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TUESDAY TECHNICAL PAPERS

Tuesday, August 16, 2011

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Chair: Clifford Hauser, Raytheon Missile Systems

TU-AM-2, Signal Integrity-1 (TC10), Room 101B

Chair: Zhiping Yang, Cisco

8:30 am **Coupling Analysis of Through-Silicon via (TSV) Arrays in Silicon Interposers for 3D Systems** 16

Biancun Xie *(Georgia Institute of Technology, Atlanta, GA, United States)*; Madhavan Swaminathan *(Georgia Institute of Technology, Atlanta, GA, United States)*; Ki Jin Han *(IBM T.J. Watson Research Center, Yorktown Heights, NY, United States)*; Jianyong Xie *(Georgia Institute of Technology, Atlanta, GA, United States)*

Abstract–This paper investigates the coupling effect between through-silicon vias (TSVs) in large TSV array structures. A coupling analysis method for large TSV arrays is proposed. Using this method the importance of coupling between TSVs for low resistivity silicon substrates is quantified both in the frequency and time domain. This has been compared with high resistivity silicon substrates. The comparison between the two indicates the importance of jitter and voltage analysis in TSV arrays for low resistivity silicon substrates due to enhanced coupling.

9:00 am **Measurement and Analysis of Vertical Noise Coupling on Low Noise Amplifier from On-Chip Switching-Mode DC-DC Converter in 3D-IC** 22

Kyoungchoul Koo *(KAIST, Daejeon, Republic of Korea)*; Myunghoi Kim *(KAIST, Daejeon, Republic of Korea)*; Sangrok Lee *(KAIST, Daejeon, Republic of Korea)*; Joungho Kim *(KAIST, Daejeon, Republic of Korea)*

Abstract–Vertical noise coupling between sub-systems of mixed-signal system in 3D-IC can seriously degrades the performance of the system. In this paper, the amount of the vertical noise coupling in a 3D-IC and its source are measured and analyzed. A 200MHz on-chip DC-DC converter and 900MHz low-noise amplifier are chosen for the noise aggressor and victim, respectively. In the test vehicle, the low-noise amplifier chip is stacked on the on-chip DC-DC converter chip. Then, the amount of vertical noise coupling is measured at the output node of low-noise amplifier in time-domain. The measurement result shows that the amount of vertical noise coupling from on-chip DC-DC converter is much stronger than RF signal at low-noise amplifier output. Increase of silicon substrate thickness of low-noise amplifier chip (noise victim) does not reduce the vertical noise coupling, since the silicon substrate has conductivity. The main noise source of the vertical noise coupling is the switching node of the on-chip DC-DC converter. The dominant noise coupling mechanism is revealed as inductive coupling between on-chip inductors in noise aggressor and victim chip from a simple spice model of the vertical noise coupling. However, the capacitive coupling also has a considerable portion in the vertical noise coupling due to the large size of on-chip inductors in the on-chip DC-DC converter.

9:30 am **Analysis of Die-to-Die Vertical Crosstalk between Clock-Tree and Voltage Controlled Oscillator in 3-D IC** 28

Sangrok Lee *(Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea)*; Kyoungchoul Koo *(Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea)*; Joungho Kim *(Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea)*

Abstract–Vertical crosstalk problem between digital and analog circuit components in 3-D IC can severely degrade the 3-D IC system performance. In this paper, we analyze the performance degradation mechanism of 3-D IC that induced by vertical crosstalk between Clock-tree and Voltage Controlled Oscillator (VCO). The 3-D IC test chip which contains Clock-tree and spiral inductor of VCO is fabricated. Lumped component vertical crosstalk model is proposed and it is validated with measurement result. Using validated vertical crosstalk model and spice circuit of VCO, circuit level simulation is performed. Performance degradation mechanism of VCO in 3-D IC is analyzed by separation of noise coupling path approach, and the main mechanism is revealed as high frequency multiplicative noise on signal path.

TU-AM-3, EBG Technologies and IC (TC4), Room 102BC

Chair: Todd Hubing, Clemson University

8:30 am **EMI Suppression of 10Gbit/s Optical Transceiver by using EBG Structure** 33
Daisuke Kawase *(Sumitomo Electric Industries, Ltd., Yokohama City, Japan)*;
Hiroyasu Oomori *(Sumitomo Electric Industries, Ltd., Yokohama City, Japan)*;
Manabu Shiozaki *(Sumitomo Electric Industries, Ltd., Yokohama City, Japan)*;
Hiromi Kurashima *(Sumitomo Electric Industries, Ltd., Yokohama City, Japan)*

Abstract–The fiber optic data transmission system plays important roles in the broadband communication. According to the market trend, the data traffic is significantly increased and larger throughput of communication system is required. Many Opto-electronics conversion devices (so called optical transceivers) are used in the system. Because of that, the electro-magnetic noise radiation becomes serious. Although noise level is proportional to the number of transceivers, a qualitative relationship between the number of transceivers and emission level is not clear. Furthermore, since there's no general design guideline to suppress EMI, it is difficult to solve this problem once it emerges. In these circumstances, recent dispersion control technology such as Electro-magnetic Band Gap (EBG) has a potential solution for this problem. In this paper, we would like to show the method of how to predict total emission level with superimposed effect of thousand of transceivers and how to determine EMI suppression design target, then, how to reach the goal with newly introduced shielding scheme. We would like to demonstrate EBG structure suitable for the optical transceivers. Its verification may be conducted followed by utilization of FEM/FDTD simulation and experiment of an in-house prototype.

9:00 am **Mitigation of Electromagnetic Field Leakage from Apertures and Enclosures using Electromagnetic Bandgap (EBG) Structures** 39
Mohammed M. Bait-Suwailam *(University of Waterloo, Waterloo, Canada)*;
Omar M. Ramahi *(University of Waterloo, Waterloo, Canada)*

Abstract–We present novel strategies to mitigate radiated emissions through apertures and enclosures using electromagnetic bandgap (EBG) structures. The proposed technique comprises loading EBG surfaces immediately around the apertures opening in order to suppress surface currents. Numerical full-wave simulations are presented to demonstrate the effectiveness of the EBG surface. In fact, by using EBG structures, more than 20-dB reduction in field leakage is achieved in the near and far-field radiation without affecting the aperture size. The proposed technique is compared against unloaded aperture and other loaded apertures with lossy resistive sheets. A practical case study from real-world environment is discussed and the concept is validated using measurements.

9:30 am **Improving the Immunity of Smart Power Integrated Circuits by Controlling RF Substrate Coupling** 45
Philipp Schröter *(Infineon Technologies AG, Neubiberg, Germany)*; Stefan Jahn *(Infineon Technologies AG, Neubiberg, Germany)*; Frank Klotz *(Infineon Technologies AG, Neubiberg, Germany)*

Abstract–This paper discusses RF substrate coupling in smart power integrated circuits. Analyses have been accomplished by measurements on wafer level. For this purpose test structures have been designed using a BCD technology for automotive applications. The determining parameters to RF substrate coupling have been evaluated by measuring structures with two transistors. The findings are applied to a typical smart power integrated circuit. It results in controlling RF substrate coupling and a circuit with a high degree of immunity against EMI. The paper closes with appropriate layout recommendations.

TU-AM-4, Electrostatic Discharge (TC5), Room 103A

Chair: William Radasky, Metatech Corporation
Co-Chair: Michael McInerney, U.S. Army Corps of Engineers

8:30 am **Property Analysis of Micro-Gap Air Electrostatic Discharge with Moving Electrode** ..... N/A
Fangming Ruan *(Guizhou Normal University, Guiyang, China)*; Liang Wu *(Guizhou Normal University, Guiyang, China)*; Feng Zhou *(Metrology Center of Communication, Beijing, China)*;
Huaiyu Wang *(Guizhou Normal University, Guiyang, China)*; Xiaolu Wang *(Guizhou Normal University, Guiyang, China)*; Ziyi You *(Guizhou Normal University, Guiyang, China)*

Abstract–Features in micro-gap electrostatic discharge(ESD) with electrode moving at certain velocity to the target shown drastically difference to common ESD. Remarkable variation of discharge parameters with electrode velocity and threshold phenomenon appeared in micro-gap is analyzed with Townsend theory and ESD model for short gap situation. Discrete effect from relative humidity and moving electrode is also briefly described

9:00 am **bModel of Secondary ESD for a Portable Product** 56
Jiang Xiao *(Missouri University of Science and Technology, Rolla, MO, United States)*; David Pommerenke *(Missouri University of Science and Technology, Rolla, MO, United States)*; James L. Drewniak *(Missouri University of Science and Technology, Rolla, MO, United States)*; Hideki Shumiya *(Sony Corporation, Tokyo, Japan)*; Takashi Yamada *(Sony Corporation, Tokyo, Japan)*; Kenji Araki *(Sony Corporation, Tokyo, Japan)*

Abstract–If a non grounded piece of metal is subjected to an ESD, a spark between this metal part and grounded metal parts can occur. This is generally called "secondary ESD". These secondary ESDs are often very close to the electronics and, as this article shows, can have much higher currents and shorter rise times than the original ESD. For that reason secondary ESD poses a very high risk of causing soft- and hard errors in the affected Device Under Test (DUT). A methodology to model the secondary Electrostatic Discharge (ESD) inside a portable electronic product is presented. It is a hybrid method that combines linear descriptions of the ESD generator and the DUT with the non-linear spark model and a model for the initiation delay (statistical time lag) of the spark. Measurement results are presented comparing discharge currents and time delays for two cases: secondary discharge between metal rod and ESD target, and inside a portable product.

9:30 am **An Evaluation of TVS Devices for ESD Protection** 62
Ram Chundru *(Apple Inc., Cupertino, CA, United States)*; Zhen Li *(Missouri University of Science and Technology, Rolla, MO, United States)*; David Pommerenke *(Missouri University of Science and Technology, Rolla, MO, United States)*; Keong Kam *(Missouri University of Science and Technology, Rolla, MO, United States)*; Cheung-Wei Lam *(Apple Inc., Cupertino, CA, United States)*; Federico Centola *(Apple Inc., Cupertino, CA, United States)*; Robert Steinfeld *(Apple Inc., Cupertino, CA, United States)*

Abstract–TVS components are widely used to protect electronic systems from ESD. However, there are various technologies of TVS components as well as numerous manufacturers for each technology. Choosing the right component is not easy, as a typical TVS data sheet does not always provide all relevant information. This paper presents the pros and cons of different technologies as well as empirical data to facilitate the design of adequate and economical ESD protection.

TU-AM-5, Nanotechnology and Advanced Materials (TC11), Room 103B

Chair: Marina Koledintseva, Missouri University of S&T
Co-Chair: Christopher L. Holloway, NIST

8:30 am **Design of Electromagnetic Wave Absorber by use of Metal Wire Array Sheet** 68
Shinichiro Yamamoto *(University of Hyogo, Himeji, Japan)*; Daisuke Ishihara *(University of Hyogo, Himeji, Japan)*; Kenichi Hatakeyama *(University of Hyogo, Himeji, Japan)*

Abstract–In this paper, properties of artificially-designed materials and their applications in electromagnetic (EM) wave absorber are discussed. First, EM-wave absorber composed of the straight length wire array sheet and a ferrite-powder/rubber mixture plate is investigated. The absorbing characteristics of the absorber using the wire array sheet can be matched at around the resonant frequency of the sheet. Next, EM absorbers using the wire array sheet having two resonant frequencies are proposed here.

9:00 am **Electromagnetic Field Radiation from MWCNTs and SWCNT Bundles: A Comparative Analysis** 72
A.G. D'Aloia *(Sapienza University of Rome, Rome, Italy)*; M.S. Sarto *(Sapienza University of Rome, Rome, Italy)*; A. Tamburrano *(Sapienza University of Rome, Rome, Italy)*

Abstract–The electromagnetic field radiated by a multiwall carbon nanotube is predicted in the frequency domain using the equivalent single conductor (ESC) formulation, and it is compared with the field radiated by a single wall carbon nanotube bundle having circular cross section and the same external diameter. The effect of the frequency and of the configuration on the near field level is investigated, in order to predict the risk of electromagnetic interference against nearby components and devices, and to define the most critical conditions.

9:30 am **High Frequency Permeability of Fe-Al-Si Granular Composite Materials** 78

Takanori Tsutaoka *(Hiroshima University, Higashi-Hiroshima, Japan)*; Taisuke Ono *(Hiroshima University, Higashi-Hiroshima, Japan)*; Aiko Tsurunaga *(Hiroshima University, Higashi-Hiroshima, Japan)*; Teruhiro Kasagi *(Tokuyama College of Technology, Tokuyama, Japan)*; Kenichi Hatakeyama *(University of Hyogo, Himeji, Japan)*; Marina Y. Koledintseva *(Missouri University of Science and Technology, Rolla, MO, United States)*

Abstract–High-frequency electromagnetic properties of Fe-Al-Si alloy (Sendust) granular composite materials have been studied by measuring their relative complex permeability and permittivity spectra. The bulk Fe-Al-Si alloy shows metallic electrical conduction, and permeability decreases rapidly with frequency. On the other hand, Sendust powder shows relatively high electrical resistivity. Sendust composite material demonstrates insulating electrical properties up to at least 65 vol.% particle content. Thus the relatively high permeability in the microwave frequency range can be obtained. Frequency dispersion characteristics of permeability for the composite were analyzed by the superposition of domain wall and gyromagnetic spin resonance formula. The particle content variation of permeability can be qualitatively described by a coherent model mixing rule.

