The Science of Electronics in Extreme Electromagnetic Environments I – Enclosure Coupling

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***Abstract*—This AFOSR Center of Excellence established in 2015 has been studying the science of electronics in extreme electromagnetic environments. This presentation focuses on advancing computational electromagnetic techniques for statistical and deterministic extreme electromagnetic interference (EEMI) modeling; on EEMI interactions within wave chaotic enclosures; and with EEMI interactions in networked complex enclosures. A companion presentation discusses EEMI effects on elemental CMOS devices, electro-optic devices, mathematical frameworks for modeling EEMI effects on digital logic circuits, and modeling EEMI effects on software execution.**

I. Introduction

The susceptibility and vulnerability of complex digital electronic systems to extreme electromagnetic interference (EEMI) from unintentional and intentional sources is a growing concern with the Electromagnetic Compatibility (EMC) test community. One important aspect of this problem is how EEMI couples into a facility and other enclosures, such as electronic casing within the facility. Taking the contextual example of a generic Personal Computer (PC), as a complex digital electronic system subjected to EEMI, Figure 1 highlights the scope of our research endeavor under the AFOSR/AFRL CoE. This paper discusses the item highlighted on the right in Figure 1.

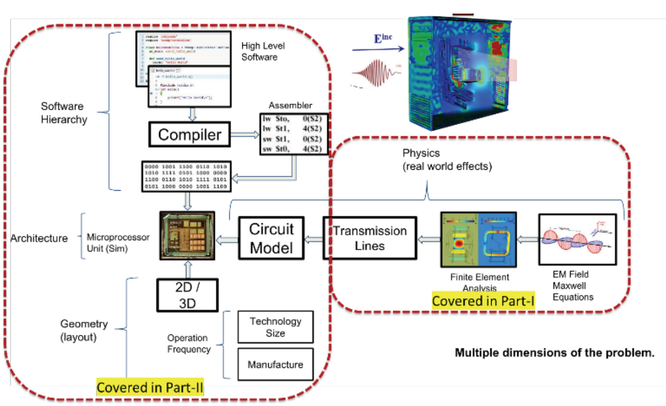

Figure 1: Scope of the AFOSR/AFRL CoE Research.

In Section II, we present an overview of our technical contributions to the EEMI coupling problem.

II. The Coupling Problem

It is recognized by many in the EEMI research community that the physics of high power microwave- (HPM)-to-enclosure-to-device level electronics coupling is extremely complex. Most electronics are located inside protective metallic enclosures, metal casings, and computer boxes. The HPM fields first need to couple into the target enclosure/casing through open apertures, seams, or through power and other cables, and then interact with the sensitive electronics. We have developed a novel statistical approach to address this problem.

A. A Novel Statistical Model – Stochastic Green's Function

In the short-wavelength regime, the complex boundary of the enclosure leads to high modal density and high modal overlap [1]. Wave solutions inside these enclosures show strong fluctuations that are extremely sensitive to the geometry of the enclosure, the location of internal sensors and electronics, and the EEMI frequency. Minor differences in the system configuration can result in significantly different field distributions within the enclosure. There is a body of publications in the literature that describes wave chaos and the random coupling model (RCM) that forms the basis for our work (see [2-5] and references therein).

In the short-wavelength regime, the wave scattering process inside complex enclosures may exhibit chaotic ray trajectories [4]. Electromagnetic fields show variability and extreme sensitivity to small perturbations. Given the complexity of this situation, it is very desirable to obtain the statistical properties of electromagnetic fields within complex enclosures. A novel statistical model for the electromagnetic coupling to electronics inside complex enclosures was developed and presented in [1]. The model was validated in experiment, Figure 2.

In [1] a physics-oriented, reduced-order modeling capability that quickly predicts the statistical electromagnetic coupling while retaining the underlying first-principles analysis was presented. The statistical model only needs the knowledge of

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site-specific features and deterministic coupling channels, e.g. the electronics, apertures, antennas, cables, etc. The interaction with other parts of the complex cavity is characterized statistically using a novel stochastic Green's function. Thus, in the vicinity of ports one can perform a deterministic calculation and then utilize the stochastic Green's function in regions away from the ports, thereby speeding the calculation.

