert system algorithms for identifying radiated emission problems in printed circuit boards,” *Proc. of the 2004 IEEE International Symposium on EMC*, Santa Clara, CA, USA, Aug. 2004, pp. 57-62.

Power Bus Radiation Model

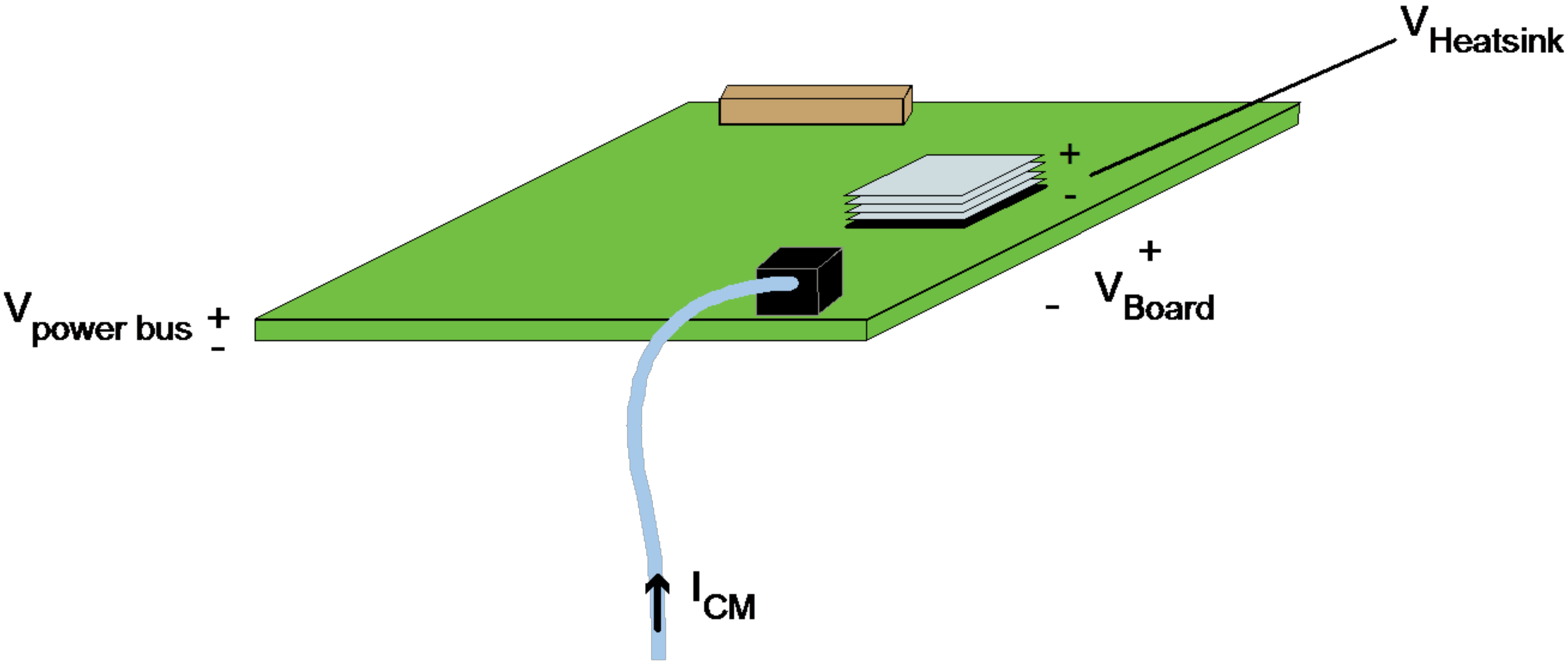
$$Q(f) = \left(\frac{1}{Q_d} + \frac{1}{Q_c} + \frac{1}{Q_{comp}} \right)^{-1}$$