TU-PM-1, Antennas-2 (TC2), Room 101A

Chair: Bob Hofmann, Hofmann EMC Engineering

1:30 pm **The Rationale to Define when EMC Antennas shall be Calibrated** 84

Alessandro Tacchini *(Reggio Emilia Innovazione, Reggio Emilia, Italy)*; Bruno Audone *(Reggio Emilia Innovazione, Reggio Emilia, Italy)*; Daniel Grossi *(Reggio Emilia Innovazione, Reggio Emilia, Italy)*

Abstract–The calibration of EMC antenna has always been a frustrating subject for most EMC laboratories for various reasons. On the other hand in many cases EMC antennas are recalibrated when it is not strictly necessary. This paper proposes a procedure to establish when EMI antennas shall be calibrated on the basis of technical considerations without making reference to abstract quality assurance rules.

2:00 pm **Proposal of Simple Reference Antenna Method for EMI Antenna Calibration** 90

Jungkuy Park *(Radio Research Agency of Korea Communication Commissions, Icheon, Republic of Korea)*; Guseon Mun *(Radio Research Agency of Korea Communication Commissions, Icheon, Republic of Korea)*; Daehoon Yu *(Radio Research Agency of Korea Communication Commissions, Icheon, Republic of Korea)*; Boweon Lee *(Radio Research Agency of Korea Communication Commissions, Icheon, Republic of Korea)*; Woo Nyun Kim *(Radio Research Agency of Korea Communication Commissions, Icheon, Republic of Korea)*

Abstract–In this paper, a simple Reference Antenna Method is proposed. The main idea is that a information for electric field at receiving gives antenna gains of transmitting antenna. The existing Reference Antenna Method(RAM) or Standard Antenna Method(SAM) have to conduct two measurements with three antennas in order to yield antenna gains or factors. The proposed method needs only one time measurement with two antennas to measure gains of Tx antenna. The reference antenna should be known for its antenna factors or hould be possible to measure a electric field at receiving location. Basic expressions for the proposed method from the electric field formula of Tx antenna are derived both in Free space and in Open Area Test Site(OATS) with a conducting plane. Measuring procedure is explained. Calibration results due to the proposed method and SSM are compared. LP antenna knowing its factors and NIST type diode loaded standard dipoles were used as the reference. They respectively measured gains of LP and biconical antenna as AUC. The comparison results between the two methods show good agreement. Measurement uncertainty of the methods is also analyzed.

2:30 pm **Efficient Experimental Procedure for Antenna Calibration in Plastic/Concrete/Metallic Conduits** 96

Riccardo Stefanelli *(iXem Labs – Politecnico di Torino, Torino, Italy)*;
Daniele Trinchero *(iXem Labs – Politecnico di Torino, Torino, Italy)*

Abstract–Wireless sensor networks have been recently proposed for applications in a large variety of systems. Among all, the possibility to insert a terminal node inside a dissipative liquid medium has attracted attention by few authors. For this reason, the paper presents the design and construction of a test bench for the experimental characterization of antennas inside liquids. The design has involved the classification of a large variety of pipelines, among which three different samples have been selected. The pipeline has consequently been configured in order to host fixed or mobile antennas, which can be wired towards the external part of the conduit, to facilitate their connection to a network analyzer. The speed and pressure of the liquid, as well as the speed of the antenna, can be controlled remotely. A de-embedding procedure has been introduced, in order to characterize the reflection loss at the antenna terminals. Finally, in case of metallic pipelines, a procedure has been introduced to test the attenuation along the longitudinal direction of the conduit.

3:30 pm **Comparison between Three-Antenna Method and Equivalent Capacitance Substitution Method for Calibrating Electrically Short Monopole Antenna** 101

Masanori Ishii *(National Institute of Advanced Industrial Science and Technology, Ibaraki, Japan)*;
Satoru Kurokawa *(National Institute of Advanced Industrial Science and Technology, Ibaraki, Japan)*;
Yozo Shimada *(National Institute of Advanced Industrial Science and Technology, Ibaraki, Japan)*

Abstract–In low-frequency bands, monopole antennas are generally used for measuring the electromagnetic interference (EMI) and estimating the electric field strength. The antenna factor is an important and widely studied characteristic. Thus far, there have been a number of measurement methods proposed for electrically short monopole antennas. A case in point is the equivalent capacitance substitution method, which is commonly used for monopole antenna measurements. On the other hand, we have proposed a near-field three-antenna method for electrically short monopole antennas. These two absolute calibration methods are of quite different origins. In light of this fact, a comparison is made between the two measurement methods by means of experiments and simulations, and the difference observed between the antenna factors is discussed.

4:00 pm **A Novel Method for Determining the Lower Bound of Antenna Efficiency** 107

Jason B. Coder *(University of Colorado Denver, Boulder, CO, United States)*;
John M. Ladbury *(National Institute of Standards and Technology, Boulder, CO, United States)*;
Mark Golkowski *(University of Colorado Denver, Denver, CO, United States)*

** Nominated for Best Symposium Paper Award*

Abstract–Determining the absolute antenna efficiency has been a difficult task since the inception of the antenna itself. While there are methods that can measure an antenna's efficiency, most are complicated and prone to high uncertainties. A new method is presented for determining the lower bound of absolute antenna efficiency using a reverberation chamber. This method is able to characterize both the transmitting and receiving efficiency of an antenna. The proposed method is first validated using numerical simulations. These simulations can provide insight into the behavior of the equations and necessary assumptions. Then, the method for transmitting efficiency is be validated using measured data from two different types of antennas: a wide band dual-ridged horn, and a narrow-band meta-material inspired antenna. Following the measurement data, possible areas for improvement of the method and it's optimization are discussed.

4:30 pm **Electro-Optical Sensor for Shielding-Effectiveness Measurements of Motor-Control-Unit Enclosures** 113

Lena Thiele *(University of Technology Braunschweig, Braunschweig, Germany)*;
Robert Geise *(University of Technology Braunschweig, Braunschweig, Germany)*

Abstract–This paper presents shielding effectiveness measurements of a small enclosure for motor control units in two frequency ranges from 10 kHz to 200 MHz and 200 MHz up to 3 GHz. Measurements take place in two different measurement environments, namely in a TEM-cell and in front of an absorber wall. Measurements done with a small electro-optical E-field sensor are shown, which is used in various configurations according to the dynamic range. The main aim of this paper is to compare the modifications of the sensor system and the two frequency ranges.

TU-PM-2, Signal Integrity-2 (TC10), Room 101B

Chair: Jianming Zhang, Intel
Co-Chair: Amy Chen, Intel

1:30 pm **Design and Experimental Verification of On-Chip Signal Integrity Analyzer (OSIA) Scheme for Eye Diagram Monitoring of a High-Speed Serial Link** 119

Minchul Shin *(KAIST, Daejeon, Republic of Korea)*; Myunghoi Kim *(KAIST, Daejeon, Republic of Korea)*; Kyoungchoul Koo *(KAIST, Daejeon, Republic of Korea)*; Sunkyu Kong *(KAIST, Daejeon, Republic of Korea)*; Joungho Kim *(KAIST, Daejeon, Republic of Korea)*

Abstract–Recently, bandwidth of data channel has increased with the development of high-performance electronic system. The method used to characterize the channel is important for successful channel design. However, conventional methods have several disadvantages to characterize the whole high-speed serial link including on-chip and package channel. In this paper, we design and experimental verification of on-chip signal integrity analyzer (OSIA) scheme for high-speed data transmission. The designed OSIA circuit can be an effective method to determine the eye diagram of an inside package channel and on-chip I/O channel because it is located at the front of a receiver circuit. The test chip for the OSIA is fabricated by a standard 0.18-μm CMOS process. The performance of the proposed OSIA is verified be measuring the eye diagram of a chip-package-board hierarchical channel with 10 ps and with 10-mV resolution. It is successfully demonstrated to monitor the eye diagram distortion affected by variation of data rate and channel loss.

Abstract–This paper presents an effective solution for the transient analysis of long bus-like interconnects with the inclusion of geometrical and material uncertainties of the structure. The proposed approach is based on the expansion of the well known frequency-domain telegraph equations in terms of orthogonal polynomials and on the back conversion to time domain via Fourier superposition. The method is validated by means of a systematic comparison with the results of Monte Carlo simulations, for an application example involving a PCB coupled-microstrip interconnect with uncertainties in the relative dielectric permittivity and trace separation.

Abstract–We propose a new parametric macromodeling technique for complex electromagnetic systems described by scattering parameters, which are parameterized by multiple design variables such as layout or substrate feature. The proposed technique is based on an efficient and reliable combination of rational identification, a procedure to find scaling and frequency shifting system coefficients, and positive interpolation schemes. Parametric macromodels can be used for efficient and accurate design space exploration and optimization. A design optimization example for a complex electromagnetic system is used to validate the proposed parametric macromodeling technique in a practical design process flow.

TU-PM-3, PCB and Filters (TC4), Room 102BC

Chair: Kermit Phipps, AMS Technology Center
Co-Chair: John Rohrbaugh, Northrop Grumman

Abstract–In printed circuit board (PCB) designs, it is common to split power/ground planes into different partitions, which leads to more crosstalk among signal traces that route crossing a split. It is of general interest to develop a crosstalk model for various geometric parameters. However, the long time required to simulate the structure with any given set of geometric parameters renders general modelling approaches such as interpolation inefficient. In this paper, we develop an empirical model based upon the compressed sensing technique to characterize the crosstalk among traces as a function of geometric parameters. A good agreement between the empirical model and full-wave simulations is observed for various test examples, with an exceptionally small number of samples.

Abstract–Printed circuit boards (PCBs) driven by a connected feed cable are considered to be one of the main sources of the electromagnetic interference (EMI) from electronic devices. Effective methods for predicting and suppressing EMI over a broad band are required. In this paper, we newly focus on identifying the frequency response of EM radiation from a strip line structure driven by a connected feed cable. To provide basic considerations for the realization of methods for predicting the EM radiation from strip line structure driven by a feed cable, the characteristics of the EMI of test model PCB are investigated in this paper experimentally and by numerical modeling. Firstly, frequency responses of common-mode (CM) current and EM radiation from a PCB without the feed cable are discussed by FDTD modeling. It was demonstrated that SL and shield structures without a feed cable are effective in suppressing the EMI. Secondly, CM current on the feed cable attached to the PCB is studied experimentally and compared with FDTD modeling. Due to the additional displacement current path, "SL" structure driven by the feed cable is not effective in suppressing EMI. EMC design guideline commonly suggests that the strip line structure rather than microstrip line structure should be used in PCB structure. The results in this study indicate that "SL" and "Shield" cases yield resonances with high level peaks, due to the feed cable. This study successfully provides a basic model to effectively predict EM radiation from a stripline structure.

TU-PM-4, Cavities and Enclosures (TC9), Room 103A

Chair: Vignesh Rajamani, Oklahoma State University
Co-Chair: Alistair Duffy, De Montfort University

1:30 pm **Estimation of the Electromagnetic Field Radiated by a Microwave Circuit Encapsulated in a Rectangular Cavity** 196

Samh Khemiri *(IRSEEM/ESIGELEC Technopôle du Madrillet, Saint Etienne de Rouvray, France)*; Abhishek Ramanujan *(IRSEEM/ESIGELEC Technopôle du Madrillet, Saint Etienne de Rouvray, France)*; Moncef Kadi *(IRSEEM/ESIGELEC Technopôle du Madrillet, Saint Etienne de Rouvray, France)*; Zouheir Riah *(IRSEEM/ESIGELEC Technopôle du Madrillet, Saint Etienne de Rouvray, France)*; Anne Louis *(IRSEEM/ESIGELEC Technopôle du Madrillet, Saint Etienne de Rouvray, France)*

Abstract–A signal, propagating in an electronic circuit enclosed in a metal cavity, can excite the cavity's natural modes. In the context of RF amplifier reliability study against electromagnetic stress, a precise characterization of radiated emissions is imposed on us. This characterization is often achieved by measuring the near field of the circuit without enclosing it in a cavity (the top cover of the cavity is kept open), which does not always resemble the electromagnetic behavior when the same circuit is shielded within the cavity. In this work, we study the changes in the carthographies of the electromagnetic field radiated under the influence of the metal cavity and we present a method to estimate the radiated field in the cavity from measurements made in the absence of the cavity. This method is validated for all frequencies except resonant frequencies

2:00 pm **Wave Chaotic Analysis of Weakly Coupled Reverberation Chambers** 202

Gabriele Gradoni *(University of Maryland, College Park, MD, United States)*; Jen-Hao Yeh *(University of Maryland, College Park, MD, United States)*; Thomas M. Antonsen, Jr. *(University of Maryland, College Park, MD, United States)*; Steven Anlage *(University of Maryland, College Park, MD, United States)*; Edward Ott *(University of Maryland, College Park, MD, United States)*

Abstract–In this paper, we analyze the field fluctuations in weakly coupled complex cavities by using the random matrix the- ory to model the chaotic scattering within each cavity. Universal (chaotic) and non-universal (absorption) features are conveniently described by the radiation impedance concept. Inherently, the development of the random field regime is accounted for taking each mode of the cavity as a random plane wave expansion. Sources and sinks inside the cavities are assumed to be electrically small. A model for cascaded cavities scenario is derived through the electric network theory and the random matrix theory for both lossy and lossless cases. Adopted physical framework is a linear chain of two-port cavities terminated by a one-port cavity. The field flowing into this last cavity is related to the current excitation through the coupling radiation impedance. Closed- form expressions are derived for two interconnected cavities, mimicking the nested reverberation chamber scenario. Finally, the practical issue of measurements in a nested reverberation chamber is presented and discussed. Accordingly, based on physical arguments, the small fluctuations theory applies. Results are of interest in interference propagation through complex electromagnetic environment or planar circuits, EMC immunity tests, and reverberation chambers.

2:30 pm **Optimal Plane-Wave Representation of Random Fields in a Reverberation Chamber** 208

James C. West *(Oklahoma State University, Stillwater, OK, United States)*; Charles F. Bunting *(Oklahoma State University, Stillwater, OK, United States)*; Vignesh Rajamani *(Oklahoma State University, Stillwater, OK, United States)*

** Nominated for Best Symposium Paper Award*

Abstract–The random electromagnetic field within a reverberation chamber is modeled using a superposition of plane waves. Based on rigorous sampling theory, the ideal continuous plane-wave spectrum within the chamber is sampled over the sphere to yield nearly ideal field statistics (including spatial autocorrelation) over a specified test volume such as that occupied by an equipment under test (EUT). The same spectral sampling (as defined by the individual plane-wave directions) is used for each trial, with randomness added to the specific fields associated with the individual plane-wave samples in the different trials. Since the sampling is fixed, the response of the EUT to only a single plane wave at each sample point must be found numerically. The response of the EUT to specific realization of random fields within the chamber is found through a linear superposition of the individual plane-wave responses weighted by appropriate random coefficients. This minimizes the number of times the field on the EUT must be solved using a numerical electromagnetics technique, giving an efficient method to numerically simulate susceptibility tests within reverberation chambers.

3:30 pm **Shielding Performance of Nanostructured Transparent Thin Films Loading Apertures of Metallic Enclosures Excited by Dipole Sources** 214

Rodolfo Araneo *(University of Rome, Rome, Italy)*; Giampiero Lovat *(University of Rome, Rome, Italy)*; Salvatore Celozzi *(University of Rome, Rome, Italy)*; Marcello D'Amore *(University of Rome, Rome, Italy)*

** Nominated for Best Symposium Paper Award*

Abstract–The electromagnetic effects of optically-transparent thin films filling a thick aperture in shielding metallic enclosures with internal dipole sources are investigated. The analysis is performed through an efficient Method-of-Moment procedure implemented in a numerical tool which is able of dealing with micro/nano thin films. The investigation is aimed at assessing the field distribution both inside and outside a metallic enclosure with an aperture loaded by glass with ITO/silver coatings. The numerical results show the best thin-film configuration as concerns the shielding effectiveness. Moreover, the effects inside the cavity produced by the aperture loading are also estimated and a preliminary investigation on the use of absorbing materials placed on the interior walls is carried out.

4:00 pm **Statistical Characterization of Complex Enclosures with Distributed Ports** 220

Thomas M. Antonsen, Jr. *(University of Maryland, College Park, MD, United States)*;
Gabriele Gradoni *(University of Maryland, College Park, MD, United States)*;
Steven Anlage *(University of Maryland, College Park, MD, United States)*;
Edward Ott *(University of Maryland, College Park, MD, United States)*

Abstract–A statistical model, the Random Coupling Model, that describes the coupling of radiation into and out of large electrical enclosures is described and generalized. Particular attention is paid to the case in which the ports are electrically large and described by multiple modes (distributed ports). We find a compact expression for a model of the enclosure impedance that can be used to generate probability distributions for fields at the enclosure's ports. Results are of interest in the evaluation of power leakage in complex metallic structures and reverberation chambers, and the evaluation of the effectiveness of shielding in the presence of apertures.

4:30 pm **Reverberation Chambers: Full 3D FDTD Simulations and Measurements of Independent Positions of the Stirrers** 226

Franco Moglie *(Università Politecnica delle Marche, Ancona, Italy)*;
Valter Mariani Primiani *(Università Politecnica delle Marche, Ancona, Italy)*

Abstract–This paper describes the developing and the testing of our FDTD code to simulate the whole reverberation chamber. In order to reduce computer load some approximations were introduced, and we validated the results with the experimental ones measured in our reverberation chamber. Simulated and measured results were compared using the same statistical software. In addition, the computations easily provide other results that cannot be obtained by measurements like the ones that regard field distribution inside the cavity. The developed FDTD code is able to simulate the statistical properties of an RC as function of its dimensions and stirrer geometry. Many numerical techniques haves been proposed to simulate reverberation chambers. Every method requires very large computer resources if a full 3D simulation is done. The developed FDTD code is able to simulate different geometries and movements of the stirrer(s) allowing the designer to obtain the best configuration using the simulator, and saving time for experimental tests. Simulations integrate experimental measurements when long measurement time or destructive tests are required.

5:00 pm **Stochastic and Statistics in Superposition of Multipole Radiators** 231

Oliver Döring *(Leibniz Universität Hannover, Hannover, Germany)*;
Adrian Kreth *(Leibniz Universität Hannover, Hannover, Germany)*;
Heyno Garbe *(Leibniz Universität Hannover, Hannover, Germany)*

Abstract–The multipole approximation is a sufficient method for fast calculations of the electromagnetic field and for complex electromagnetic environments with many field sources. In this paper, the influences on the superposition of electromagnetic fields generated by multipole sources are under consideration. The phase angle of the multipole field sources is unknown when estimating multipole parameters. Therefore, the influence of random phase angles on interference patterns is under investigation. This paper demonstrates two phase independent superposition methods. Additionally, a probability distribution for field strength values is derived. This distribution demonstrates the influence of random variables on the probability of field strength values.

TU-PM-5, Special Session: Solving Large EM Problems), Room 103B

Chair: Albert Ruehli, Missouri University of S & T
Co-Chair: Giulio Antonini, University of L'Aquila

1:30 pm **Electromagnetics-Thermal Co-Analysis of Real-Life 3-D ICs using Non-Conformal Domain Decomposition Method** 237

Yang Shao *(The Ohio State University, Columbus, OH, United States)*; Zhen Peng *(The Ohio State University, Columbus, OH, United States)*; Jin-Fa Lee *(The Ohio State University, Columbus, OH, United States)*

Abstract–Advances in integrated circuit (IC) and package technologies, such as the increase of the number of metal layers and 3-D stacking technique, have paved the way for faster speed and higher performance in today's electronic products. However, continuing down-scaling in feature size poses crucial issues, such as the parasitic couplings between circuit elements and localized Joule heat dissipation. In this work, we introduce a systematic computational Electromagnetic (CEM)-thermal coupling approach capable of dealing with multiscale problems such as 3-D ICs and subsystems. A non-conformal finite element domain decomposition method is utilized to iterative the electrostatic, full-wave electromagnetic and thermal simulation. Moreover, we included preliminary numerical results demonstrating the effectiveness of the proposed approach.

2:00 pm **Multipoint Model Order Reduction of Delayed PEEC Systems** 243

Francesco Ferranti *(Ghent University-IBBT, Ghent, Belgium)*; Michel Nakhla *(Carleton University, Ottawa, Canada)*; Giulio Antonini *(Università degli Studi dell'Aquila, L'Aquila, Italy)*; Tom Dhaene *(Ghent University-IBBT, Ghent, Belgium)*; Luc Knockaert *(Ghent University-IBBT, Ghent, Belgium)*; Albert E. Ruehli *(Missouri University of Science and Technology, Rolla, MO, United States)*

Abstract–We present a new model order reduction technique for electrically large systems with delay elements, which can be modeled by means of neutral delayed differential equations. An adaptive multipoint expansion and model order reduction of equivalent first order systems are combined in the new proposed method that preserves the neutral delayed differential formulation. An adaptive algorithm to select the expansion points is presented. The proposed model order reduction technique is validated by pertinent numerical results. A comparison with a previous model order reduction algorithm based on a single point expansion is performed to show the considerably improved modeling capability of the new proposed technique.

2:30 pm **An H^2-Based Linear-Complexity Solution of Surface Integral Equations for 3-D Impedance Extraction** 249

Wenwen Chai *(Purdue University, West Lafayette, IN, United States)*; Dan Jiao *(Purdue University, West Lafayette, IN, United States)*

Abstract–A new H^2-matrix based kernel-independent algorithm of linear complexity is developed for the surface integral equation based impedance extraction of arbitrarily shaped 3-D lossy conductors embedded in dielectric materials. The new algorithm greatly accelerates the iterative solution of a scalar-based surface integral equation for impedance extraction. It outperforms state-of-the-art iterative impedance solvers with fast CPU time, modest memory consumption, and without sacrificing accuracy, for both small and large number of unknowns.

3:30 pm **Skin-Effect Model for Time and Frequency Domain PEEC Solver** 254

Giulio Antonini *(Università degli Studi dell'Aquila, L'Aquila, Italy)*; Albert E. Ruehli *(Missouri University of Science and Technology, Rolla, MO, United States)*

Abstract–A challenging issue for the solution of large electromagnetic problems is the efficient modeling of the broadband skin-effect for conducting planes and 3D shapes. Unfortunately, the inclusion of such models can be very costly in compute time and memory requirements. Considerable progress has recently been made in the design of skin-effect models. Several properties of the model are desirable for the solution of practical problems, like the broadband frequency domain or the time domain applicability. In this paper, we present a new model which meets some of these challenges and which is suitable for the PEEC solution method.

4:00 pm **Solution of Large Multiscale EMC Problems with Method of Moments Accelerated via Low-Frequency MLFMA** 260

Jonatan Aronsson *(University of Manitoba, Winnipeg, Canada)*; Mohammad Shafieipour *(University of Manitoba, Winnipeg, Canada)*; Vladimir Okhmatovski *(University of Manitoba, Winnipeg, Canada)*

Abstract–The paper demonstrates that for large-scale EMC problems not exceeding 120 wavelength in size the low-frequency MLFMA based on spherical wave function expansions is advantageous to its high-frequency counterpart based on plane wave expansions. In the latter the depth of the tree is restricted by the smallest size of the leaf-level box size of 0.1 wavelength making it inefficient at either low-frequencies or for problems with multi-scale features. The low-frequency MLFMA, however, has no limitation on the depth of the tree and allows for full-wave acceleration of Moment Method from DC to frequencies at which the models spans up to 120 wavelengths. Such broadband behavior of the low-frequency MLFMA is made possible through construction of numerically stable translation operators for the spherical wave functions with orders reaching 180. This paper provides an overview of the algorithms allowing for stable high order translations of spherical functions. The LF-MLFMA accelerated RWG MoM utilizing one such algorithm is demonstrated in the frequency range from 1MHz to 2.5GHz for the problem of plane wave coupling to antennas onboard the F5 fighter jet at fixed discretization featuring 2 million surface elements.

4:30 pm **A Novel Characterization Method of the Radiation Emission for Electromagnetic Compatibility** 264

Ping Li *(University of Hong Kong, Pokfulam, Hong Kong)*;
Lijun Jiang *(University of Hong Kong, Pokfulam, Hong Kong)*

Abstract–Conventionally the radiation emissions from PCB boards, electronic devices and antennas were characterized through the near field (NF) – far field (FF) transformation to find the equivalent sources. In this paper, a new methodology without NF-FF transformation is presented. Based on the uniqueness theorem, it only employs the measured tangential field over a spherical surface to rigorously characterize the outward radiation emission. The dyadic Green's function for the perfect magnetic conductor (PMC) sphere is derived using spherical wave functions. Based on this dyadic Green's function and integral equations, the NF-FF transformation is not necessary any more. To facilitate feasible near field measurements, only the tangential magnetic field is needed. As the proof of the concept, the radiations of Hertzian dipoles are analyzed. This approach can be directly used to characterize the radiation from PCBs and antennas.

TU-PM-6, Special Session: EMC in Space, Room 103C

Chair: Ray Perez, Jet Propulsion Laboratory
Co-Chair: James Lukash, Lockheed Martin

1:30 pm **Design Approach and Spacecraft EMI Test Methodology for High Power Communication Spacecraft** 270

Alexander Bogorad *(Lockheed Martin Space Systems, Newtown, PA, United States)*; Kevin August *(Lockheed Martin Space Systems, Newtown, PA, United States)*; Matt Deeter *(Lockheed Martin Space Systems, Newtown, PA, United States)*; James Lukash *(Lockheed Martin Space Systems, Sunnyvale, CA, United States)*; Roman Herschitz *(Lockheed Martin Space Systems, Newtown, PA, United States)*

Abstract–Modern communication spacecraft present challenging Electromagnetic Interference (EMI) problem due to high power generation (10 kilowatts and higher), and requirements to accommodate various communication payloads from UHF to Ka frequencies on the same platform. Such spacecraft are designed to stringent military specification to achieve electromagnetic compatibility (EMC). This paper describes EMI design approach and test methodology which were successfully implemented on one such satellite program to ensure compliance with stringent EMI requirements using best commercial practices.

2:00 pm **Application of the Power Balance Method to E Field Calculation in the ARIANE 5 Launcher Payloads Cavities** 284

André Schaffar *(EADS ASTRIUM Space Transportation, Les Mureaux, France)*;
Pierre-Nicolas Gineste *(EADS ASTRIUM Space Transportation, Les Mureaux, France)*

Abstract–The present paper reports the main results of a study the aim of which being to apply the Power Balance Method to the electric field calculation in the ARIANE 5 launcher cavities of the payload section and in the launcher avionics bay, in case of payload telemetry transmission. This method is applicable if the cavity is oversized and complex. In that case the E field distribution follows a known statistical law which leads to an average value of the electric field and its standard deviation. The frequency band of interest is 1 -40 GHz. The study details the analytical procedure to be applied and reports the experimental determination of a critical loss factor.

TUESDAY POSTERS

Tue AM, Poster Papers, Room

Chair: Randy Flanders, RTF Compliance

Meet and Greet Authors 10:00 am to noon Tuesday.

Display of papers from 12:00 pm to 5:30 pm Tuesday in Room 102A.

10:00 am **Analysis of the Source Bus Line Current in LCD Panel based on a New MSL Model** 384
M. Yamaguchi *(Tohoku University, Sendai, Japan)*; S. Dhungana *(Tohoku University, Sendai, Japan)*

Abstract–This paper proposes a new microstrip line (MSL) based model of the source bus line of a thin film transistor (TFT)-type large-size liquid crystal display (LCD) panel, being valid when all TFTs are in an on-state. This analysis is useful for analyzing the distortion of the pulse current waveform in the source bus lines and for designing the time constant (RC product) of the source bus current to be shorter. Such improvement will lead to solve problems such as image shifts and color blurs. The model verification is demonstrated by analyzing the magnetic field generated by the source bus line current. Measurement is performed by a planar shielded-coil type RF magnetic field probe we previously developed. The MSL model well explained the measurements. The model calculation also revealed that the rise time of source bus line current increases up to half of its length and remains constant in the remaining half.

10:00 am **The Test Verification and Comparison of SAE-ARP1173 and MIL-DTL-83528C for EMI Gaskets Characterization** 388
Jing Shenhui *(Southeast University, Nanjing, China)*; Jiang Quanxing *(Southeast University, Nanjing, China)*; Wang Weike *(China Aero-Polytechnology Establishment, Beijing, China)*; Huang Juying *(China Aero-Polytechnology Establishment, Beijing, China)*; Liu Chang *(Nanjing Institute of Electronic Technology, Nanjing, China)*

Abstract–Two test systems are constructed to give verification of ARP-1173-2004 and MIL-DTL-83528C-2001. Test frequency ranges are 400Hz-400MHz and 20MHz-10GHz respectively. Typical test results for several different types of gaskets are given. The technical details of these two methods are compared and analyzed.

WEDNESDAY TECHNICAL PAPERS

Wednesday, August 17, 2011

WED-AM-1, Emissions-1 (TC2), Room 101A

Chair: Ghery Pettit, Intel Corporation

8:30 am **High Harmonic Distortion in a New Building due to a Multitude of Electronic Equipment** 393
R.B. Timens *(University of Twente, Enschede, Netherlands)*; F.J.K. Buesink *(University of Twente, Enschede, Netherlands)*; V. Ćuk *(Eindhoven University of Technology, Eindhoven, Netherlands)*; J.F.G. Cobben *(Eindhoven University of Technology, Eindhoven, Netherlands)*; W.L. Kling *(Eindhoven University of Technology, Eindhoven, Netherlands)*; F.B.J. Leferink *(Thales Nederland B.V., Hengelo, Netherlands)*

Abstract–In modern buildings virtually all electric loads are non-linear. Neither the applicable standards for supply of electrical energy nor those for consumption of electrical energy take into account the replacement of linear loads by non-linear loads. Low power equipment is exempted in standards assuming that all other (linear) loads dominate the power quality. In modern buildings there is a huge number of non-linear loads in lighting, monitor, computer and small power supplies and only a very limited number (or no) conventional linear loads. This is causing unacceptable interference with costly consequences. This paper analyzes current standards and the (exemptions for) harmonic current consumption of modern devices. The increase in harmonic distortion in a new building due to a multitude of non-linear equipment is shown. This forced the owner of the building to make costly changes in the power supply network.

9:00 am **Assessment of the Usability of the Workbench Faraday Cage Method** 399
Morten Sørensen *(Aalborg University, Aalborg, Denmark)*; Ondrej Franek *(Aalborg University, Aalborg, Denmark)*; Søren K. Christensen *(Bang & Olufsen a/s, Struer, Denmark)*; Gert Frølund Pedersen *(Aalborg University, Aalborg, Denmark)*; Hans Ebert *(Aalborg University, Aalborg, Denmark)*

Abstract–The workbench Faraday Cage method (WBFC) is a time efficient module pre-compliance test regarding radiated emission. This work investigates the method's usability and credibility and concludes that for this particular case the WBFC perform a comparative precise compliance test for frequencies below 360 MHz while it is essentially useless for higher frequencies.

9:30 am **A Round-Robin Test on Effectiveness of a VHF LISN for Radiated Emission Measurements** 405

Chiharu Miyazaki *(Mitsubishi Electric Corporation, Kamakura, Japan)*; Katsuyuki Tanakajima *(Intertek Japan K.K., Ibaraki, Japan)*; Masanori Yamaguchi *(EMC Education, Tokyo, Japan)*; Kiyoshi Endo *(TUV SUD Ohtama, Ltd., Kanagawa, Japan)*; Hidenori Muramatsu *(NEC AccessTechnica, Ltd., Shizuoka, Japan)*; Jiro Kawano *(VCCI Council, Tokyo, Japan)*

Abstract–VCCI Technical Sub-committee has investigated the dispersion of radiated emission measurement results. It was confirmed that one of the main cause of the dispersion of radiated emission measurement results was the difference of the power line-to-ground impedance of the power supply for the equipment under test (EUT). For the improvement of the dispersion, VCCI Council manufactured the experimental VHF LISN (Very High Frequency Line Impedance Stabilization Network). And we performed the round-robin test on the effectiveness of the VHF-LISN.

WED-AM-2, Signal Integrity-3 (TC10), Room 101B

Chair: Antonio Ciccomancini Scogna, CST
Co-Chair: Francesco Ferranti, Ghent University

8:30 am **FPGA Core PDN Design Optimization** 411

Zhuyuan Liu *(Altera Corporation, San Jose, CA, United States)*; Shishuang Sun *(Altera Corporation, San Jose, CA, United States)*; Peter Boyle *(Altera Corporation, San Jose, CA, United States)*

Abstract–This paper analyses and quantifies the impact of numbers of package power and ground balls and on-package decoupling capacitors (OPD) on an FPGA's on-chip core power distribution network (PDN) performance. Measurement methodologies are developed to study the PDN quality in both time domain and frequency domain. The PDN performance is evaluated from three aspects, the PDN noise amplitude, core logic maximum operation frequency, and system clock jitter. The findings help chip designers optimize the PDN design to achieve a cost and performance balance.

9:00 am **Measurement of Multiple Switching Current Components through a Bulk Decoupling Capacitor using a Lab-Made Low-Cost Current Probe** 417

Liang Li *(Missouri University of Science and Technology, Rolla, MO, United States)*; Jingook Kim *(Missouri University of Science and Technology, Rolla, MO, United States)*; Hanfeng Wang *(Missouri University of Science and Technology, Rolla, MO, United States)*; Songping Wu *(Missouri University of Science and Technology, Rolla, MO, United States)*; Yuzo Takita *(Sony Corporation, Tokyo, Japan)*; Hayato Takeuchi *(Sony Corporation, Tokyo, Japan)*; Kenji Araki *(Sony Corporation, Tokyo, Japan)*; Jun Fan *(Missouri University of Science and Technology, Rolla, MO, United States)*

Abstract–This paper presents a measurement-based data-processing approach to obtain parameters of multiple current components through a bulk decoupling capacitor for power integrity studies. A lab-made low-cost current probe is developed to measure the induced voltage due to the time-varying switching current. Then, a post data-processing procedure is introduced to separate and obtain the parameters of multiple current components. The results obtained by the proposed method are validated with other approaches.

9:30 am **Analytical Expressions for Transfer Function of Supply Voltage Fluctuation to Jitter at a Single-Ended Buffer** 422

Jingook Kim *(Missouri University of Science and Technology, Rolla, MO, United States)*; Soumya De *(Missouri University of Science and Technology, Rolla, MO, United States)*; Ketan Shringarpure *(Missouri University of Science and Technology, Rolla, MO, United States)*; Siming Pan *(Cisco Systems, Inc., San Jose, CA, United States)*; Brice Achkir *(Cisco Systems, Inc., San Jose, CA, United States)*; Jun Fan *(Missouri University of Science and Technology, Rolla, MO, United States)*; James L. Drewniak *(Missouri University of Science and Technology, Rolla, MO, United States)*

Abstract–In this paper, the transfer function of a supply voltage fluctuation to jitter is analytically solved for a single ended buffer in closed-form expressions. The expressions for the jitter transfer function is validated by comparison with HSPICE simulation, and applied to an example for statistical jitter estimation.

WED-AM-3, Shielding Theory (TC4), Room 102BC

Chair: Vil Arafiles, DoD
Co-Chair: John Kraemer, Rockwell Collins

8:30 am **Shielding Effectiveness of Metallic Enclosure with Rectangular Apertures at Various Polarizations** ..... N/A

Hwan Su Yoo *(Chungnam National University, Daejeon, Republic of Korea)*; Soong Keun Lee *(Chungnam National University, Daejeon, Republic of Korea)*; Eun Ha Kim *(Korea Automotive Technology Institute, Cheonan, Republic of Korea)*; Seung Real Ryu *(Korea Automotive Technology Institute, Cheonan, Republic of Korea)*; Jae Hyun Lee *(Chungnam National University, Daejeon, Republic of Korea)*; Dong Chul Park *(Chungnam National University, Daejeon, Republic of Korea)*

Abstract–Shielding effectiveness of metallic rectangular enclosure with rectangular apertures at horizontal polarization (HP), vertical polarization (VP), and circular polarization (CP) is investigated using CST's Microwave Studio tool. The magnetic polarizability of the rectangular apertures and the resonance modes of the metallic rectangular enclosure are introduced to analyze the simulation results. The dependence of the shielding effectiveness on the location of the calculation probe inside the enclosure and the arrangement of the rectangular apertures are investigated.

9:00 am **High-Performance Laminated Thin-Film Shield with Conductors and Magnetic Material Multilayer** 432

Keiju Yamada *(Toshiba Corporation, Yokohama, Japan)*; Masaaki Ishida *(Toshiba Corporation, Yokohama, Japan)*; Shimada Yutaka *(Tohoku University, Sendai, Japan)*; Masahiro Yamaguchi *(Tohoku University, Sendai, Japan)*

Abstract–This paper presents a laminated thin-film shield consisting of conductors and magnetic materials multilayer. The laminated shield provides a high shield performance in an ultrahigh frequency (UHF) band because the magnetic materials have high permeability and multi-reflection occur in the shield. Furthermore, the shield performance is enhanced at ferromagnetic resonance (FMR) frequency of the magnetic materials because the magnitude of complex permeability is maximized due to large imaginary part of permeability. We examined the shield mechanism of the laminated shield and a conductor shield by means of impedance calculations. The shield performance obtained by the impedance calculations coincides with that by finite element method (FEM) simulations. The laminated shield is fabricated using a CoNbZr thin-film layer with a thickness of 0.2 um and two Cu layers with a thickness of 0.4 um. Measured shield effectiveness of the laminated thin-film shield is 27 dB higher than that of the conductor shield at a frequency of 470 MHz, which is similar to the impedance calculation and FEM simulation.

9:30 am **Application of Double Layer Frequency Selective Surface for SMPS Shielding** 438

T.R. Suresh Kumar *(Muthayammal Engineering College, TamilNadu, India)*;
C. Venkatesh *(EBET Group of Institutions, TamilNadu, India)*

Abstract–While designing the metallic enclosure for electromagnetic shielding of electronic circuits, apertures on the enclosure walls for the purpose of signal cabling and ventilation become unavoidable. Conventional Enclosure design involves a repeated procedure where the hole position and locations are varied until the Shielding Effectiveness (SE) requirements met. In this paper Double Layer Frequency Selective Surface (DLFSS) is used to construct the walls of the SMPS Enclosure which involves simple procedure. The FSS constructed from Jerusalem Cross type apertures, etched on conducting walls without any dielectric substrate (to enable ventilation) act as a spatial band-pass filter. Even the design objective of the EM Shielding Enclosure is all-stop filter characteristics, the ventilation requirement impose the enclosure to allow certain band of EMI to pass. So the DLFSS is designed to pass a band of EMI at 15GHz which is acceptable to satisfy the EMC and ventilation requirements. DLFSS and Conventional SMPS enclosures are modelled and shielding effectiveness is calculated and compared.

WED-AM-4, Topics in HPEM (TC5), Room 103A

Chair: William Radasky, Metatech Corporation
Co-Chair: Michael McInerney

8:30 am **An Equivalent Source Model for the Study of Radiated Electromagnetic Fields in Multi-Machine Electric Drive Systems** 442

M.R. Barzegaran *(Florida International University, Miami, FL, United States)*;
A. Sarikhani *(Florida International University, Miami, FL, United States)*;
O.A. Mohammed *(Florida International University, Miami, FL, United States)*

Abstract–In this paper we develop an equivalent model for electrical machines which is useful for the study of radiated electromagnetic fields in a multi source environment. The proposed models are created from a representative cylinder loops and cubes carrying a set of currents in the cylinder branches as well as voltages at the nodes of the cubes or loops. The amount of current and voltage of the model are obtained based on the current density and electric field displacement of the windings of the actual machines. The geometry of the cube model were calculated based upon a genetic algorithm-based particle swarm minimization process taking into consideration the actual size and the operating conditions of drive system being studied. To investigate the accuracy of model, the electric and magnetic fields propagated from the model at a point far from the drive systems were compared with the actual model. The simulated results show excellent accuracy and practical simulation time compared to full three dimensional finite element model of actual machine. This makes the proposed model ideal for the development of accurate tools for the estimation of radiated electromagnetic field emissions from electric drives and multi conductor environments during their development stage. For verification, the equivalent model is used in multi machine scale and the results of the equivalent model of multi machine case match the result of the actual model case.

9:00 am **Zero CM Voltage Multilevel Inverters for Smart Grid Applications** 448

Robert Smolenski *(University of Zielona Gora, Zielona Gora, Poland)*; Adam Kempski *(University of Zielona Gora, Zielona Gora, Poland)*; Jacek Bojarski *(University of Zielona Gora, Zielona Gora, Poland)*; Piotr Lezynski *(University of Zielona Gora, Zielona Gora, Poland)*

Abstract–In the paper multilevel inverters with common mode (CM) voltage compensators are recommended as voltage sources that can constitute the main components of the energy balancing systems for end-user customers. These systems are a part of the modern LV and MV smart grids. Measurements have been provided from a power system consisting in multilevel inverters and a passive compensator assuring sinusoidal output voltages and zero CM voltage. The presented theoretical analyses and experimental results show that the main application problem with magnetic saturation of the CM choke becomes less important in multilevel inverters with specially selected modulation. This allows a reduction in size, weight and cost of inductive components of compensators in such applications.

9:30 am **Behavioral Circuit Modeling of Chokes with Multi-Resonances using Genetic Algorithm** 454

Stanislav Skibin *(ABB Switzerland Ltd., Baden-Dättwil, Switzerland)*;
Ivica Stevanović *(ABB Switzerland Ltd., Baden-Dättwil, Switzerland)*

Abstract–In this paper, a novel multi-resonance SPICE-compatible behavioral model of chokes and corresponding parameter extraction procedure are presented. The model takes into account common-mode and differential-mode behavior of the choke and can be applied to modeling both common-mode chokes and coupled DC chokes. The model parameters are obtained from a parameter extraction procedure based on genetic algorithm. The accuracy of the model and the validity of the method are demonstrated. Using this procedure, reliable models in the EMI conducted emission frequency range have been obtained.

WED-AM-5, Cables and Coupling (TC4)), Room 103B

Chair: Philip Keebler, EPRI

8:30 am **Modeling of Common Mode Currents Induced by Motor Cable in Converter Fed AC Motor Drives** 459

Jaroslaw Luszcz *(Gdansk University of Technology, Gdansk, Poland)*

Abstract–Analysis of conducted EMI in AC motor fed by pulse width modulated voltage converters requires to consider parasitic capacitances in converters, motor windings and feeding cables to be taken into account. Motor voltage transients and related common mode currents are significantly correlated with resonance effects occurring in load circuits. An analysis of frequency converter load impedance characteristics allows for identification and determination of frequency ranges in which the foremost contributions to EMI noise generation have the voltage ringing phenomena associated with the load parasitic capacitances. This paper presents a method to model an AC motor with a feeding cable in conducted EMI frequency range up to 30 Mhz. Distributed parasitic capacitances of AC motor windings are modeled by a ladder circuit. The proposed circuit model allows for an analysis of the influence of the motor feeding cable parameters on common mode currents generated in AC motor drive system, particularly in AC motor itself. The simulation results obtained based on the proposed ladder circuit model are verified by the experimental tests which has been carried out for an exemplary adjustable speed AC motor drive application.

9:00 am **On EM Disturbances over Digital Equipment used for Monitoring and Events Recording in a Power System** 465

Petre-Marian Nicolae *(University of Craiova, Craiova, Romania)*; Dorina-Mioara Purcaru *(University of Craiova, Craiova, Romania)*; Ileana-Diana Nicolae *(University of Craiova, Craiova, Romania)*; George Mihai *(ICMET, Craiova, Romania)*; Marian Duță *(ICMET, Craiova, Romania)*

Abstract–Some characteristics of a digital equipment used for parameters monitoring and events recording in a power system are presented. The PC-XX/104 PROCESS CONTROL equipment (PC/104 compatible) refers to modular structures that use a central unit for data acquisition and processing. The basic constructive variants include 8 analogue inputs (4 for voltages, 4 for currents) with (non)unified signals. The equipment can also operate in systems where several equipment are connected in a FB232 compatible network to provide communication between equipment separated by considerable distances. A synchronization between their real-time clocks is required in this case. For these equipment one presents specific matters related to the transmission modalities of EM disturbances that might influence data acquisition and processing. A special attention is paid to the capacitive couplings that allow the transmission of disturbances whose values exceed the limits imposed by the CISPR 11 norms. According to these norms, the solutions proposed for the improvement of the EMC corresponding to the digital equipment used for parameters monitoring and events recording in a power system are correct, certifying the obtaining of measurements immune to external EM disturbances.

9:30 am **Scrambling Data Signals for EMC Compliance** 471

David Norte *(InfoPrint Solutions Company, LLC, Boulder, CO, United States)*

** Nominated for Best Symposium Paper Award*

Abstract–This paper discusses the benefits of scrambling high-speed data signals for reducing the electromagnetic radiation from the electrical interconnects that propagate these signals. It is shown how maximum length sequences, generated through the use of tapped shift register scrambling structures, can significantly mitigate the electromagnetic interference from data signals that are inherently periodic in the time-domain. Specifically, it is shown how a 7-bit scrambler enabled the EMC margin of a system to be increased from -3.5dB without the scrambler, to +5.5dB with the scrambler, resulting in a +9dB improvement in the EMC performance of the system.

WED-PM-1, Emissions-2 (TC2) Room 101A, Room 101A

Chair: Don Heirman, Don HEIRMAN Consultants
Co-Chair: Tom Fagan, Raytheon Missile Systems

1:30 pm **Digital Automatic Calibration Method for a Time-Interleaved ADCs System used in Time-Domain EMI Measurement Receiver** 476
Hassan Hani Slim *(Technische Universität München, Munich, Germany)*;
Peter Russer *(Technische Universität München, Munich, Germany)*

Abstract–The sampling rate of state of the art analog to digital converters (ADCs) limits the base-band frequency range of real-time time domain electromagnetic interference (TD-EMI) measurement systems to 1 GHz. In this paper, a time interleaved sampling architecture is introduced to overcome this limitation and to extend the baseband of the time-domain EMI receiver. Using three parallel time-interleaved ADC converters a TD-EMI measurement system with 3 GHz base bandwidth has been realized. The misalignment effects are studied and an automatic calibration routine is introduced. The 40 dB spurious free dynamic range required by the CISPR standards is achieved.

2:00 pm **A Novel Time-Domain EMI Measurement System for Measurement and Evaluation of Discontinuous Disturbance According to CISPR 14 and CISPR 16** 480
Stephan Braun *(Gauss Instruments GmbH, Munich, Germany)*

Abstract–Measurement of electromagnetic interference has been performed in the past by EMI receivers operating in frequency domain. For the measurement of discontinuous disturbance for IT and Household appliances EMI receivers are used to tune to a specific frequency. The output of the Intermediate Frequency is connected to a disturbance analyzer. The measurement is repeated at four frequencies. Due to the limited dynamic range of the IF-Output in many cases the measurement has to be repeated with a higher attenuator setting. Such disturbance analysis can take up to 16 hours for the measurement of one device under test. Measurements of electromagnetic interference in time-domain allow to reduce the scan time in comparison to automated scans performed by the tuned selective voltmeters, which are known as EMI receivers. By real-time implementation of several thousand Quasi-Peak Detectors on the FPGA and real-time evaluation of the virtual IF-Signal at several frequencies calculated at the same time scan time is reduced. In this paper a time-domain EMI measurement system covering the frequency range 9~kHz~-~18~GHz is presented that allows to measure emissions according to CISPR 16-1-1, and perform the discontinuous disturbance analysis as described by CISPR 16-1-1, CISPR 14-1 and CISPR 22. Measurements on household appliance are shown.

2:30 pm **Noise Cancelling Algorithms for FPGA-Based Time-Domain EMI Measurements in Real-Time** 484
Arnd Frech *(Gauss Instruments GmbH, Munich, Germany)*; Steffen Limmer *(Technische Universität München, Munich, Germany)*; Peter Russer *(Technische Universität München, Munich, Germany)*

Abstract–Traditionally measurements of electromagnetic interference (EMI) are carried out in frequency domain resulting in long testing times according to the frequency range and resolution in frequency. By applying time-domain technology EMI measurements can be done now in real-time for a broad frequency range of several hundred megahertz. This paper presents advanced strategies with real-time capability for adaptive noise cancellation based on a powerful hardware platform to enable EMI measurements in the presence of electromagnetic ambient noise on open test sites. Frequency domain and time-domain adaptive filtering are compared. Two adaptive filter algorithms are enhanced in respect of implementing the noise cancelling algorithm on field programmable gate arrays. Ensuring a continuous high data-throughput by an optimized digital signal processing real-time noise suppressing is shown in frequency bands of over 125 MHz at once.

WED-PM-2, Signal Integrity-4 (TC10), Room 101B

Chair: Xiaoning Ye, Intel
Co-Chair: Jun Fan, Missouri University of Science and Technology

1:30 pm **Automated Dielectric Constant and Loss Tangent Characterization using Cavity Resonators** 509
Pavithra Pasunoori *(San Diego State University, San Diego, CA, United States)*;
A. Ege Engin *(San Diego State University, San Diego, CA, United States)*

Abstract–A simple method for dielectric constant characterization is the full sheet resonance method. In this technique, the dielectric constant is extracted from the resonance frequencies of a parallel-plate waveguide resonator. The standard method cannot be applied to extract the loss tangent. Recently, the full-sheet resonance method has been extended to extract the loss tangent as well. The new method makes use of a new rapid plane solver and resonators with shorted boundaries. The materials properties are extracted by fitting the simulations to measurements. In this paper, we will demonstrate how the fitting process can be automated. In order to extract the dielectric constant and loss tangent, many simulations need to be run to find the parameters that provide the best match with the measurements. This is a computationally expensive approach. We will present a new method based on tracking sensitivity, which provides a parameterized macromodel for the resonators. Using this approach, the simulation data can be expressed as a low-order rational function of the complex permittivity. Hence, varying the complex permittivity to find the best fit can be done in negligible time after the macromodel has been generated. This new method will be applied to extract the dielectric constant and loss tangent of FR-4.

2:00 pm **Effect of Anisotropy on Extracted Dielectric Properties of PCB Laminate Dielectrics** 514
Marina Y. Koledintseva *(Missouri University of Science and Technology, Rolla, MO, United States)*;
James L. Drewniak *(Missouri University of Science and Technology, Rolla, MO, United States)*;
Scott Hinaga *(Cisco Systems, Inc., San Jose, CA, United States)*

Abstract–The effect of anisotropy of fiber-glass-filled epoxy resin composites, typically used as laminate dielectrics for manufacturing of printed circuit boards (PCB) is studied. It is shown that the extracted dielectric properties, the dielectric constant (Dk) and the dissipation factor (Df), depend significantly on the measurement technique, and first of all, how the electric field in a test fixture or a test vehicle is oriented with respect to the glass fiber bundles in the composite dielectric. The comparison of the dielectric properties obtained using the traveling-wave technique based on the S-parameter measurements and the split-post dielectric resonator technique are shown, and the discrepancy between the results is explained from the point of view of anisotropy and composite mixing theory.

2:30 pm **Roughness Characterization for Interconnect Analysis** 518
Yuriy Shlepnev *(Simberian Inc., Las Vegas, NV, United States)*;
Chudy Nwachukwu *(Isola Group, Chandler, AZ, United States)*

Abstract–A novel method for practical prediction of interconnect conductor surface roughness effect on multi-gigabit digital signals is proposed. A differential impedance operator of a conductor is constructed with Trefftz finite elements and locally adjusted with a correction coefficient to account for the roughness effect. Any correction coefficient derived for the additional power loss due to roughness can be used with the proposed method. Modified Hammerstad's correction coefficient is proposed and used here as an example. A test board is manufactured and investigated up to 50 GHz. Parameters of the conductor roughness model are identified with generalized modal S-parameters. An increase of effective dielectric constant due to conductor surface roughness is observed and explained by capacitive effect of spikes on the surface of conductor. It is shown that the constructed interconnect models are consistent with the measured data.

3:30 pm **Nickel Characterization for Interconnect Analysis** 524
Yuriy Shlepnev *(Simberian Inc., Las Vegas, NV, United States)*;
Scott McMorrow *(Teraspeed Consulting Group LLC, Narragansett, RI, United States)*

Abstract–Landau-Lifshits model of ferromagnetic metal permeability is proposed in the paper for broad-band characterization of nickel in PCB/packaging interconnects made of copper plated with nickel and gold (ENIG finish). Unknown parameters of the plated nickel are identified with the measured generalized modal S-parameters of nickel-plated microstrip line segment and electromagnetic analysis of the same segment with multi-layered conductor interior model. The model predicts dispersive frequency dependency of nickel permeability with a resonance between 2 and 3 GHz. The resonance produces an anomaly in the insertion loss and group delay consistent with the experimental data.

4:00 pm **Modeling SMT Ferrite Beads for SPICE Simulation** 530

C. Rostamzadeh *(Robert Bosch LLC, Plymouth, MI, United States)*; F. Grassi *(Politecnico di Milano, Milan, Italy)*; F. Kashefi *(Khavaran Institute of Science and Technology, Mashhad, Iran)*

Abstract–A practical approach for lumped-parameter circuit modeling of SMT ferrite beads is introduced. Vector Network Analyzer (VNA) measurements are utilized to provide the frequency-dependent characteristics for SPICE analysis. The measured data is imported into the simulation environment via Analog Behavioral Models (ABM) accounting for the frequency-dependent behavior of the ferrite sheets. It demonstrates a significant departure from a simple R-L-C circuit network. Model accuracy is validated up to 2 GHz by realization of an ad hoc test-board and by experimental characterization of the component in terms of Insertion Loss.

4:30 pm **Ferrite Bead Model Extraction and Its Application in High-Performance ASIC Analog Power Filtering** 536

Jianmin Zhang *(Cisco Systems, Inc., San Jose, CA, United States)*; Kelvin Qiu *(Cisco Systems, Inc., San Jose, CA, United States)*; Liming Yin *(Cisco Systems, Inc., San Jose, CA, United States)*; Rick Brooks *(Cisco Systems, Inc., San Jose, CA, United States)*; Bill Chen *(Tsinghua University, JiaXing, China)*

Abstract–High performance ASICs (Application-Specific Integrated Circuits) are getting dominant in modern high-end networking systems. Provisions on the power supplies for these extremely high integrated ASICs are somewhat demanding and strict especially for sensitive analog power rails. To meet the power requirements from ASIC vendors, ferrite bead is used to fulfil the analog filtering. In order to complete the filter design and analysis, a genetic algorithm is developed to extract circuit model from a ferrite bead impedance curve. The extracted circuit model is used for filter performance analysis. As a case study, the designed filter is implemented on a PCB (printed circuit board) in a real product. Measured power noise on the analog power rail confirms that the ferrite bead filter design is successful and the analog power meets the specifications from ASIC vendors.

WED-PM-3, Electromagnetics (TC4), Room 102BC

Chair: Dan Hoolihan, Hoolihan EMC Consulting

1:30 pm **Near-Field H to E Transformation using Plane Wave Spectrum Theory** 542

Zhenwei Yu *(Missouri University of Science and Technology, Rolla, MO, United States)*; Yaojiang Zhang *(Missouri University of Science and Technology, Rolla, MO, United States)*; Soji Sajuyigbe *(Intel Corporation, Hillsboro, OR, United States)*; Rodrigo Camacho *(Intel Corporation, Hillsboro, OR, United States)*; Jason A. Mix *(Intel Corporation, Hillsboro, OR, United States)*; Kevin Slattery *(Intel Corporation, Hillsboro, OR, United States)*; Matthew S. Halligan *(Missouri University of Science and Technology, Rolla, MO, United States)*; Jun Fan *(Missouri University of Science and Technology, Rolla, MO, United States)*

Abstract–Near-field measurements are widely used to indicate the radiation from integrated circuits (IC). To minimize the number of field components measured in a near-field scan, it is necessary to calculate the electric field from magnetic field or vice versa. In this paper, a method based on plane wave spectrum theory is proposed to perform the H to E transformation, and a filtering technique is proposed to address the noise problem in the calculation. A simple active circuit in a 3-D full-wave simulation tool is used to validate this method. This method is useful to reduce the number of field components to be measured, resulting in faster near-field scanning.

2:00 pm **Comparison of NEC Simulation and Measurement Methods for the Solution of Coupling between Airborne Antennas** 547

Mustafa Emre Aydemir *(Turkish Air Force Academy, Istanbul, Turkey)*

Abstract–In this study, the optimization of the electromagnetic interference (EMI) induced by two aircraft on-board VHF-UHF transreceiver antennas is implemented. The EMI reduction is implemented by varying the antenna positions and orientations. The transreceiver antennas are modelled as single monopole antennas therefore the problem is reduced to antenna-to-antenna coupling optimization. The Method of Moments (MoM) is selected for the EMI analysis and the continuous parameter Genetic Algorithm (CPGA) is chosen for the optimization method. The results of the numerical analysis are verified by the measurement on a 1:10 scaled model in an anechoic chamber.

2:30 pm **Modelling Electromagnetic Field Coupling from an ESD Gun to an IC** 553

Ji Zhang *(Missouri University of Science and Technology, Rolla, MO, United States)*;
Daryl G Beetner *(Missouri University of Science and Technology, Rolla, MO, United States)*;
Richard Moseley *(Freescale Semiconductor, Inc., Austin, TX, United States)*; Scott Herrin *(Freescale Semiconductor, Inc., Austin, TX, United States)*; David Pommerenke *(Missouri University of Science and Technology, Rolla, MO, United States)*

** Nominated for Best Symposium Paper Award*

Abstract–IC designers require fast and accurate methods of simulating immunity of ICs to ESD events to adequately predict and analyze ESD issues. The common method of predicting electromagnetic field coupling from an ESD gun to an IC, however, requires substantial simulation time and does not typically account for the full IC layout. Here we propose an efficient methodology for calculating the electromagnetic field coupling from an ESD gun to an IC while fully considering the non-linear circuit elements in the IC core. Voltages and currents within the IC are found by merging full-wave simulations of an ESD gun with a SPICE model of the IC and the coupled electromagnetic energy. The capability of the proposed method was verified through experiments on a pseudo- integrated circuit structure. Results show the promise of the method. This hybrid modelling method can significantly accelerate simulation time compared with traditional full-wave modelling techniques and can allow the designer to better explore the variation in coupling that occurs with small changes in the test setup, such as the position and orientation of the gun and IC.

3:30 pm **On the Possibility to Detect and Visualize Electromagnetic Coupling Paths** 559

Hongyu Li *(Missouri University of Science and Technology, Rolla, MO, United States)*;
Victor Khilkevich *(Missouri University of Science and Technology, Rolla, MO, United States)*;
David Pommerenke *(Missouri University of Science and Technology, Rolla, MO, United States)*;
Yaojiang Zhang *(Missouri University of Science and Technology, Rolla, MO, United States)*;
Jun Fan *(Missouri University of Science and Technology, Rolla, MO, United States)*

Abstract–Out of the source – coupling path – victim concept, the coupling path is the most difficult to identify. This paper discusses several possible methods to detect and visualize electromagnetic coupling paths in EMC problems. The authors do not have a ready-made solution and hope this paper could inspire others to join us in the search of methods for the detection and visualization of coupling paths.

4:00 pm **Suppression of RF Interference using Balanced Filter in Communication System** 564

Hung-Chuan Chen *(National Taiwan University, Taipei, Taiwan)*;
Tzong-Lin Wu *(National Taiwan University, Taipei, Taiwan)*

Abstract–A new differential feeding scheme is proposed to degrade the influence of common-mode noise on antennas. The radiation pattern of the antenna becomes asymmetrical as the common-mode noise coupled to the antenna. The conventional differential feeding line is replaced with the proposed balanced filter. The balanced filter is designed at the operating frequency of the antenna and provide over 40 dB common-mode rejection level around the differential-mode passband. By incorporating the proposed balanced filter into the antenna, the radiation pattern of the antenna becomes symmetrical and the cross-polarization level is also reduced over 25 dB at the operating frequency of the antenna.

4:30 pm **Methodological Approach to Making an Electromagnetic Chart for Object of Informatization** ..... N/A

Fedor Baidin *(FSUE "CenterInform", Saint-Petersburg, Russian Federation)*;
Michael Zhukovsky *(FSUE "CenterInform", Saint-Petersburg, Russian Federation)*;
Ruslan Kirichek *(FSUE "CenterInform", Saint-Petersburg, Russian Federation)*;
Vladimir Chvanov *(FSUE "CenterInform", Saint-Petersburg, Russian Federation)*

Abstract–A methodical approach has been suggested for development of the informatization object electromagnetic map, which allows to optimize placement of the object elements in the premises and determine the levels of external loadings during the testing for resistance to deliberate electromagnetic influences. General principles have been considered, and an example of practical realization of map development on a model object has been given.

WED-PM-4, Transients and Material Characterizations (TC9), Room 103A

Chair: Al Roden, Aerospace Corp
Co-Chair: Richard Dubroff, Missouri University of Science & Technology

1:30 pm **Full-Wave EMC Simulations using Maxwell Garnett Model for Composites with Cylindrical Inclusions** 573

M.H. Nisanci *(University of L'Aquila, L'Aquila, Italy)*; F. de Paulis *(University of L'Aquila, L'Aquila, Italy)*; M. Koledintseva *(Missouri University of Science & Technology, Rolla, MO, United States)*; A. Orlandi *(University of L'Aquila, L'Aquila, Italy)*

Abstract–Four different models for effective dielectric properties of biphasic composite containing random or aligned cylindrical inclusions are considered in this paper. These models are based on the Maxwell Garnett (MG) mixing rule. The effects of distribution and orientation of cylindrical inclusions in a composite material is studied. An equivalent averaged material with Debye-like frequency characteristics, suitable for timedomain full-wave numerical electromagnetic simulations is retrieved. This Debye model is derived from the Maxwell Garnett formulation. The numerical model test structure consists of a composite slab inserted in a rectangular waveguide. Simulations are run for the frequency range above the cut-off frequency of the fundamental mode TE10. The differences between the proposed models are quantified using the Feature Selection Validation (FSV) tool. The comparison of the models provides an insight on the effect of inclusion orientation and distribution.

2:00 pm **Investigation on Electromagnetic Responses of Some Complex Wire-Surface Composite Objects using Hybrid TDIE-TDPO based MOT Method** 579

Wei Luo *(Shanghai Jiao Tong University, Shanghai, China)*; Wen-Yan Yin *(Zhejiang University, Hangzhou, China)*; Ming-Da Zhu *(Shanghai Jiao Tong University, Shanghai, China)*; Jun-Fa Mao *(Shanghai Jiao Tong University, Shanghai, China)*

** Nominated for Best Symposium Paper Award*

Abstract–An efficient hybrid method, based on time-domain integral equation (TDIE) and time-domain physical optics (TDPO), is proposed for investigating on electromagnetic responses of some complex wire-surface composite objects illuminated by an electromagnetic pulse (EMP), respectively. Three triangular-type basis functions are used to represent the currents on the bodies, wires, and wire/surface junctions, respectively. A set of hybrid TDIE-TDPO equations are solved by marching-on-in-time scheme (MOT). In comparison with the full TDIE-based MOT method, computational complexity is reduced drastically using our developed hybrid TDIE-TDPO method, and with the accuracy maintained successfully. Numerical results of EMP responses of some composite objects are given to demonstrate its versatility, accuracy and efficiency.

2:30 pm **Solution of Time-Domain MFIE and CFIE using Adaptive MOO Method for Transient Scattering in the Presence of an EMP** 585

Ming-Da Zhu *(Shanghai Jiao Tong University, Shanghai, China)*; Xi-Lang Zhou *(Shanghai Jiao Tong University, Shanghai, China)*; Wen-Yan Yin *(Zhe Jiang University, Hangzhou, China)*

Abstract–The adaptive marching-on-in-order method (MOO) to solve time-domain magnetic and combined field integral equations is proposed for capturing transient responses of some 3-D PEC objects illuminated by an EMP. We directly employ an exact temporal Galerkin testing with no central approximation used, and using surface current density of the object as the unknown without employing the Hertz vector. The fast Fourier transform (FFT)-based blocking scheme is further implemented. This method is similar to the improvement over the earlier MOO for solving time-domain eclectic field integral equation. Transient electromagnetic responses of some typical conductive objects are obtained and compared for validating both computational accuracy and applicability of our proposed three TDIE-MOO algorithm.

3:30 pm **Transient Electromagnetic Topology-Based Analysis of EMP Interaction with a Computer Network** ..... N/A

Haiyan Xie *(Northwest Institute of Nuclear Technology, Xi'an, China)*;
Jianguo Wang *(Northwest Institute of Nuclear Technology, Xi'an, China)*;
Ruyu Fan *(Northwest Institute of Nuclear Technology, Xi'an, China)*

** Nominated for Best Symposium Paper Award*

Abstract–This paper reviews the transient electromagnetic topology (TEMT) technique, which can be used for the vulnerability analysis of nonlinear systems, and discusses whether the TEMT method is appropriate to analyse complex systems. The interferences generated by electromagnetic pulses (EMPs) on a computer network given by different standards are studied by using the TEMT method. The results indicate that the EMP defined by the international electrotechnical commission generates largest interferences on this computer network and the TEMT method has the ability to solve such complicated problems.

4:00 pm **Mixed Finite Element Time Domain Method based on Iterative Leapfrog Scheme for Fast Simulations of Electromagnetic Problems** 596

Tadatoshi Sekine *(Shizuoka University, Hamamatsu-shi, Japan)*;
Hideki Asai *(Shizuoka University, Hamamatsu-shi, Japan)*

Abstract–This paper describes a fast finite-element timedomain (FETD) method using an iterative procedure of a leapfrog scheme. It is well known that existing FETD methods based on the leapfrog scheme has a limitation on a time step size because the scheme is one of the explicit time integration methods. To overcome the limitation and develop a more numerically stable FETD method, we improve the leapfrog scheme by using a matrix splitting algorithm. First, an existing mixed E-B finite element method is reviewed to discretize a space components of Maxwell's curl equations. Then, it is shown that the existing leapfrog mixed (LM)-FETD method is equivalent to the scheme based on the Crank-Nocolson (CN) method and the matrix splitting algorithm. After that, we propose the iterative leapfrog mixed (ILM)-FETD method. Because iterative solutions in the ILMFETD method converge to the solutions obtained by the CN-FETD method, which is unconditionally stable, the proposed method can use a relatively larger time step size than the existing LM-FETD method. Some numerical results show that the ILMFETD method is about 4 times faster than the existing LM-FETD method with appropriate accuracy.

4:30 pm **Analytical and Numerical Simulation Models for Calculating EMI into Circuits Due to ESD Radiated Fields** 602

Spartaco Caniggia *(EMC Consultant, Milano, Italy)*;
Francescaromana Maradei *(Sapienza Università di Roma, Rome, Italy)*

Abstract–This paper provides a discussion on the validity of analytical and numerical models for calculating interference into circuits due to ESD radiated fields. The analytical model consists in the dipole model proposed by Wilson et All in [1] to model the discharge tip. An ESD produced by a generator for testing is numerically modeled using the soft-ware tool MicroWave Studio (MWS). In this simulation model the body of the generator and the effect of the strap is taken into account. The aim of the discussion is to investigate the limitations of the dipole model, the influence of the ESD gun and strap used in a realistic testing, and pro-vide some considerations on the overestimation occurring with the use of the simple analytical model.

5:00 pm **A Comparison of Electric Field Sensors Distortion Characteristics in the Hermite-Gauss Signal Subspaces** 607

Shekoofeh Saboktakin Rizi *(University of Manitoba, Winnipeg, Canada)*;
Behzad Kordi *(University of Manitoba, Winnipeg, Canada)*

Abstract–In addition to the classical time-domain distortion characteristic known as fidelity, one can evaluate sensor distortion characteristic using the transformation matrix concept in linear algebra. In this paper, electromagnetic field sensor transformation matrix is calculated based on a set of Hermite-Gauss orthonormal functions. The transformation matrices are calculated for a 5-cm Asymptotic Conical Dipole (ACD), wire monopoles of lengths 5 and 8.5 cm, and L-antennas with the same heights using the simulated voltages. The simulation is performed by solving an Electric Field Integral Equation (EFIE) on wire structures using the Method of Moments (MoM). Transformation matrices are calculated for the sensors with the same level of sensitivity as a measure of distortion. Transformation matrices are compared to each other using a numerical measure.

WED-PM-5, Special Session: Signal Integrity for High Speed Connectors), Room 103B

Chair: Howard Johnson, Signal Consulting Inc.

1:30 pm **High-Speed Backplane Connectors** 612
Howard W. Johnson *(Signal Consulting Inc., Twisp, WA, United States)*

Abstract–Printed circuit board (PCB) backplanes and backplane connectors form the cornerstone of many large system architectures, particularly in the fields of communication and high-performance computing. This paper investigates the limits to the electrical performance of backplane connectors. It discusses the main factors affecting performance, and predicts the future of backplane connector development.

2:00 pm **Multiport VNA Measurement Uncertainty – Signal Integrity Applications** 619
Brett Grossman *(Intel Corporation, Hillsboro, OR, United States)*; Michael Peterson *(Intel Corporation, Hillsboro, OR, United States)*; Jose Torres *(Intel Corporation, Chandler, AZ, United States)*

Abstract–Vector network analyzer (VNA) measurements are often stated without an indication of the estimated uncertainty. Understanding the uncertainty can lead to understanding the sources of uncertainty and targeting improvements in the metrology to address the largest sources. Connector repeatability in manually probed measurements can be a primary source of uncertainty with this metrology. A measurement capability assessment provides the method for evaluating the total uncertainty. Evaluation of the probe launch and cable movement provided substantial opportunities to improve the capability. Implementing improvements identified through the measurement capability assessment (MCA) process has resulted in a doubling of the highest frequency where the metrology is deemed capable.

2:30 pm **Benefits of Reversing the Circuit Manufacturing and Assembly Processes for Electronic Products** 624
Joseph Fjelstad *(Verdant Electronics, Cupertino, CA, United States)*

Abstract–The paper reviews the benefits of reversing the electronic manufacturing process to preclude the need for solder which has been a method of choice for more than six decades. The paper discusses details of prospective future structures which can be manufactured in a reverse manner and suggests some of the performance benefits both electrical and mechanical that can be secured.

WED-PM-6, Special Session: EMC in Space, Room 103C

Chair: Ray Perez, Jet Propulsion Laboratory
Co-Chair: James Lukash, Lockheed Martin

1:30 pm **Design and Development of an Equipotential Voltage Reference (Grounding) System for a Low-Cost Rapid-Development Modular Spacecraft Architecture** 629
James A. Lukash *(Lockheed Martin Space Systems, Sunnyvale, CA, United States)*; Earl Daley *(NASA Ames Research Center, Moffet Field, CA, United States)*

Abstract–This work describes the design and development effort to adapt rapid-development space hardware by creating a ground system using solutions of low complexity, mass, & cost. The Lunar Atmosphere and Dust Environment Explorer (LADEE) spacecraft is based on the modular common spacecraft bus architecture developed at NASA Ames Research Center. The challenge was building upon the existing modular common bus design and development work and improving the LADEE spacecraft design by adding an Equipotential Voltage Reference (EVeR) system, commonly referred to as a ground system. This would aid LADEE in meeting Electromagnetic Environmental Effects (E3) requirements, thereby making the spacecraft more compatible with itself and its space environment. The methods used to adapt existing hardware are presented, including provisions which may be used on future spacecraft.

2:00 pm **An Electromagnetic Modelling Tool for Radio Frequency Interference Caused by Plasma Plumes** 635

M. Bandinelli *(IDS Ingegneria dei Sistemi, Pisa, Italy)*; L. Pandolfo *(IDS Ingegneria dei Sistemi, Pisa, Italy)*; J.L. Araque Quijano *(Polytechnic of Turin, Turin, Italy)*; G. Vecchi *(Polytechnic of Turin, Turin, Italy)*; H. Pawlak *(OHB-System AG, Bremen, Germany)*; F. Marliani *(European Space Agency, Noordwijk, Netherlands)*

Abstract–Electric propulsion is a commercially attractive solution for attitude and position control of geostationary satellites. Hall-effect ions thrusters generate a localized plasma flow in the surrounding of the satellite, whose impact on the communication system needs to be qualitatively and quantitatively assessed. An electromagnetic modelling tool was developed and integrated into a commercial numerical solver. The plasma plume was modelled as a time-varying low density non-homogeneous dielectric. The geometrical optics (GO) approximation was used to study the propagation through the plume. Equivalent currents were computed on a surface around the plasma plume (Huygens principle) and made radiate to get the scattered field ("aperture integration"). Measurements were performed on two Hall-effect and one HEMP thrusters in a vacuum facility to validate the modelling tool. The test data of the HET PPS-1350 manufactured by Snecma are reported.

2:30 pm **EMI/EMC, Lightning, Radiation Shielding Design Approach for the Dragon COTS Spacecraft: Part I** 641

W. Elkman *(Space Exploration Technologies, Hawthorne, CA, United States)*;
J. Trinh *(Space Exploration Technologies, Hawthorne, CA, United States)*;
P. McCaughey *(Space Exploration Technologies, Hawthorne, CA, United States)*;
W. Chen *(Space Exploration Technologies, Hawthorne, CA, United States)*

Abstract–Designing the Dragon COTS (Commercial Orbital Transfer System) for EMI/EMC interface compliance to the International Space Station (ISS) is a complex task. It involves designing Dragon for self-compatibility, compatibility with the Falcon 9 Launch Vehicle, designing to the LEO Space radiation environment, as well as interface compatibility to the ISS mechanical, electrical and RF interfaces. This paper describes the Space Exploration Technologies tailored approach to achieve Dragon spacecraft self-compatibility, compatibility with the Eastern Launch Range RF requirements and interface compatibility to SSP 30237, 30238 and 30243, respectively, the ISS requirements for EMC emissions and susceptibility, and test methods for verification and overall ISS EMC compatibility. The detailed design analysis methods used to predict design performance are described, as well as the detailed tailored test methods used to verify functional performance and margins to the Falcon 9 LV, Eastern Launch Range RF requirements, and the ISS suite of EMC and survivability requirements.

3:30 pm **EMI/EMC, Lightning, Radiation Shielding Verification Approach for the Dragon COTS Spacecraft: Part II** 647

W. Elkman *(Space Exploration Technologies, Hawthorne, CA, United States)*;
J. Trinh *(Space Exploration Technologies, Hawthorne, CA, United States)*;
P. McCaughey *(Space Exploration Technologies, Hawthorne, CA, United States)*;
W. Chen *(Space Exploration Technologies, Hawthorne, CA, United States)*

Abstract–Designing the Dragon COTS (Commercial Orbital Transfer System) for EMI/EMC interface compliance to the International Space Station (ISS) is a complex task. It involves designing Dragon for self-compatibility, compatibility with the Falcon 9 Launch Vehicle, designing to the LEO Space radiation environment, as well as interface compatibility to the ISS mechanical, electrical and RF interfaces. This paper describes the Space Exploration Technologies tailored approach to achieve Dragon spacecraft self-compatibility, compatibility with the Eastern Launch Range RF requirements and interface compatibility to SSP 30237, 30238 and 30243, respectively, the ISS requirements for EMC emissions and susceptibility, and test methods for verification and overall ISS EMC compatibility. The detailed design analysis methods used to predict design performance are described, as well as the detailed tailored test methods used to verify functional performance and margins to the Falcon 9 LV, Eastern Launch Range RF requirements, and the ISS suite of EMC and survivability requirements.

4:00 pm **Geosynchronous ESD Environment Characterization via in situ Measurements on Host Spacecraft** 653

Justin J. Likar *(Lockheed Martin Space Systems, Newtown, PA, United States)*; Alexander L. Bogorad *(Lockheed Martin Space Systems, Newtown, PA, United States)*; Robert E. Lombardi *(Lockheed Martin Space Systems, Newtown, PA, United States)*; David Pitchford *(SES Engineering, Luxembourg, Luxembourg)*; Roman Herschitz *(Lockheed Martin Space Systems, Newtown, PA, United States)*

Abstract–Controlling and mitigating spacecraft charging effects requires prudent design, test, and verification measures to related to material surface properties when exposed to a variety of operational and environmental conditions. In this paper we use two targeted sensors to characterize the surface charging environment and threat of surface / differential charging for June to October 2010. Surface potential measurements and ~4 keV to ~40 keV electron flux measurements are utilized to investigate the timescale of charging events, study complementary results amongst sensors on nearby spacecraft, and develop a process for near-real time charging threat assessment aboard host spacecraft. Findings are relevant for assessments of space system impacts resulting from surface discharges and ESD, simulations of surface charging, and laboratory testing of flight systems designs.

4:30 pm **Solar Radio Burst Effects on Wireless Systems** 661

Dale E. Gary *(New Jersey Institute of Technology, Newark, NJ, United States)*

Abstract–The Sun is capable of producing strong radio emission during times of flaring activity that can directly affect wireless communication and navigation systems without warning. We give some examples of specific effects that have been documented, including increased dropped-call levels on cellular telephone systems and system-wide interference on the Global Positioning System (GPS). To assess the potential and degree of risk presented by radio outbursts from the Sun, we survey what is known about the frequency of occurrence of solar bursts as a function of frequency and time. We show that a firm assessment of risk remains unknown due to lack of complete coverage in the monitoring of solar bursts, but we present some expectations based on current knowledge. We conclude that effects on wireless systems in space are likely to occur, but can be mitigated by considering and accounting for solar burst properties.

THURSDAY TECHNICAL PAPERS

Thursday, August 18, 2011

THU-AM-1, Reverberation (TC2), Room 101A

Chair: Diane Kempf, Naval Air Warfare Center Aircraft Division

8:30 am **Impact of Statistical Parameter Options on Reverberation Chamber Test Environment** 665

Vignesh Rajamani *(Oklahoma State University, Stillwater, OK, United States)*; Gustav J. Freyer *(Consultant, Monument, CO, United States)*

Abstract–Electromagnetic compatibility immunity tests help to assure that electronic equipment will function properly in its operational electromagnetic environment. Several techniques are available to perform Standards compliance testing. All available techniques yield uncertainties in the immunity test results. The statistical isotropy of the electromagnetic environment in a Reverberation Chamber implies similar magnitude fields in any arbitrary direction providing an all aspect angle test. This paper addresses the magnitude of the variations in the three dimensional fields resulting from specific choices in test parameters.

THU-AM-2, Electromagnetic Band Gap Filters (TC10), Room 101B

Chair: Tzong-Lin Wu, National University of Taiwan
Co-Chair: Francesco De Paulis, University of L'Aquila

8:30 am **Analysis and Design of GHz Power Noise Isolation using 45° Rotated Photonic Crystal Fence** 699
Antonio Ciccomancini *(CST of America, Inc., Framingham, MA, United States)*; Antonio Orlandi *(University of L'Aquila, L'Aquila, Italy)*; Tzong-Lin Wu *(National Taiwan University, Taipei, Taiwan)*; Ting-Kuang Wang *(National Taiwan University, Taipei, Taiwan)*

Abstract–A photonic crystal fence (PCF) is proposed for noise isolation with minimum use of high dielectric constant (DK) rods material. Only three rows of periodic high-DK rods are used in the PCF, but broadband and high efficient noise suppression are retained. It will be shown that a 450 rotated square lattice represents a good compromise in terms of both high-DK material reduction (cost reduction) and noise suppression performance. A design flow for choosing the high-DK rod radius, pitch, and dielectric constant for the PCF is also demonstrated.

9:00 am **Compact Configuration of a Planar EBG based CM Filter and Crosstalk Analysis** 704
F. de Paulis *(University of L'Aquila, L'Aquila, Italy)*; L. Raimondo *(University of L'Aquila, L'Aquila, Italy)*; B. Archambeault *(IBM Corporation, Research Triangle Park, NC, United States)*; S. Connor *(IBM Corporation, Research Triangle Park, NC, United States)*; A. Orlandi *(University of L'Aquila, L'Aquila, Italy)*

Abstract–This paper introduces a compact configuration for a planar EBG-based common mode filter in order to reduce its dimensions in the layout phase of a printed circuit board. The performance of the proposed CM filter is studied both in frequency and time domain looking at the common mode reduction and the correct propagation of the intentional differential signal. The energy coupling from the common mode signal to the power plane cavity resonant modes can create crosstalk problems on other traces crossing the same gaps. The fundamental mechanisms of this effect are investigated and the crosstalk at the near end and far end are quantified and compared to the ideal case of a solid reference plane.

9:30 am **Noise Isolation Modeling of Partial EBG Power Bus using Segmentation Method and Cavity Model in Multi-Layer PCBs** 710
Myunghoi Kim *(KAIST, Daejeon, Republic of Korea)*; Kyoungchoul Koo *(KAIST, Daejeon, Republic of Korea)*; Joungho Kim *(KAIST, Daejeon, Republic of Korea)*

Abstract–In this paper, we present a new modeling approach based on a segmentation method for noise isolations of a power bus in which partial electromagnetic bandgap (EBG) structures are embedded. When the EBG structure is inserted partially in the power bus, the stopband characteristics such as the cut-off frequencies and the noise isolation level are different from those predicted by the models assuming infinite EBG cells. The proposed modeling approach enables to predict the noise coupling coefficient of the partial EBG power bus accurately in the stopband as well as the passband. In the proposed modeling, the partial EBG power bus is divided into three segments of the partial EBG structures and the different size rectangular power/ground planes. The partial EBG structure is further divided vertically and modeled as the transmission line networks with via structure and a rectangular plane cavity model. The proposed modeling approach based on the segmentation method has been validated by good agreement between the modeling result and the electromagnetic simulation result.

10:30 am **Bandwidth-Enhanced EBG Structure for Power Noise Suppression in 60 GHz RF SiP** 715
Chuen-De Wang *(National Taiwan University, Taipei, Taiwan)*; Tzong-Lin Wu *(National Taiwan University, Taipei, Taiwan)*

Abstract–A novel EBG structure is proposed to mitigate power noise in the power distribution network of RF SiP. The design concepts and measured results of the proposed EBG structure are investigated in this paper. Finally, the proposed EBG PDN is employed to suppress the power noise and intermodulation distortion of the RF output spectrum.

11:00 am **A Novel and Cost-Effective Method to Suppress GHz Common-Mode Radiation for Slot-Crossing Differential Lines** 720

Hao-Hsiang Chuang *(National Taiwan University, Taipei, Taiwan)*;
Tzong-Lin Wu *(National Taiwan University, Taipei, Taiwan)*

Abstract–By placing two asymmetrical open-stubs (ground resonators) beside the slot-crossing differential line, the radiated emission induced by common-mode noise is greatly reduced around the interested frequency. According to the proposed equivalent circuit model and the design formulas, these ground resonators can provide a shorting path for the common-mode return current around the resonant frequency and prevent the noise from exciting the antenna-like slotline. Based on the proposed concept, the solution board and the reference board are both fabricated by typical PCB process. The experimental results demonstrate that the normalized total loss of the common-mode is effectively reduced by the connected ground resonators around the designed frequency range. Also, the simulated results indicate that the radiated emission caused by the slot-crossing common-mode noise is greatly reduced more than 5 dB from 2.34 GHz to 3.55 GHz. It is a cost-effective solution to reduce the radiated emission from the slot-crossing common-mode noise around GHz frequency range on high-density package or PCB.

THU-AM-3, EMC in Circuits and Devices (TC4), Room 102BC

Chair: Philip Keebler, EPRI
Co-Chair: Randy Flanders, RTF Compliance

8:30 am **A Fast Analysis of Electromagnetic Immunity Responses of RF Amplifier Circuit under CW/Digital-Modulation Schemes** 724

Han-Chang Hsieh *(National Taiwan University, Taipei, Taiwan)*; Jay-San Chen *(Bureau of Standards, Metrology & Inspection, Taipei, Taiwan)*; Chi-Hsueh Wang *(National Taiwan University, Taipei, Taiwan)*; Cheng-Nan Chiu *(Da-Yeh University, Changhua, Taiwan)*; Ming-Shing Lin *(National Yunlin University of Science & Technology, Yunlin, Taiwan)*; Chun Hsiung Chen *(National Taiwan University, Taipei, Taiwan)*

Abstract–This paper presents a fast analysis of the radiated susceptibility (RS) problem associated with the microstrip amplifier, which is illuminated by a uniform plane incident wave. By using the field-equations incorporated ADS commercial circuit platform, the electromagnetic immunity responses of RF amplifier circuits, especially under digital modulation scheme, may efficiently be addressed. In this study, the simulated field-induced terminal voltages of microstrip single-stage RF amplifier circuit are presented and carefully examined with the results from measurements also included for validation.

9:00 am **Prediction and Reduction of Electromagnetic Conducted Emission in Active Clamp Forward Converter** 729

Yan Zhou *(Huawei Technology Co., Ltd., ShenZhen, China)*; Yongfa Zhu *(Huawei Technology Co., Ltd., ShenZhen, China)*; Qingliang Song *(Huawei Technology Co., Ltd., ShenZhen, China)*; Zhaoguo Jin *(Huawei Technology Co., Ltd., ShenZhen, China)*; Dan Yang *(Huawei Technology Co., Ltd., ShenZhen, China)*; Xuequan Yu *(Huawei Technology Co., Ltd., ShenZhen, China)*

Abstract–Now, the main way to solve the conducted electromagnetic interference of power converter is "testing – modifying – testing". This causes delivery delays and cost increases. This paper presents a flow for solving these problems. The whole-link circuit models of active clamp forward (ACF) converter are constructed based on the CE noise sources and paths. The conducted emission (CE) noise can be predicted by the whole-link circuit models which have been verified by experiment. A set of CE noise reduction techniques for ACF converter are proposed which have been confirmed by experiment.

9:30 am **EMC Problems of Power Electronic Converters** 734

Pavel Drabek *(West Bohemia University, Pilsen, Czech Republic)*

Abstract–Power electronic converters produce not only characteristic harmonics, but also both non-characteristic harmonics and interharmonics. This paper presents the physical background of both non-characteristic harmonics and interharmonics. Generation causes are explored and discussed in detail. Extensive series of simulation of different power converter topologies are provided and compared with experimental results and existing standards. This research offers missing background for standards covering low-frequency EMC.

10:30 am **Numerical and Metrological Investigations for Pacemakers with Unipolar and Bipolar Electrodes in Electric and Magnetic Fields** 740

Sven Hille *(University of Applied Science, Institute of Electrical Engineering, Leipzig, Germany)*; Karl Friedrich Eichhorn *(University of Applied Science, Institute of Electrical Engineering, Leipzig, Germany)*; Karl-Heinz Gonschorek *(Dresden University of Technology, Dresden, Germany)*

Abstract–The influence of active medical implants, in the special one the heart pacemakers, in the low frequency response is still actual in spite of many studies in this area. In low-frequency electric fields it is gone out with the analytic calculation of the induced voltage at the pacemaker entrance always from a homogeneous electric field. In this Paper a procedure is introduced with one conversion for inhomogeneous electric fields can be considered. Furthermore are carried out to numerical calculations for university-polar and bipolar electrodes in a human model and are compared to measurements in a bowl model. With these results the security factor of the bipolar electrode can be calculated compared with the university-polar electrode.

11:00 am **Detect VR Noise Coupling Sources through Near Field Scanning** 746

Xiaoning Ye *(Intel Corporation, Hillsboro, OR, United States)*; Amy Luoh *(Intel Corporation, Hillsboro, OR, United States)*

Abstract–This paper uses near field scanning (NFS) techniques to detect noise coupling sources due to switching voltage-regulators (VR) in a typical computer system. The fast switching of the VR FETs couples significant amounts of noise to signal lines in proximity, resulting in degraded signal performance, system malfunction, etc. Detecting all the potential noise sources has been a challenging task due to the complexity of VR design and the layout of the board. The near field scanning technique is utilized as a brute-force measurement-based method to identify and verify potential noise sources. Applications of the techniques are reported in the paper, where noise sources are revealed and design changes are made to mitigate the noise coupling issue.

THU-AM-4, HPM Effects (TC5), Room 103A

Chair: William Radasky, Metatech Corporation
Co-Chair: Michael McInerney, U.S. Army Corps of Engineers

8:30 am **Can Intentional Electrical Discharges be used for HPM Protection?** 752

Mats Bäckström *(Combitech AB, Linköping, Sweden)*; Ulf Jordan *(Swedish Defense Research Agency FOI, Stockholm, Sweden)*; Dan Andersson *(Chalmers University of Technology, Gothenburg, Sweden)*; Arkady V. Kim *(Institute of Applied Physics, Nizhny Novgorod, Russian)*; Mietek Lisak *(Chalmers University of Technology, Gothenburg, Sweden)*; Olof Lundén *(Swedish Defense Research Agency FOI, Stockholm, Sweden)*

** Nominated for Best Symposium Paper Award*

Abstract–The possibility to protect electronics against High Power Microwaves (HPM) using an intentional electrical discharge has been investigated. The case considered here is a resonant slot, located e.g. in an antenna array or in a Frequency Selective Surface (FSS). The reduction of the pulse energy through the slot is regarded to be the most important parameter of merit. Experimental and theoretical research showed that a spark in the middle of a 46.1 x 0.1 mm resonant slot, induced by the incident HPM-pulse gave a reduction of the transmitted pulse energy of about 24 dB. The studies showed that the investigated approach can provide a quite good level of protection that at least reduces the requirements on additional protection components such as limiters integrated in receivers located behind the slot. In order to achieve a sufficiently strong enhancement of the electric field to initiate breakdown in wide slots one presumably has to introduce a small pointed gap in the middle of the slot. This may in turn require that a radioactive sample is located close to the gap in order to produce a sufficient number of seed electrons necessary for triggering the discharge.

9:00 am **Induced Currents on Electric Detonators for Improvised Explosive Device Pre-Detonation** 758

Jake Galuga *(Royal Military College of Canada, Kingston, Canada)*; Joey R. Bray *(Royal Military College of Canada, Kingston, Canada)*

Abstract–Electric hotwire detonators are commonly used in the construction of improvised explosive devices. This paper explores the electromagnetic susceptibility of a commercial detonator when it is exposed to continuous wave, linearly-polarized plane wave radiation. The aim is to assess the feasibility of inducing sufficient current in the detonator to cause its explosion. For selected lead wire configurations, analytical formulae are used to predict the resonant frequencies of the detonators. Computer modeling is then used to simulate the induced current on the detonator's bridge wire during electromagnetic illumination. The predictions are compared with experimental measurements of induced current on commercial detonators.

THU-AM-4, Information Leakage (TC5), Room 103A

Chair: Tetsuya Tominaga, NTT Corporation
Co-Chair: William Radasky, Metatech Corporation

10:30 am **Non-Invasive EMI-Based Fault Injection Attack against Cryptographic Modules** 763
Yu-ichi Hayashi *(Tohoku University, Sendai, Japan)*; Naofumi Homma *(Tohoku University, Sendai, