Modeling and Statistical Characterization of Electromagnetic Coupling to Electronic Devices

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***Abstract*— The electromagnetic susceptibility of electronic devices varies substantially from one device to another. The objective of the following study is to better understand the statistical variation in coupling to printed circuit boards (PCBs) and their attached cables, and thus their susceptibility. Models are being developed to estimate coupling to wiring harnesses and PCB traces. The voltage coupled depends on the frequency, angle of arrival, and polarization of the incident wave, as well as the characteristics of the receiving structure. The statistical characteristics of the coupled voltage with variations in the arrival angle, polarization and typical variations in the receiving structure (e.g. length of wiring harness, size of connector, board size, trace location, etc.) are being found through simulations. These variations in coupling were used to predict the frequency content of the incident wave that is most likely to cause an over voltage or current within the studied parameter space. Existing models explore differential mode coupling to traces and common-mode coupling to harnesses. Differential mode models of the harness and connectors are under development. These and the previous modeling blocks ultimately create a "toolbox" with which estimate the statistical variation in coupling to a variety of devices.**

I. Introduction

Susceptibility of an electronic device can be found through testing or can be found through simulations of highly-detailed electromagnetic models [1], but it is difficult to predict how a device will react when only minimal information is known about its internal design. A modern device typically includes both printed circuit boards (PCBs) and cables or wire harnesses. At low frequencies, most energy couples to the cables and similarly large structures. At gigahertz frequencies, smaller structures like traces and integrated circuit (IC) packages become important. Both of these structures should be modeled to properly estimate the coupling that can be expected when illuminating the device with a plane wave containing energy from hundreds of megahertz to several gigahertz. The following paper summarizes work performed to develop a simple models of coupling to harnesses, connectors, and PCB traces, explains a study that was performed to estimate the statistical variations in coupling among a range of characteristics of the device and incident wave, and demonstrates how this information might be used to estimate the frequency content of a wave that is most likely to cause a susceptibility issue among the devices.

II. Modeling of Coupling to PCBs and Harnesses

Models were developed to estimate the common-mode coupling to harnesses, and to estimate the differential mode coupling to PCB traces, connectors, and individual wire pairs within the harness. Initial efforts were focused on developing a common mode model of coupling to small wiring harnesses that were 30 cm long or less. This first model used solid PEC rods to approximate the wiring harness, which was shown to match measured common mode currents in a target harness within ~6 dB [2]. The advantage of using this simple model is that many variations of this configuration can be explored through simulations very quickly. Simple models of a trace above a ground plane were also developed as shown in Fig 1. In the statistical study of the coupling to these structures, the harness length, connecting location of the harness, the position of the trace, the length of the trace, and the size of the ground plane are all varied randomly. Full-wave simulations were used to estimate the far-field patterns generated when stimulating a particular port (e.g. one side of the trace), and then reciprocity theory was used to estimate the induced voltage from a planewave excitation from "all" angles of arrival and polarizations [3, 4]. Statistical characteristics of the coupled voltage were estimated from 500-1000 such simulations, assuming specific probability density function for the angle of arrival and polarization of the incident wave.

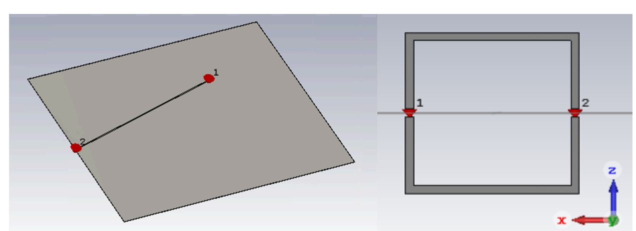

Fig. 1. (Left) Simple PCB structure of a trace above a ground plane. (Right) A split-loop structure used to generate a differential model of a harness.

Additional work is underway to estimate the differential mode coupling to harnesses and connectors. Initial efforts are modeling the harness connector as a split loop, as shown in

Fig. 1, as results can be validated theoretically [5]. A split loop antenna contains two ports, so that the antenna has a transfer impedance (from one end of the wires to the other) as well as an inherent antenna factor. This allows the split loop to be modeled as an individual "block" which is part of a chain of components that make up the complete harness. Wires in the harness can be modeled either as a straight 2-wire transmission line, or as a twisted wire pair [6].

Differential mode coupling to the overall harness and board can be estimated using multiple modeling blocks, including connectors, twisted wire pairs to approximate longer lengths of wiring harnesses, jumper wires to model short connections on PCBs, and short traces on the PCB, as shown in Fig. 2. Using reciprocity and network theory, each of these structures can be investigated independently. The structures can then be cascaded together to offer a highly flexible model capable of predicting coupling for a broad variety of devices.

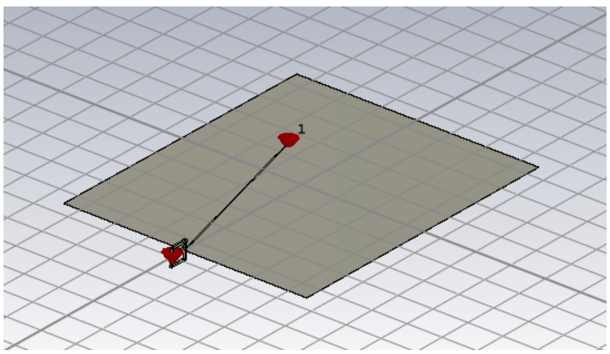

Fig. 2. (Top) Cascading a simple PCB with a split loop.

III. Application of Statistics

Once the statistical variation in coupling is known, these statistics can be used to predict the likely susceptibility of the electronics in the dataset to specific waveforms. By way of example, a simple approach toward estimating the frequency content of the incident signal most likely to cause a susceptibility issue was explored by assuming the incident waveform contained only two frequencies, and finding which two frequencies which were most likely to cause an over voltage or current among the studied devices. We assumed a susceptibility occurred if the received voltage exceeded the threshold at one of the two frequencies, and that no interaction between the two frequencies occurred. The coupled voltage for the 2 frequencies was calculated separately for 500 geometries, and were analyzed to find the probability of exceeding the voltage threshold for the entire dataset. While this formulation of the multi-frequency problem idealizes the real world application, it does demonstrate that the probability of exceeding the voltage or current threshold increases when the incident waveform contains multiple frequencies, rather than just a single narrowband signal. Fig. 2a shows the probability that the coupled voltage will exceed a given threshold, given random trace size and orientation, board size, and incident angle and polarization, and a source containing two frequencies from 100 MHz to 5 GHz. The probability that the voltage at one of the two frequencies will exceed the set threshold is maximized when one frequency is around 1 GHz and the other around 1.5 GHz. Fig. 2b shows the probability of exceeding a threshold when the bandwidth of the signal expands around a center frequency. The probabilities decrease above ~2 GHz because of dielectric loss in the PCB. The highest probability of exceeding the threshold voltage is between 1-2 GHz.

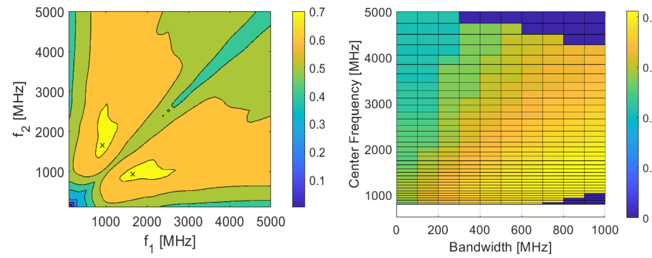

Fig. 2. (Left) Probabilities of exceeding a threshold voltage with a pair of narrowband source. (Right) Probability of exceeding a threshold voltage with a wideband source with given center frequency and bandwidth. Color bars indicate probability [0-1].

IV. Conclusions

Models are being developed to estimate the statistical variations in coupling to electronic devices, where limited information is available about the device characteristics like PCB layout, harness geometry, etc. Models include coupling to traces, to harnesses, to individual pairs of wires in a harness, and to connectors. Analyzing these components individually and later combining them together in blocks allows much more rapid evaluation than can be estimated directly in a 3D modeling tool. The statistical characteristics, once found, can be used to estimate the probability that a device will see an over voltage or current, even when the device geometry and the angle and polarization of arrival of the incident waveform are not known precisely. The statistical characteristics of coupling provides better insight into the mechanisms that cause susceptibility and of the waveforms which are most likely to cause problems.

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