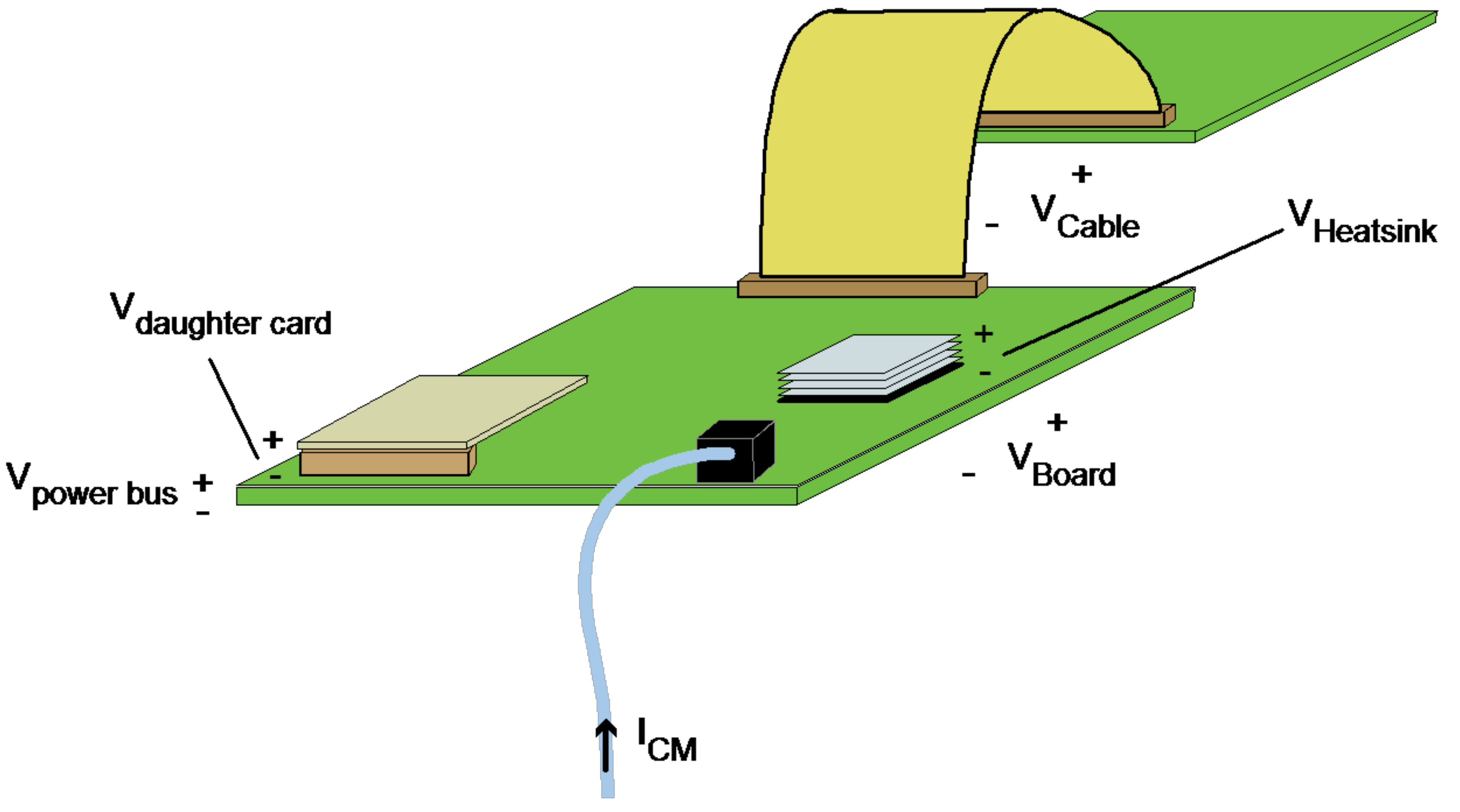
$$|E| = \frac{120 I_i}{\varepsilon_r \min(a,b)} \cdot \frac{h}{r} \cdot Q(f)$$

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.