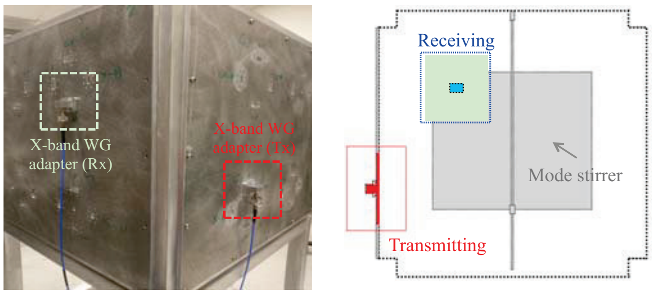

Figure 2: Left: Experimental set-up; right: computational model.

B. Networked Cavities - STUWEE

Predicting the statistical nature of short-wavelength reverberation within random interconnections of large complicated cavities finds applications in several fields of physics and engineering. To aid in developing this predictive capability, this research at the University of New Mexico describes the development and validation of a mathematical framework that fuses the RCM with the electromagnetic topology model of Baum-Liu-Tesche (BLT). We name this framework as the statistical topological approach using wave-chaos for electromagnetic effects (STUWEE). STUWEE has been developed into a computer code which enables the user to rapidly assess the statistical description of the induced electromagnetic fields within a user-specified, interconnected network of large complicated cavities. Figure 3 presents the experimental set-up and BLT topological model used in the study [6].

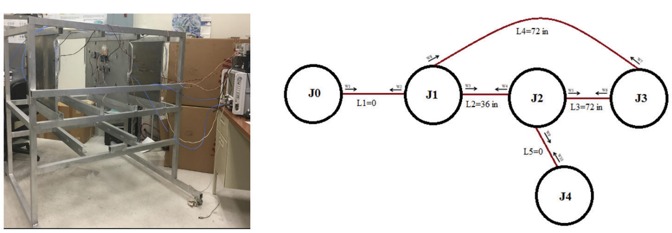

Figure 3: Left: Experimental set-up for three networked cavities; right: BLT topological network for three randomly interconnected cavities.

We have validated that the RCM applies to the cavities above 6 GHz for 1-port, 2-port, and 3-port measurements. Our results show good agreement between experimentally and theoretically fusing the RCM with the BLT EM topology model, Figure 4.

III. Conclusions

We have demonstrated that a stochastic Green's function provides for a rapid technique to calculate the electromagnetic fields away from a port in a complex enclosure in the short-wavelength limit. This was validated in experiment. We also demonstrated that combining the RCM and BLT provides the user with a quick solution to the statistical description of the induced electromagnetic fields within large interconnected cavities. Using a statistical approach in solving large complicated problems is highly reliable and less expensive than performing a deterministic simulation of an entire facility [7]. Predicting the nature of the scattering of short wavelength waves in random interconnected networks of large complicated enclosures is encountered in diverse fields such as acoustics, wireless communications, and electromagnetic compatibility engineering.

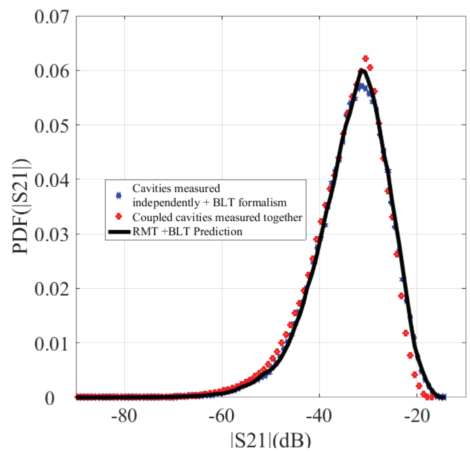

Figure 4: BLT formalism results for three cascaded interconnected cavities.

Acknowledgement

This work was supported by AFOSR/AFRL Grant FA9550-15-1-0171 and AFOSR DURIP Grant FA9550-15-1-0379.

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[7] See http://ece-research.unm.edu/AFOSR-COE/index.html for an extended publication list