Prediction and measurement of induced voltages inside complicated enclosures using wave-chaos

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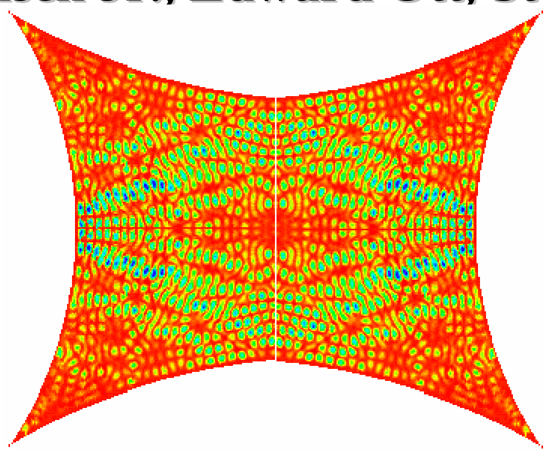


Project funded by USAF-MURI and DURIP programs

Motivation :- The "Four Famous" Questions:

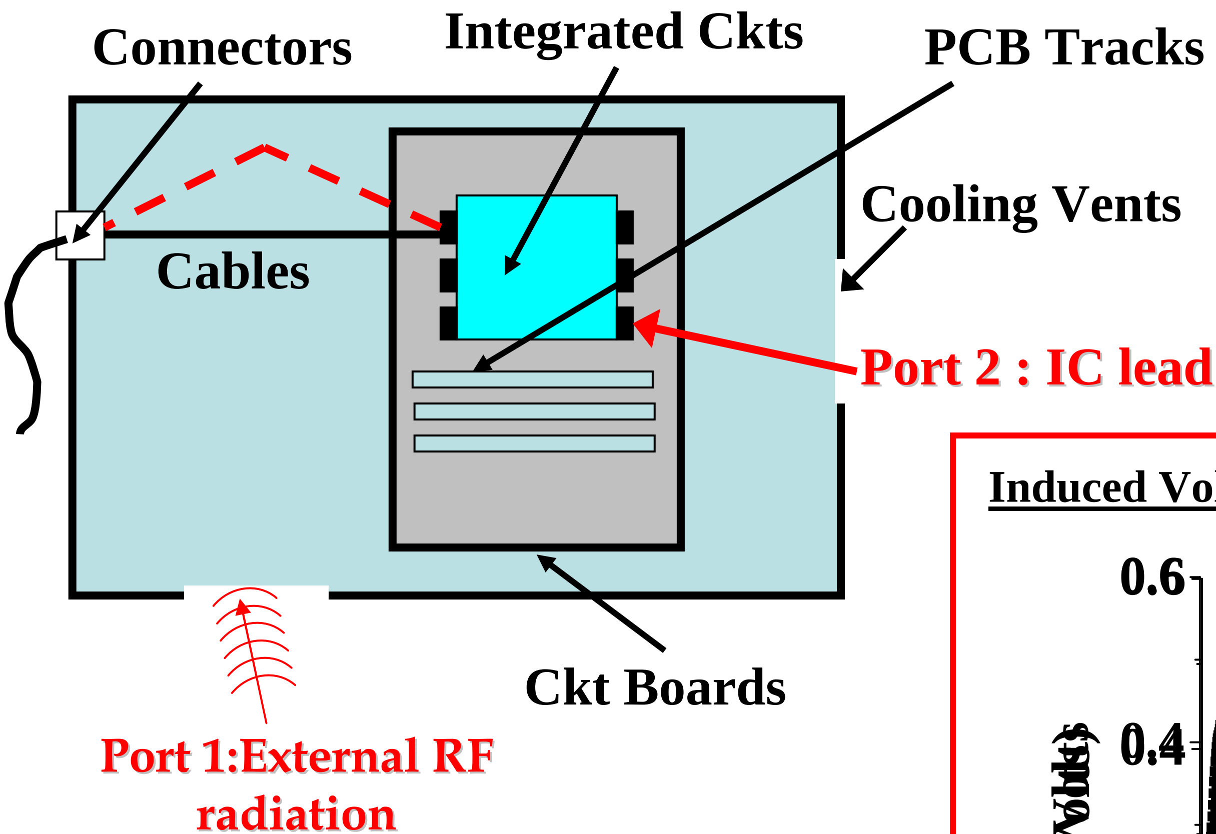
- Is there some <u>fast</u>, <u>simple</u> and <u>accurate</u> way to predict the voltages induced at specific points within a complicated metallic enclosure (e.g. computer-box) due to external radiation?

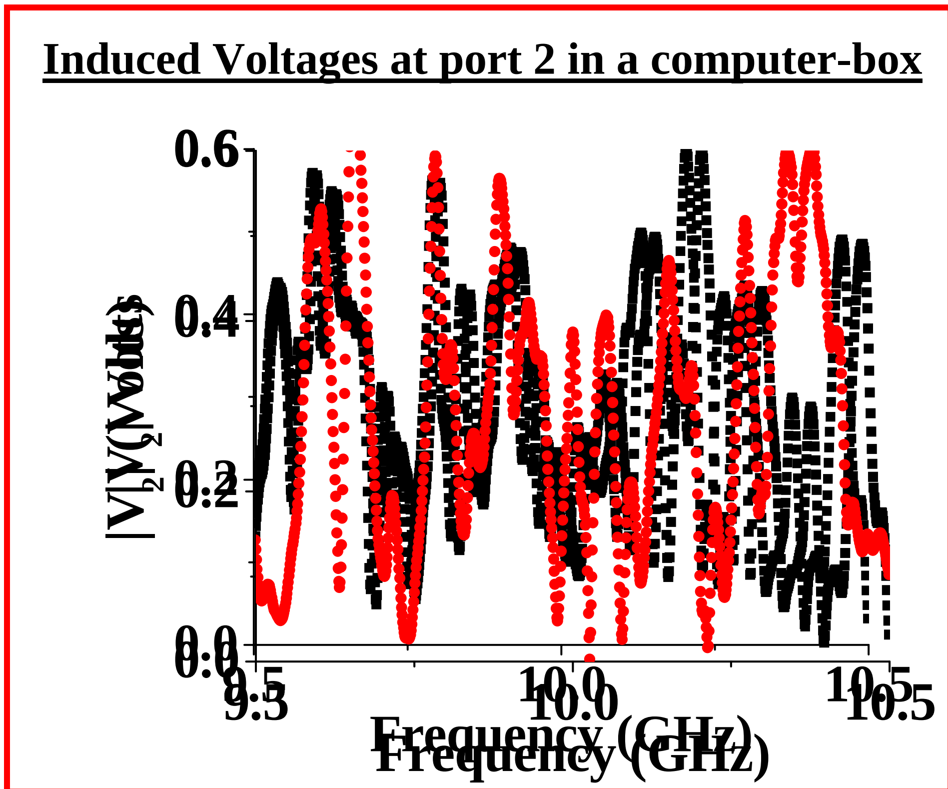
- What factors determine the nature of these induced voltages ?

- Is there some "optimally shaped" wave-form for the external radiation, for which the electronics within the enclosure is most susceptible ?

- Is it possible to engineer an enclosure to make it resistant to HPM attack ?

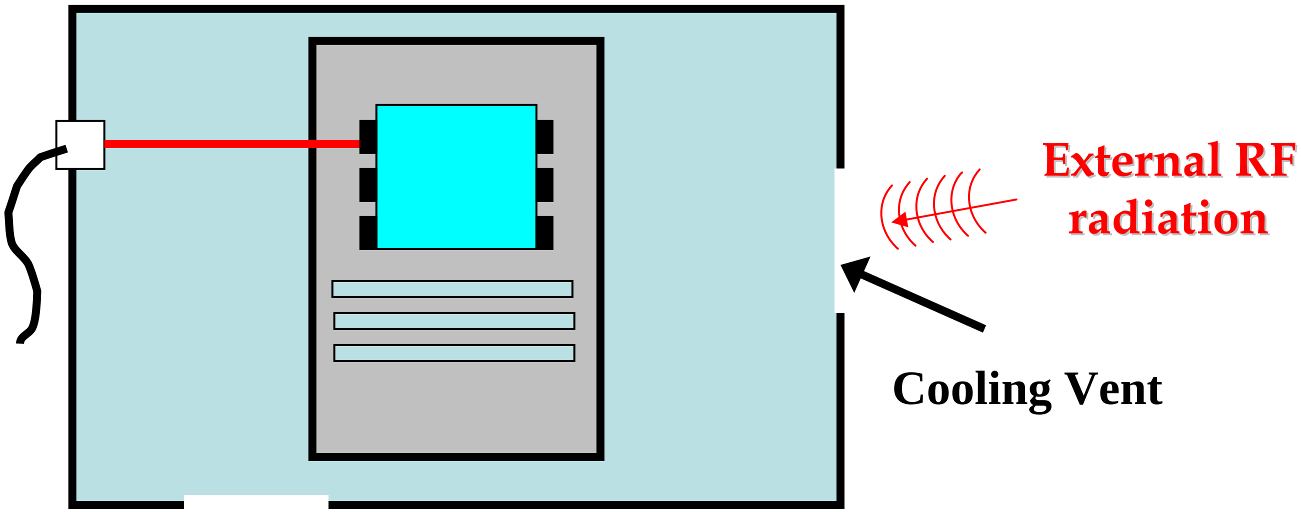
1. Can we predict the voltages induced at specific locations in a computer-box due to a external RF radiation?



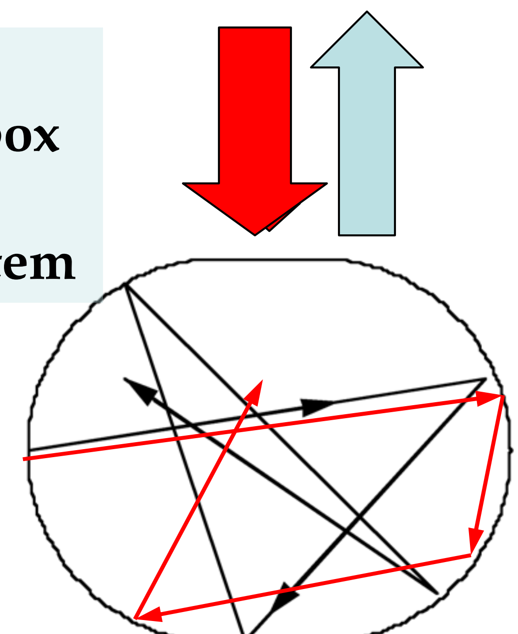


- Extreme sensitivity to system details makes numerical EM solutions based on Maxwell's equations impractical.
- Use Statistical Description !!

Our outlook to this problem:- Formulating the Random Coupling Model



Treat the computer-box as a wave-chaotic system



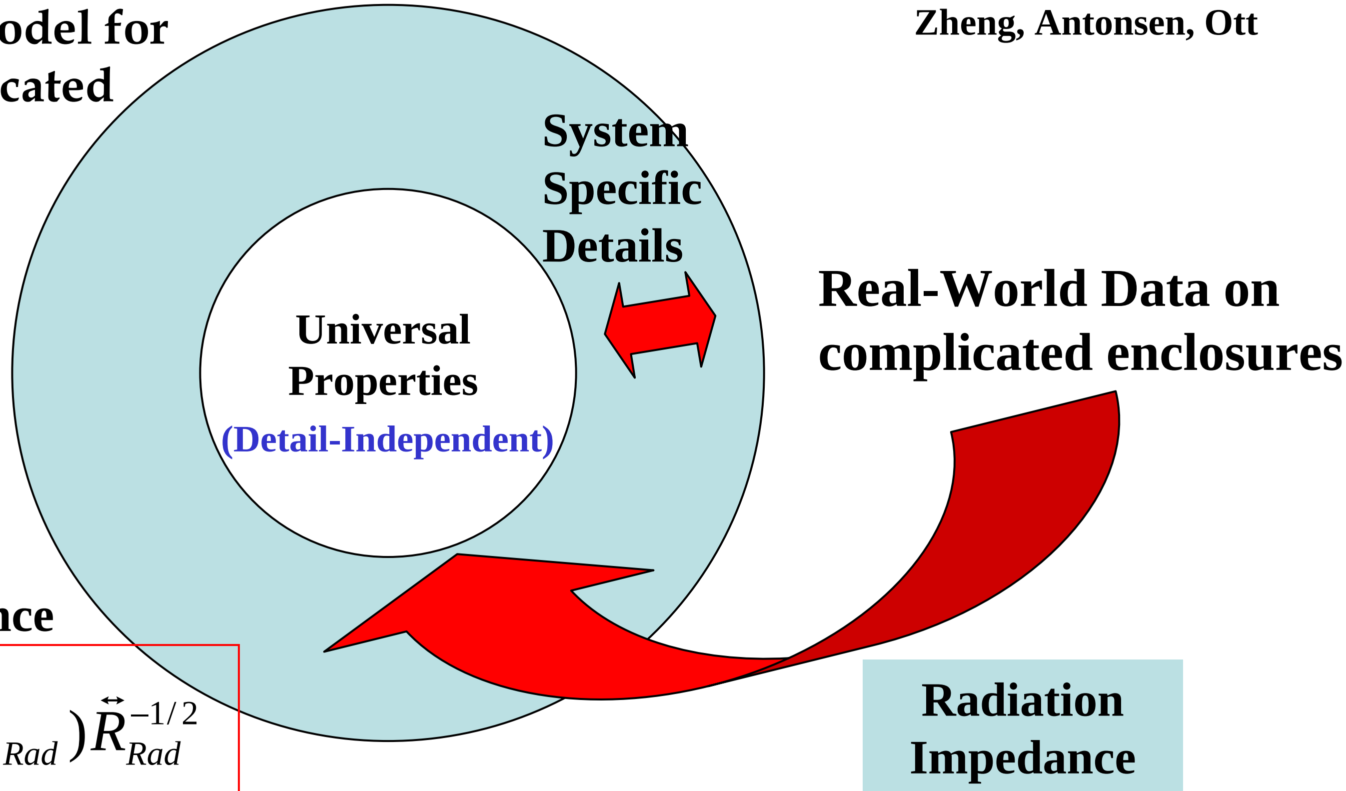
- Use <u>Universal</u> Properties of Wave Chaotic Systems to predict induced voltage <u>distributions</u> at specific locations inside the enclosure.

Random Coupling Model (RCM)- "In a Nut Shell"

Electromagnetics, **26**, 3 (2006).
Electromagnetics, **26**, 37 (2006).

Zheng, Antonsen, Ott

- **RCM: Stochastic model for impedance of complicated enclosures**



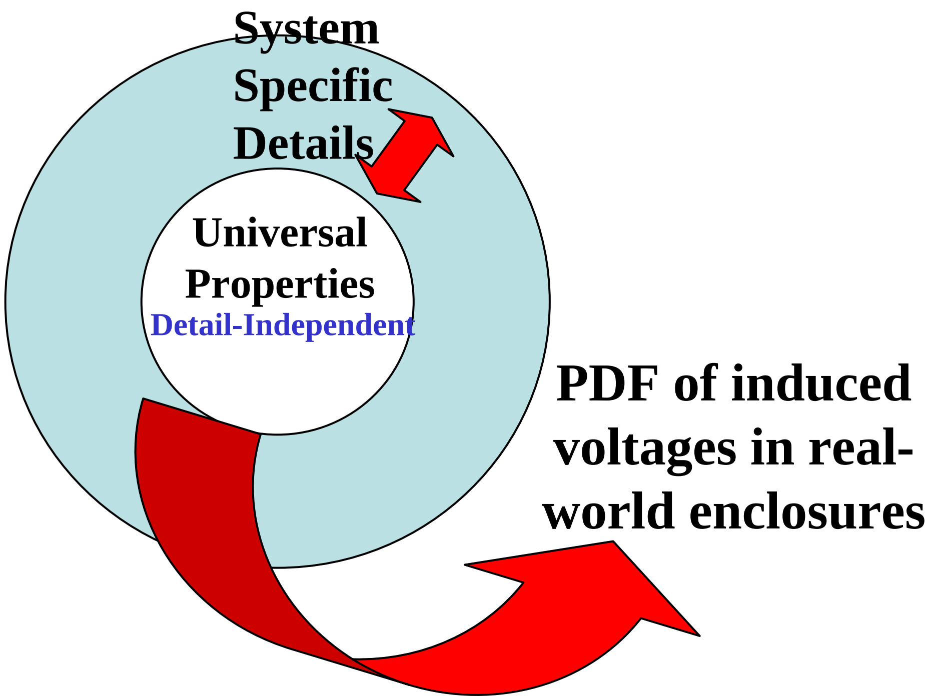
Normalized impedance

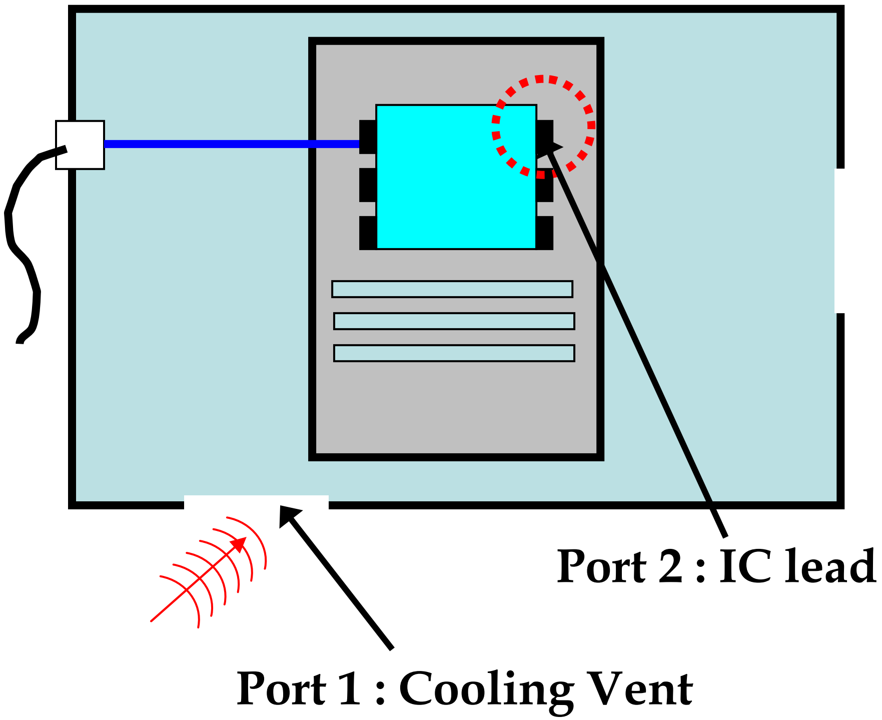
$$\overleftrightarrow{z} = \overleftrightarrow{R}_{Rad}^{-1/2}(\overleftrightarrow{Z}_{Cavity} - j\overleftrightarrow{X}_{Rad})\overleftrightarrow{R}_{Rad}^{-1/2}$$

- **Statistical Description of normalized impedance depends <u>only</u> on a dimensionless "loss-parameter"**

$$\alpha = \frac{k^2}{\Delta k_n^2 Q}$$

Implications of RCM to Real-world 3D cavities





2. What minimum information do I need to predict the range of voltages on port 2 because of 'x' watts of power injected into port 1?

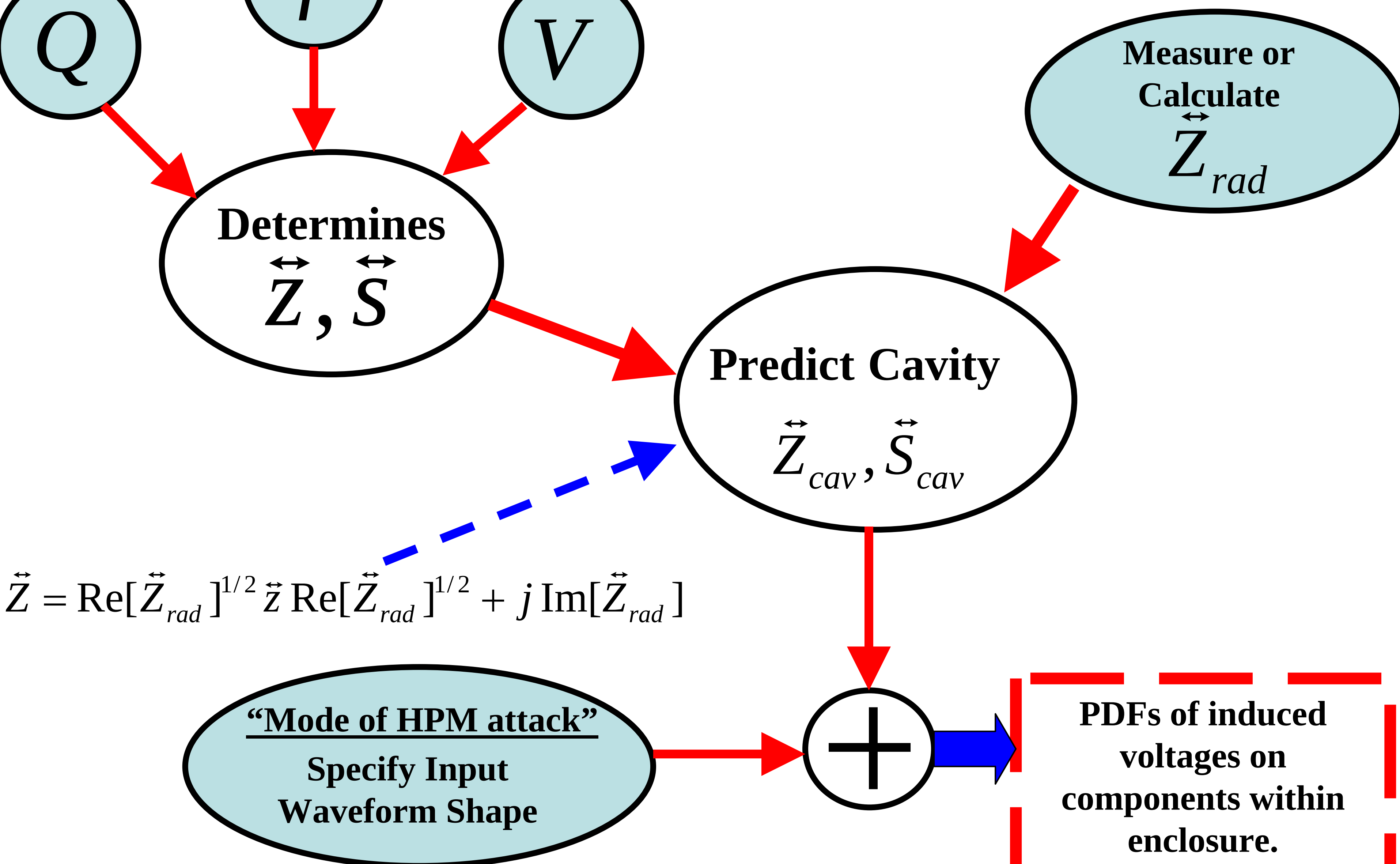
Minimum Information to predict PDF of induced voltages at port 2:

Frequency, Volume
Losses } α

Radiation impedance of the ports
Radiated power Wave-form from port 1

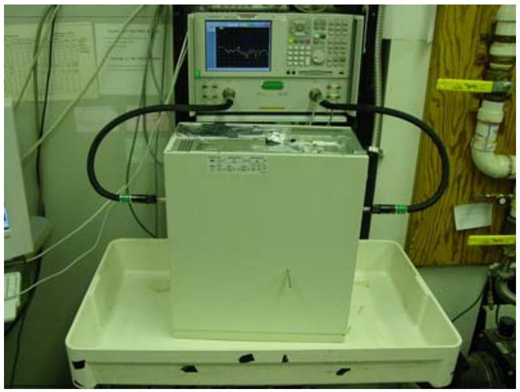
} Determine the shape and scales of the induced voltage PDFs

“Terrapin algorithm” for *a priori* prediction of Induced Voltage PDFs

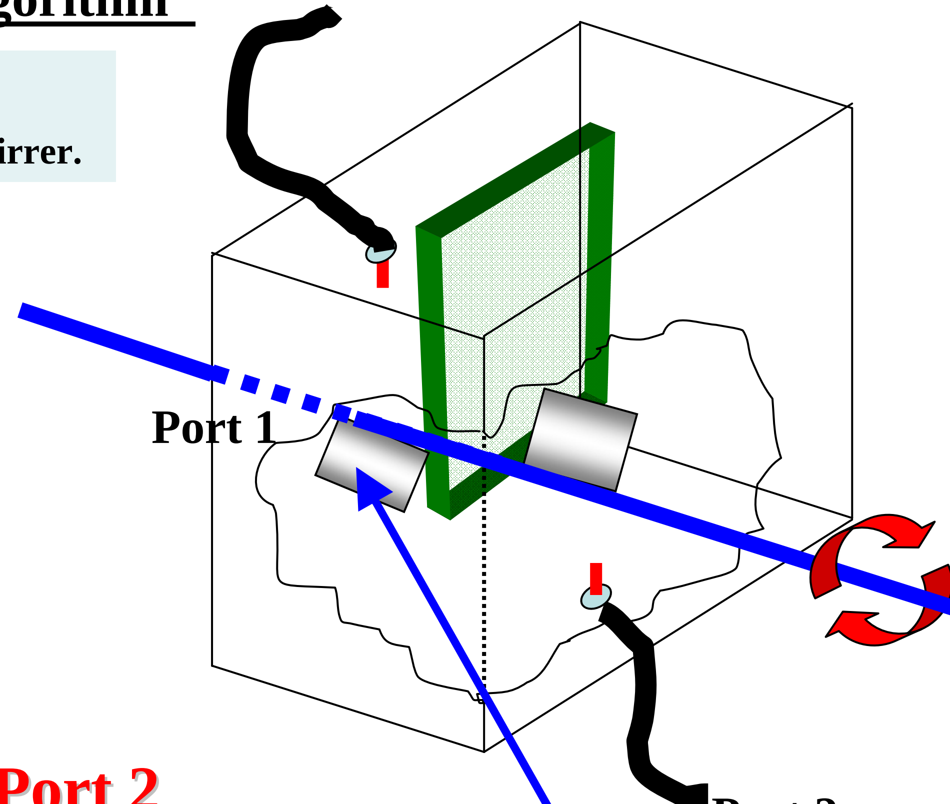


"3D Real-World" Test of the Random Coupling Model and the "Terrapin Algorithm"

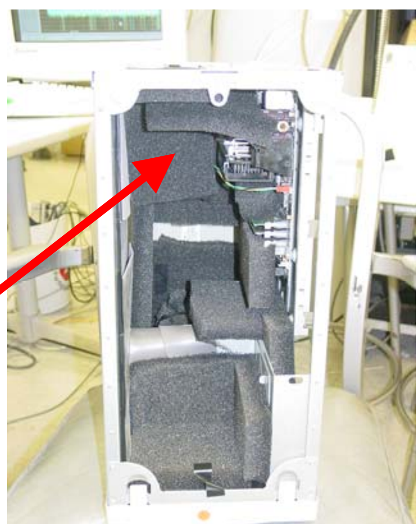
- **Frequency Range: 2GHz to 20 GHz (λ<<L)**
- **Ensemble Averaging over ~20 positions of the mode-stirrer.**



Experimental Setup [Cavity Case]

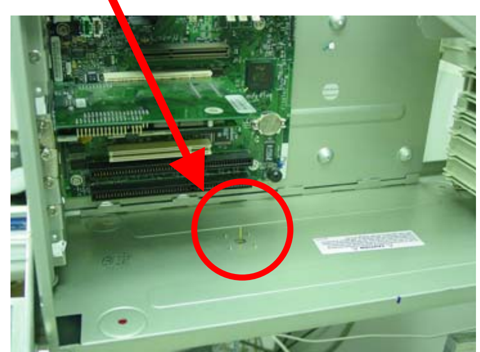


Microwave absorber

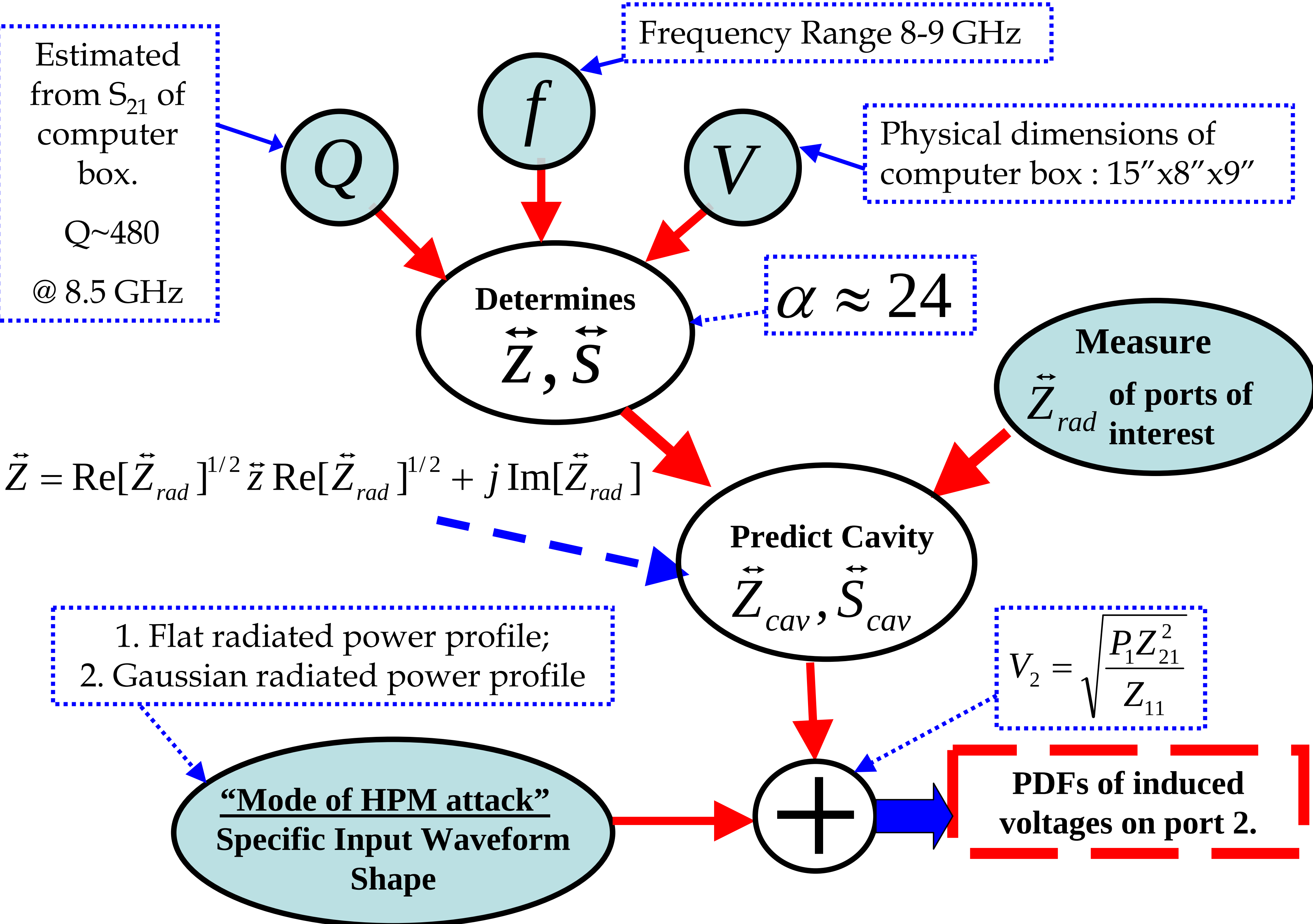


Port Radiation Measurement Setup

Port 2

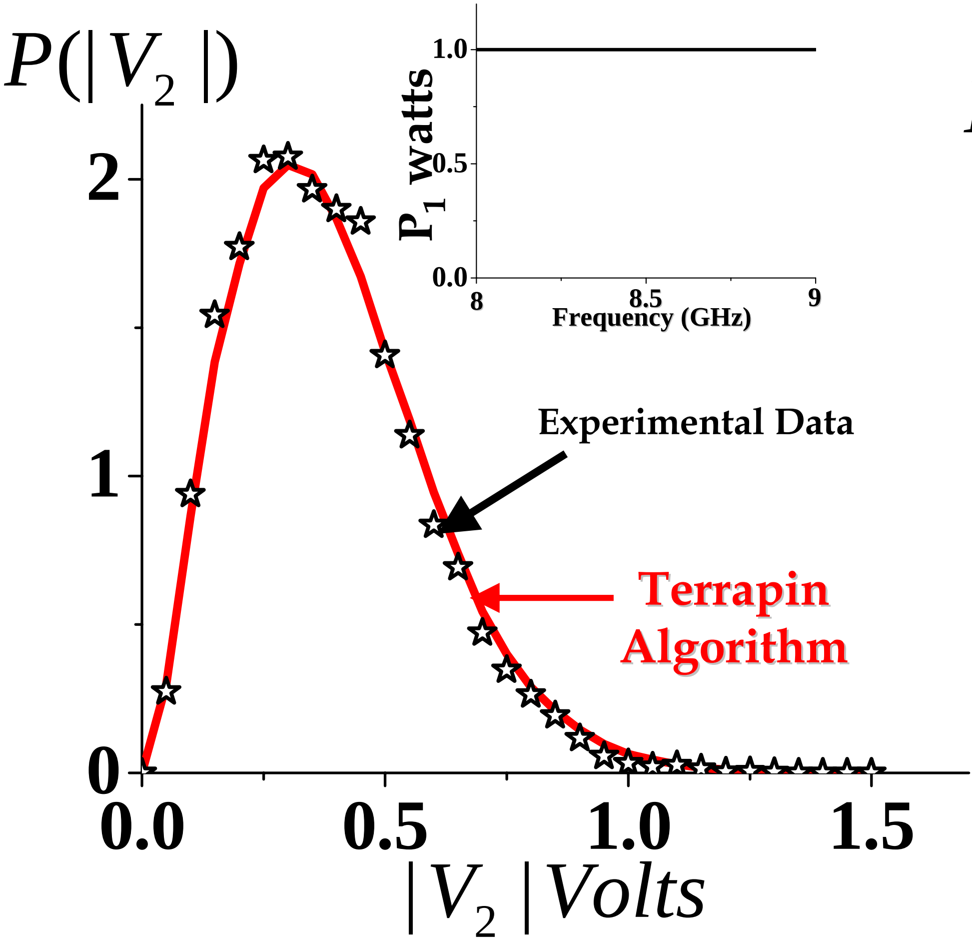


Tutorial: Using the "Terrapin Algorithm" on the computer-box:

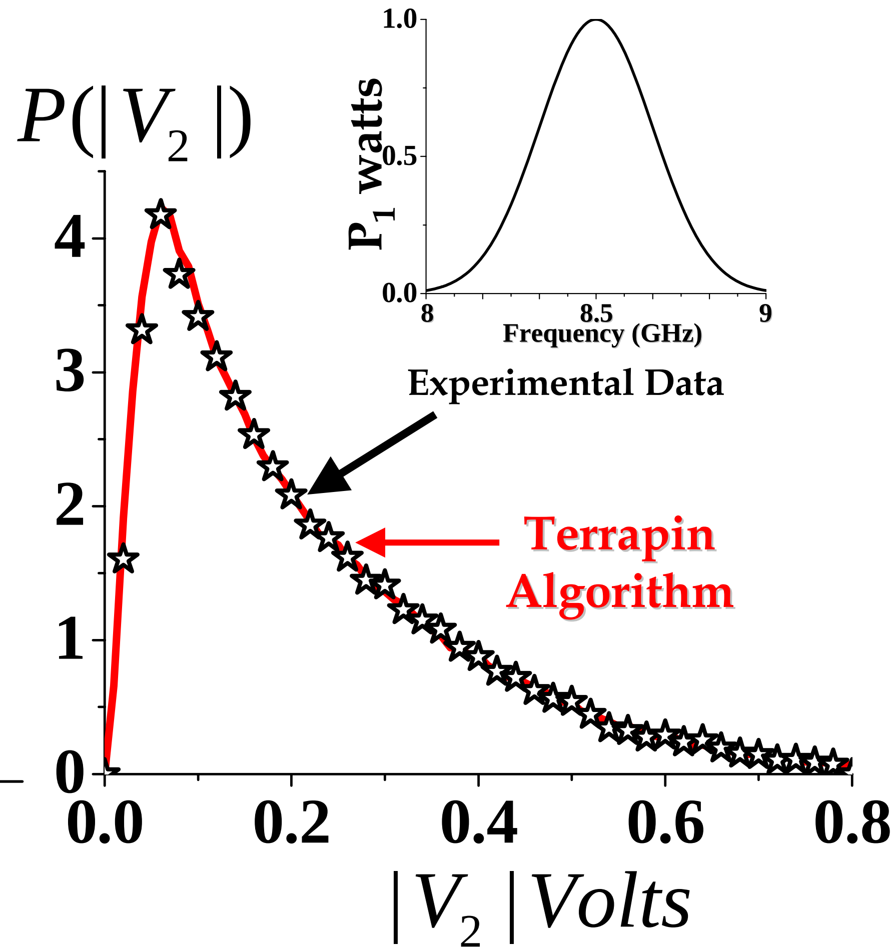


PDF of induced voltages on port 2 of computer-box for different power profiles radiated from Port 1

Flat power-profile radiated from port 1

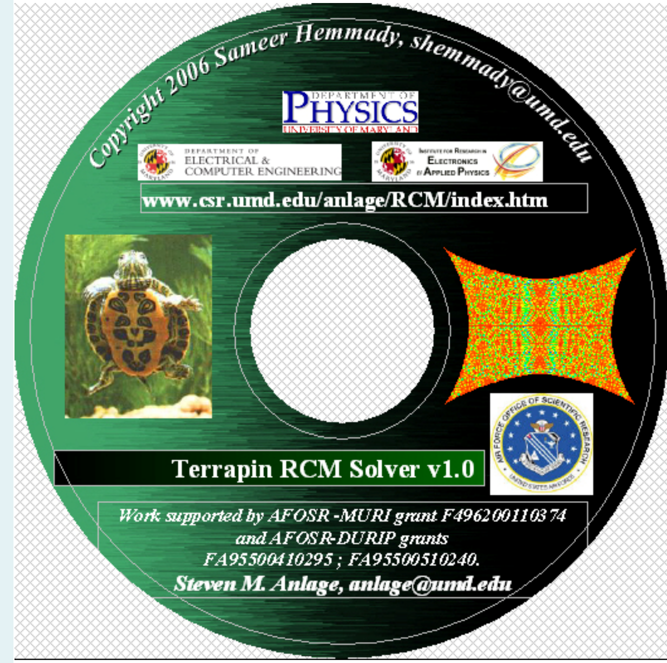


Gaussian-shaped power-profile radiated from port 1

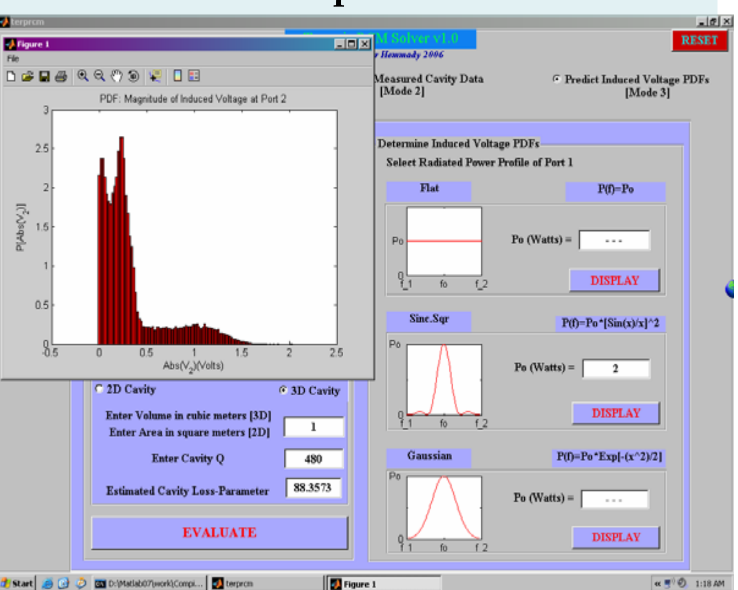


For the End-User : Terrapin RCM Solver v1.0

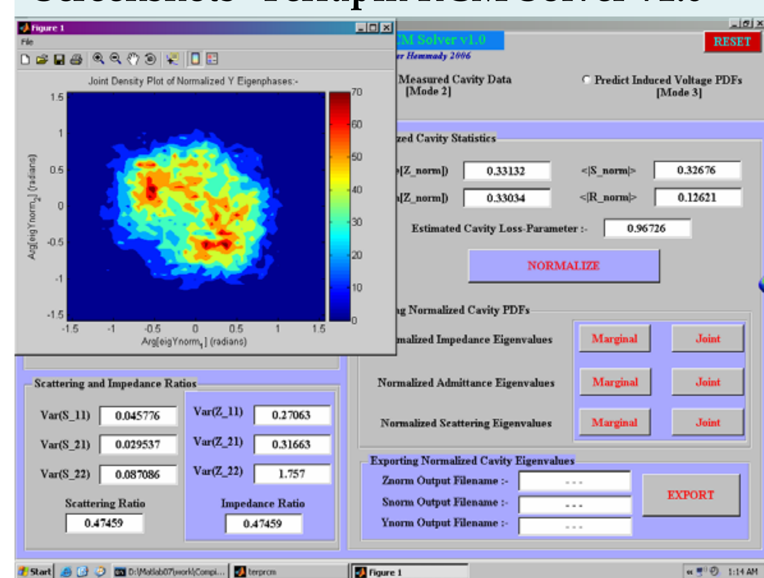
- User-friendly, stand-alone, GUI code using RCM
- Current Capabilities- **Typical run-time ~ 5 to 15 mins**
  - Predict induced voltages in real-world, complicated 2D/3D enclosures with minimum of user-inputs
  - Determine universal fluctuations in user-supplied data on real-world 2D/3D enclosures
  - Generate universal PDFs for user-specified α
- **www.csr.umd.edu/anlage/RCM/index.htm**



Screenshots- Terrapin RCM Solver v1.0



Screenshots- Terrapin RCM Solver v1.0



Conclusions: Extensively validated RCM for 2D/3D cavities. IT WORKS!!

• Is there some fast, simple, accurate way to determine *a priori* the voltages induced at specific points within a complicated metallic enclosure (computer-box) due to external radiation?

Use a Statistical Description (RCM).

www.csr.umd.edu/anlage/RCM/index.htm

• What factors determine the nature of these induced voltages ?

Frequency, Volume of Enclosure, Typical Q of Enclosure,

Radiation Impedance of ports, shape of external radiation wave-form

• Is there some "optimally shaped" waveform for the external radiation, for which the internal electronics is most susceptible ?

See talks by Dr. Steven Anlage ; Dr. John Rodgers to follow…..

"Terrapin Algorithm" : quick insight into induced voltages for given excitation

• Is it possible to engineer an enclosure to make it resistant to HPM attack ?

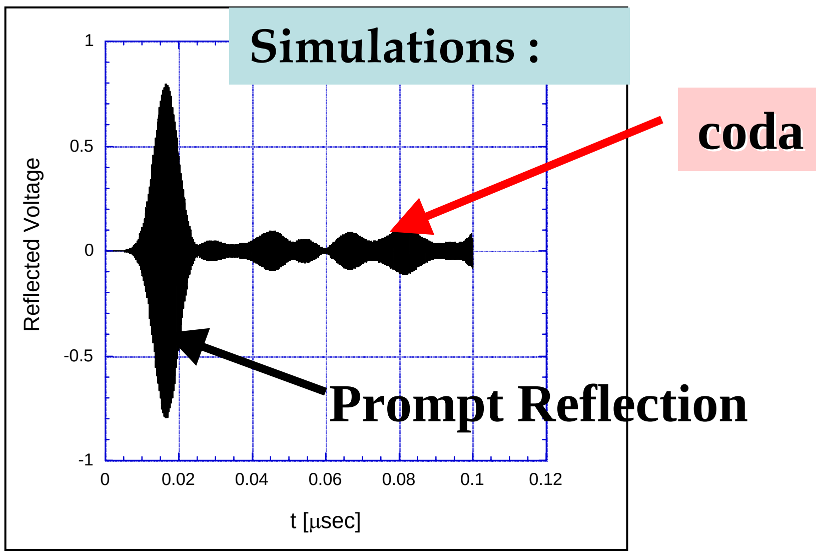
Higher α => more resistant.

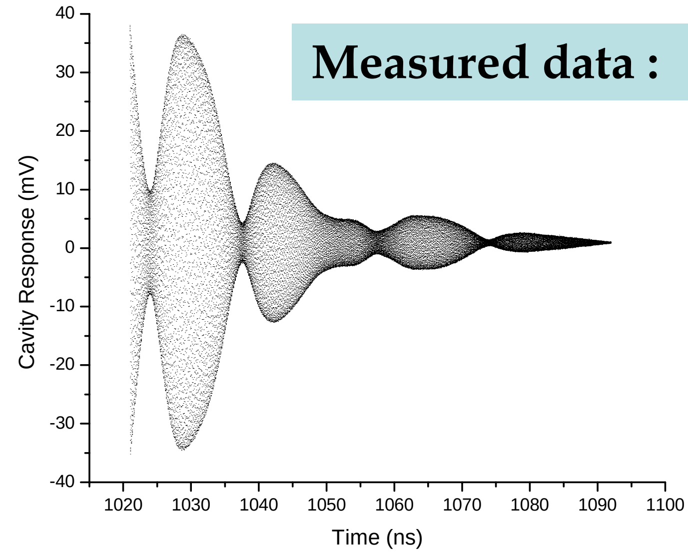
Radiation Impedance Engineering

Non-Reciprocal Media (Ferrites)

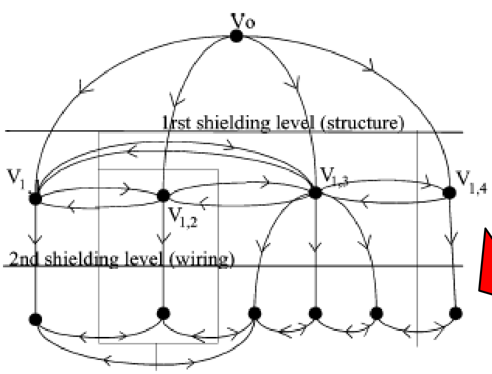
Future Work:

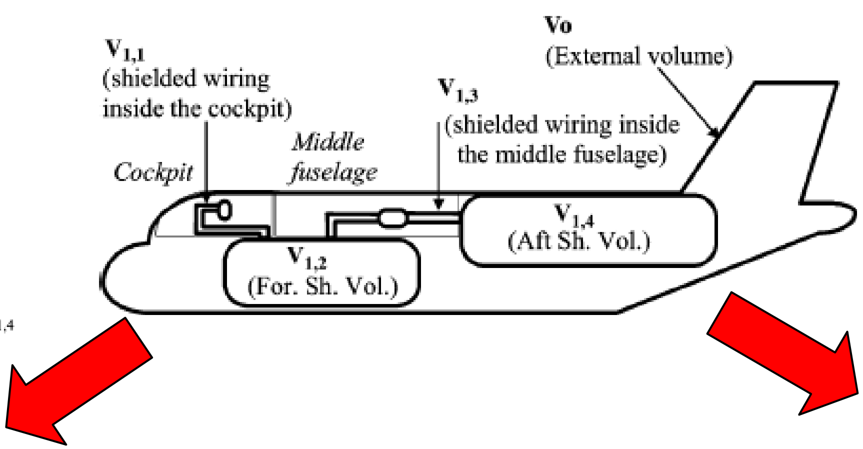
- **Time Domain RCM theory / Experiments: (Hart, Bertrand, Antonsen, Ott, Anlage)**

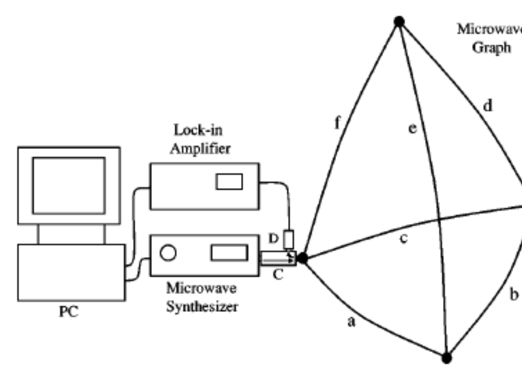




- **Quantum Graphs and its applications to EMC topology:**







<u>Publication List:</u> www.csr.umd.edu/anlage/RCM/index.htm

1. <u>S.Hemmady</u>, *et. al*. "Experimental test of Universal Conductance Fluctuations by means of Wave-Chaotic Microwave Cavities"- **cond-mat/0606650 (submitted to Phys. Rev. B-RC).**
2. <u>S.Hemmady</u>, *et. al*. "Universal Impedance, Admittance and Scattering Fluctuations of wave-chaotic systems"- **cond-mat/0501231 (submitted to Phys. Rev. E).**
3. <u>S.Hemmady</u>, *et. al*. "Universal Impedance Fluctuations in Wave-Chaotic Systems" **Phys. Rev. Lett. <u>94</u>, 014102 (2005).**
4. <u>S.Hemmady</u>, *et. al*. "Universal Statistics of the Scattering Coefficient of Chaotic Microwave Cavities"- **Phys. Rev. E. <u>71</u>, 056215 (2005).**
5. <u>S.Hemmady</u>, *et. al*. "Aspects of the Scattering and Impedance Properties of Chaotic Microwave Cavities"- **Acta Physica Polonica A <u>109</u>, 65 (2006).**
6. <u>X. Zheng</u>, *et. al*. " Characterization of Fluctuations of Impedance and Scattering Matrices in Wave-Chaotic Systems"- **Phys. Rev. E. <u>73</u>, 046208 (2006).**
7. <u>T.M Antonsen</u> , *et. al*. "Statistical Model for Scattering Matrices of Open Cavities" **URSI EMTS 2004 825-827 (2004).**

<u>Random Coupling Model Publications:</u>

1. X. Zheng, T.M.Antonsen, and E. Ott –Electromagnetics, **<u>26</u>**, 3 (2006).
2. X. Zheng, T.M.Antonsen, and E. Ott –Electromagnetics, **<u>26</u>**, 37 (2006).

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