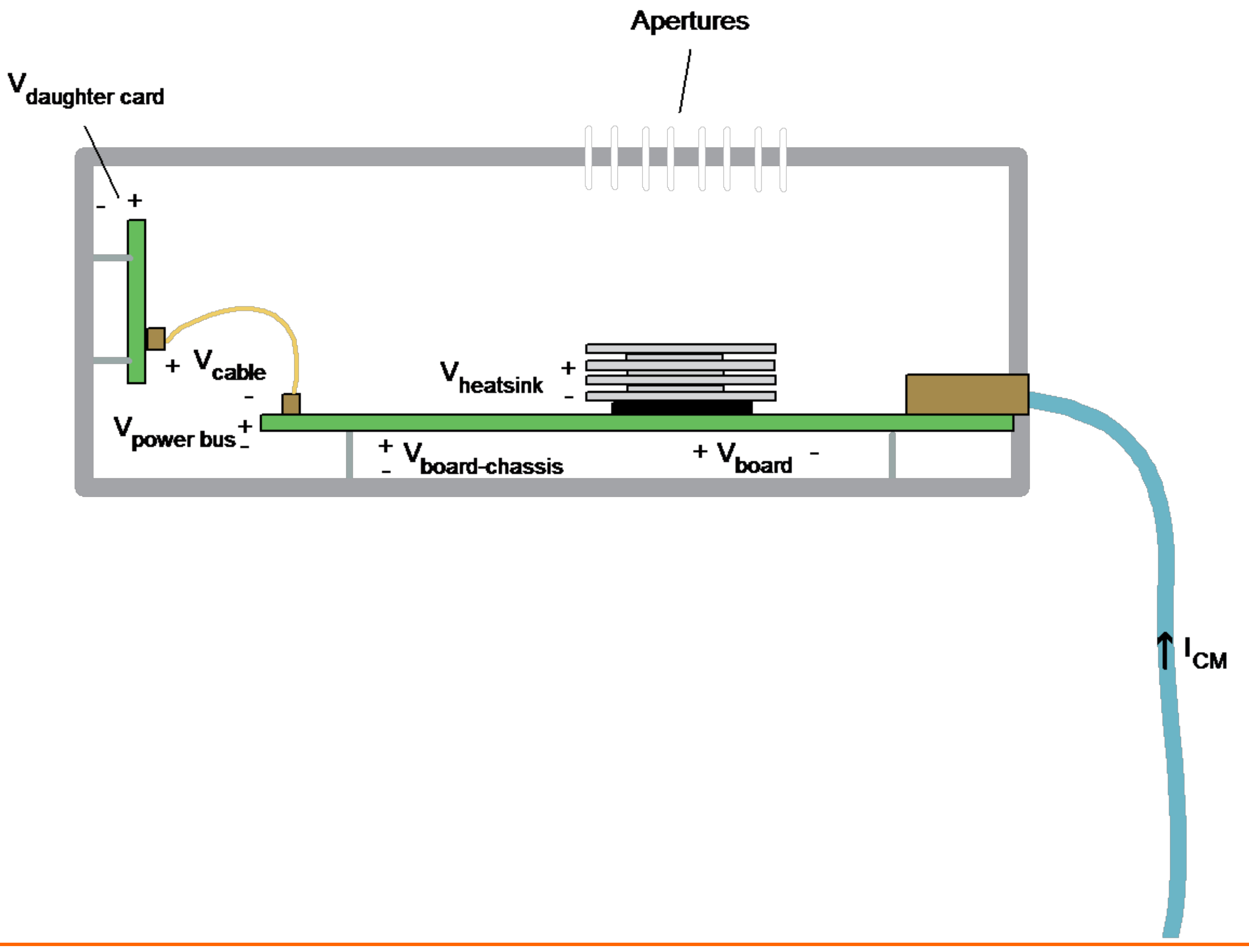
PCB Expert System Structure



System-Level Extensions



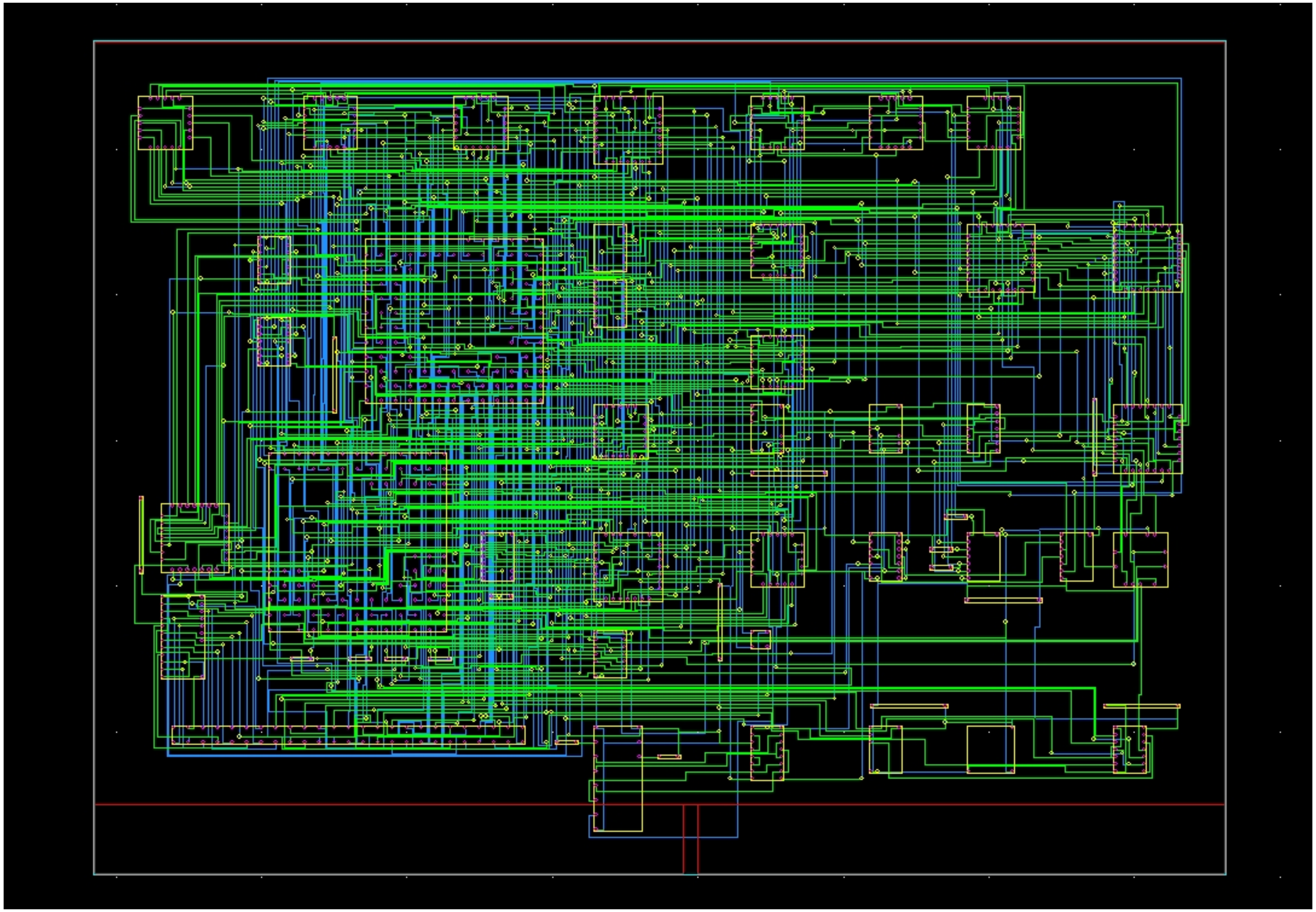
System-Level Extensions



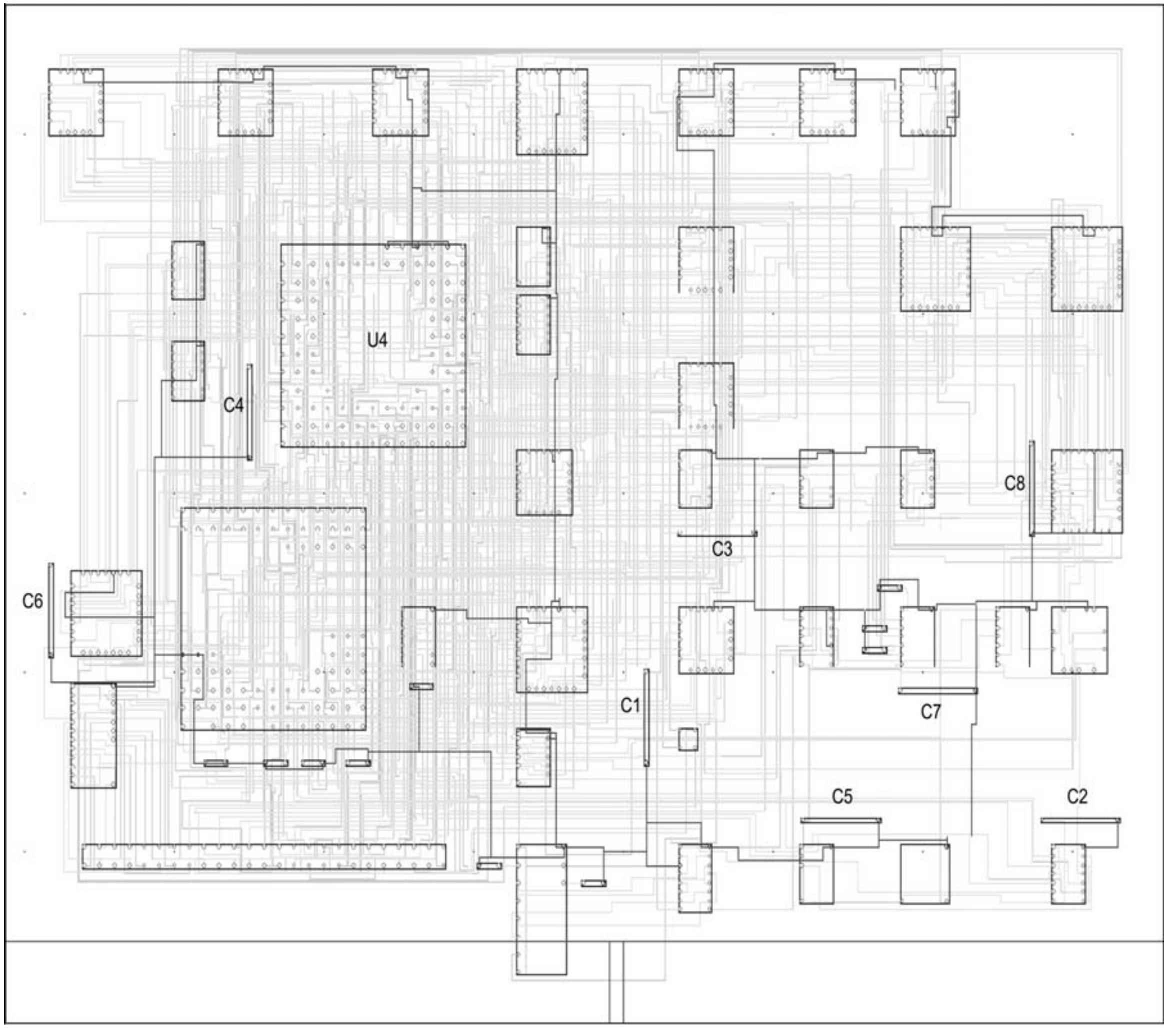
PCB Expert System Algorithms

- 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.

Validation of Software



Validation of Software

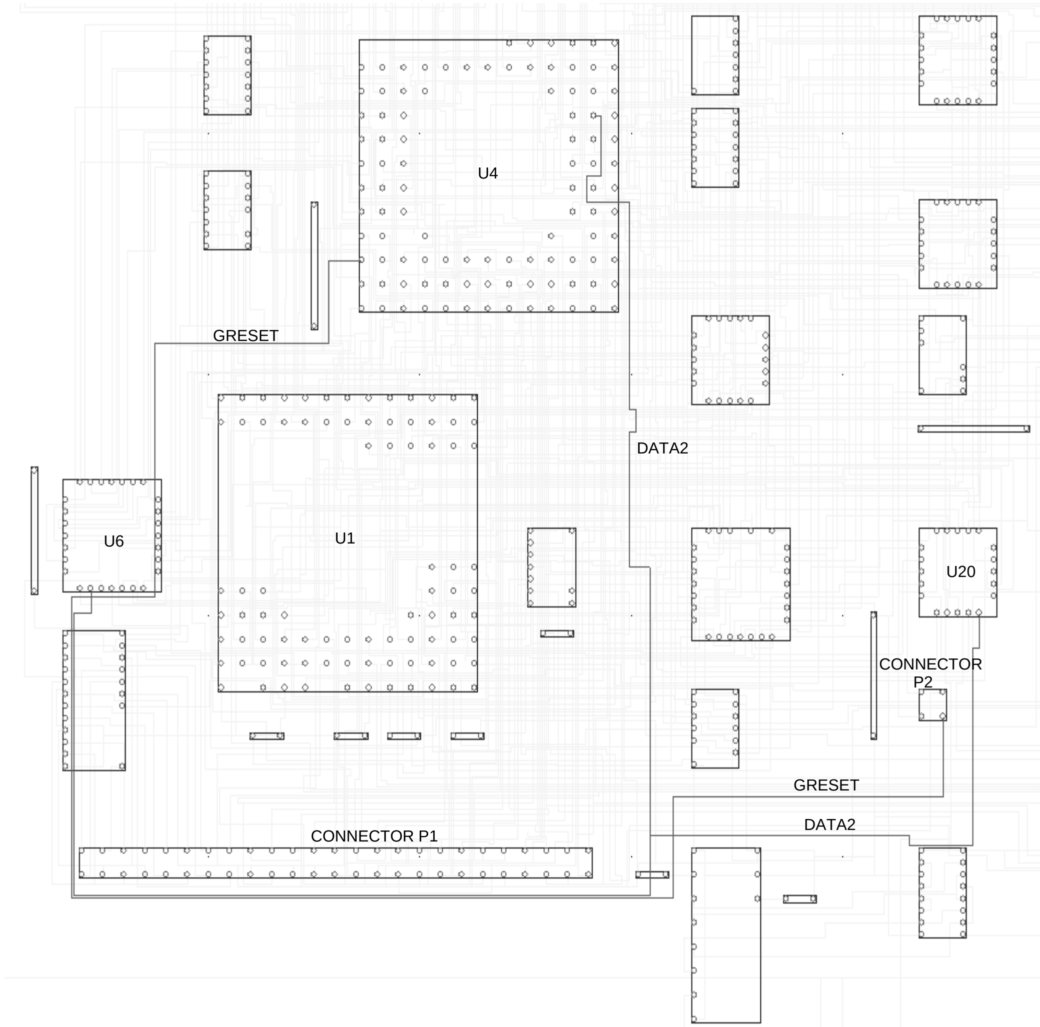


Validation of Software

Problem	Advice
UMR Signal Net Analysis - This net is coupled to I/O Net GRESET.	Re-Route this net or I/O Net GRESET

DRC	Net	Summary	TotaL_E/Frequency	DM_E/Frequency	ICM_E/Frequency	VCM_E/Frequency	Antennas
All	All	All	All	All	All	All	All
UMR Signal Net Analysis	DATA2	Edge Rate Too Fast	28.0 450.0	24.0 710.0	19.0 595.0	27.0 130.0	C--B
UMR Signal Net Analysis	DATA2	Coupled to I/O Net	28.0 450.0	24.0 710.0	19.0 595.0	27.0 130.0	C--B
UMR Signal Net Analysis	DATA2	Voltage driven common mode	28.0 450.0	24.0 710.0	19.0 595.0	27.0 130.0	C--B

Validation of Software



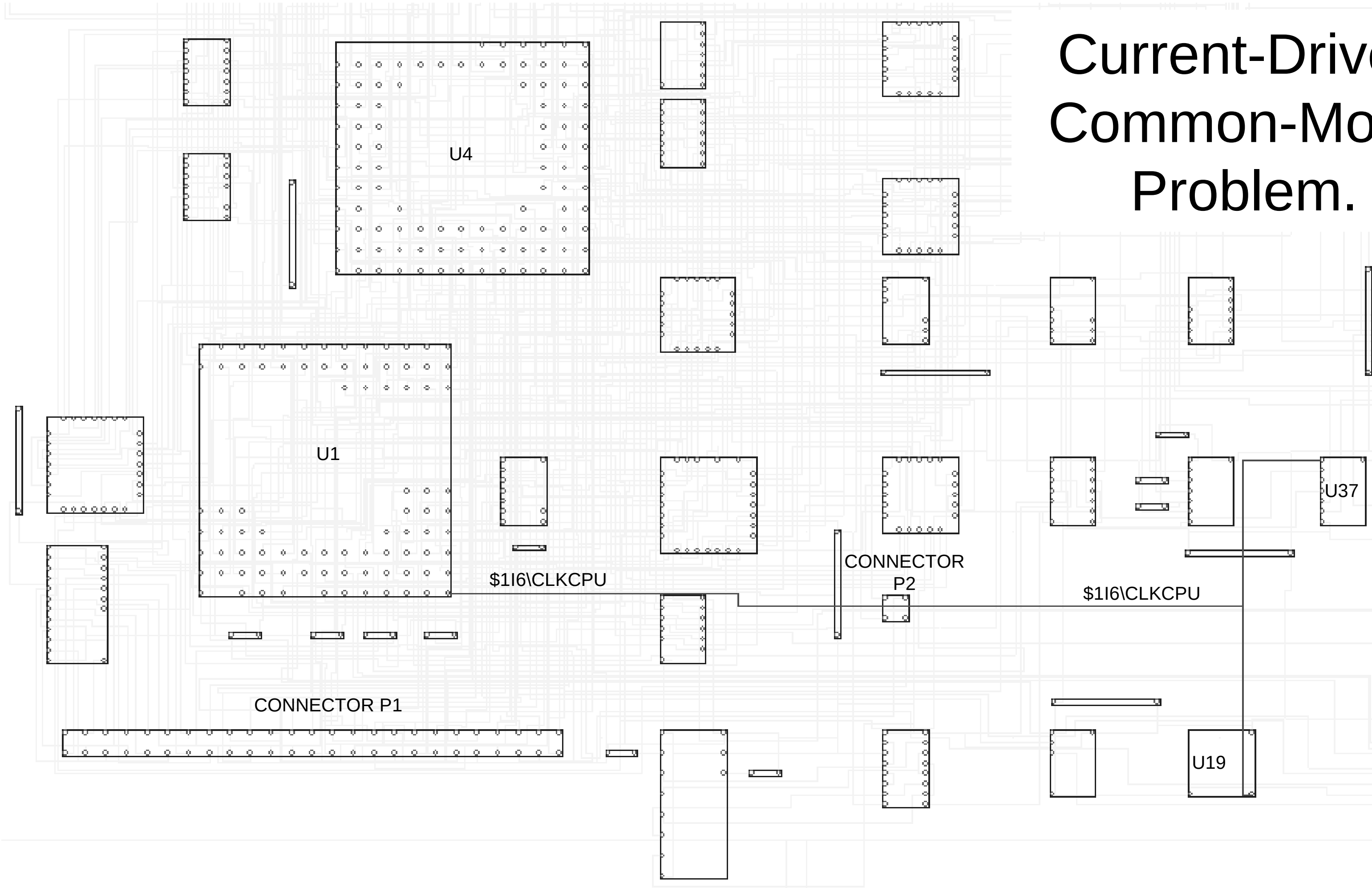
View of left half of board showing the problem nets.

Validation of Software

Problem	Advice
UMR Signal Net Analysis - The ground noise voltage drives Connector P2 against Connector P1.	Locate Connector P2 and Connector P1 closer to each other

DRC	Net	Summary	TotaL_E/Frequency	DM_E/Frequency	ICM_E/Frequency	VCM_E/Frequency	Antennas
All	All	All	All	All	All	All	All
UMR Signal Net Analysis	$1I6\CLKCPU	Current driven common mode	52.0 650.0	50.0 750.0	49.0 450.0	-99.0 50.0	C--C
UMR Signal Net Analysis	$1I6\CLKCPU	Edge Rate Too Fast	52.0 650.0	50.0 750.0	49.0 450.0	-99.0 50.0	C--C
UMR Signal Net Analysis	$1I6\CLKCPU	Too Much Surface Route	52.0 650.0	50.0 750.0	49.0 450.0	-99.0 50.0	C--C

Validation of Software



Current-Driven Common-Mode Problem.

Maximum Allowable Power Bus Voltage

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

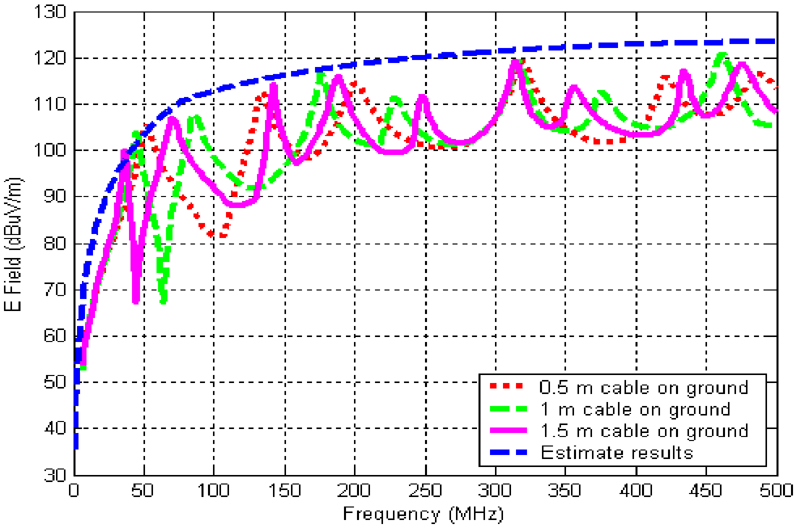
$$cable\_rad\_factor \equiv \begin{cases} \sin\left(2\pi l_{cable} / \lambda\right) & when\ l_{cable} \le \frac{\lambda}{4} \\ 1.0 & otherwise \end{cases}$$

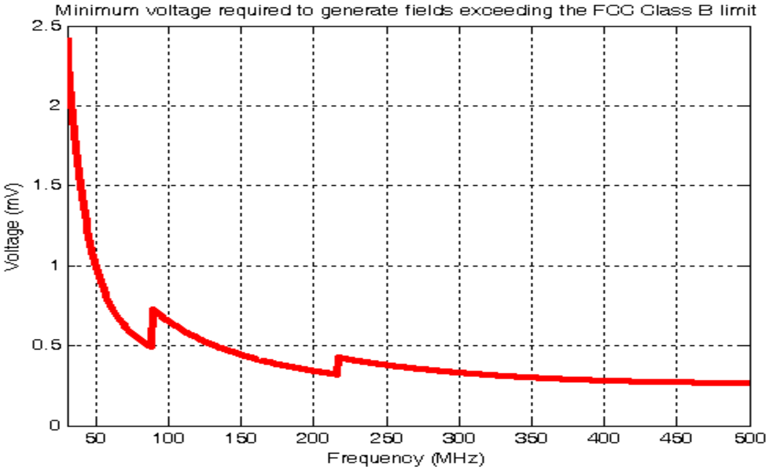
$$board\_size\_factor \equiv \begin{cases} \sin\left(2\pi l_{board} / \lambda\right) & when\ l_{board} \le \frac{\lambda}{4} \\ 1.0 & otherwise \end{cases}$$

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

Expert System Field Calculation Performed in Reverse

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





Expert System Tools Are Not Design Rule Checkers!

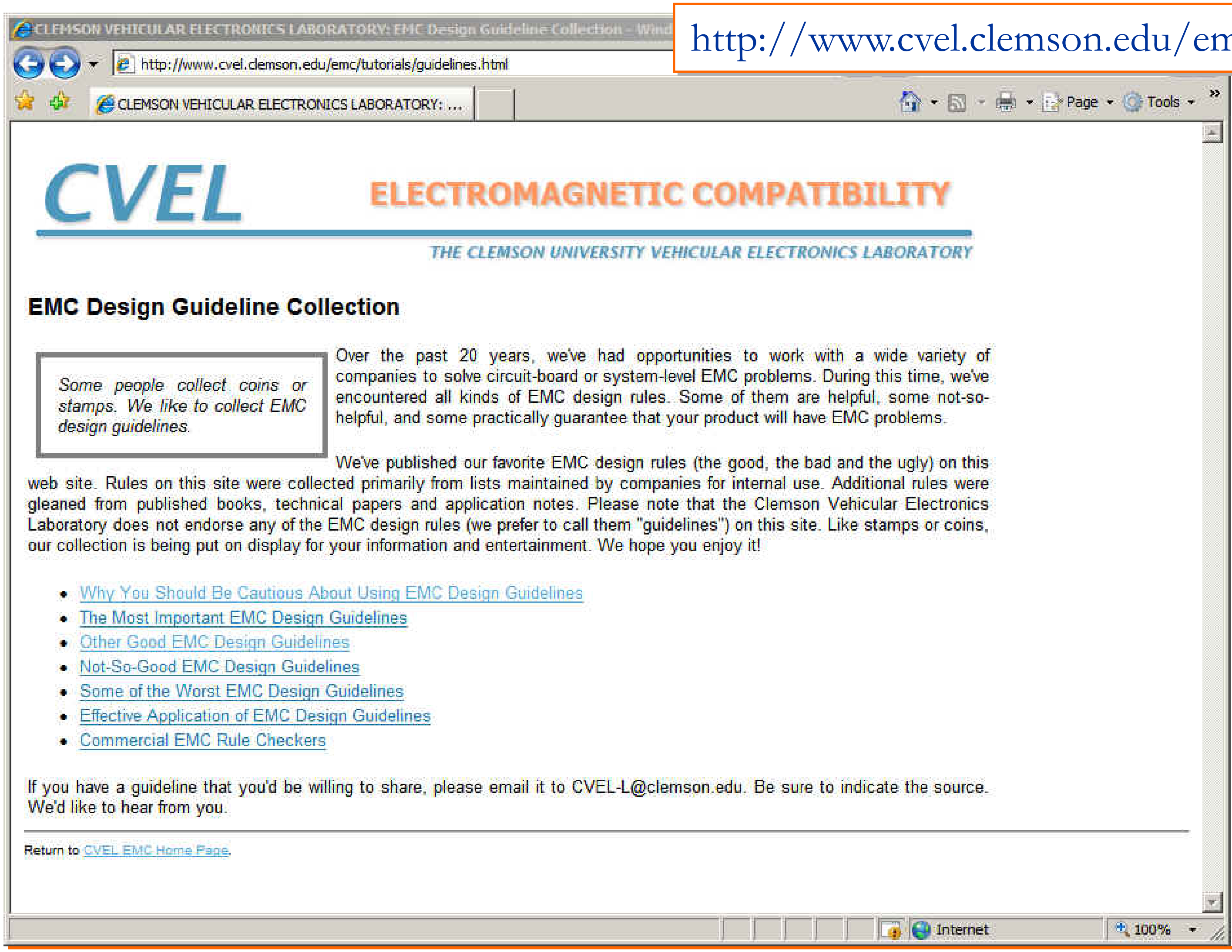
Design Rule Checkers

Scan a board layout looking for design rule violations.

Advantages –	Easier to understand what the software is doing Easier to use.
Disadvantages –	Design rules don't apply in all situations Higher board cost to meet unnecessary design rules Will not detect problems that don't violate a pre-defined rule

EMC Design Guideline Collection

http://www.cvel.clemson.edu/emc/



EMC Design Guideline Collection

Some people collect coins or stamps. We like to collect EMC design guidelines.

Over the past 20 years, we've had opportunities to work with a wide variety of companies to solve circuit-board or system-level EMC problems. During this time, we've encountered all kinds of EMC design rules. Some of them are helpful, some not-so-helpful, and some practically guarantee that your product will have EMC problems.

We've published our favorite EMC design rules (the good, the bad and the ugly) on this web site. Rules on this site were collected primarily from lists maintained by companies for internal use. Additional rules were gleaned from published books, technical papers and application notes. Please note that the Clemson Vehicular Electronics Laboratory does not endorse any of the EMC design rules (we prefer to call them "guidelines") on this site. Like stamps or coins, our collection is being put on display for your information and entertainment. We hope you enjoy it!

- Why You Should Be Cautious About Using EMC Design Guidelines
- The Most Important EMC Design Guidelines
- Other Good EMC Design Guidelines
- Not-So-Good EMC Design Guidelines
- Some of the Worst EMC Design Guidelines
- Effective Application of EMC Design Guidelines
- Commercial EMC Rule Checkers

If you have a guideline that you'd be willing to share, please email it to CVEL-L@clemson.edu. Be sure to indicate the source. We'd like to hear from you.

Return to CVEL EMC Home Page.

Conclusion

Four measurement and analysis technologies that were relatively unknown just a few years ago are becoming essential tools for EMC analysis.

- Near-Field Scanners
- Time/Frequency Domain Analyzers
- Mini-TEM Cells
- Expert System Techniques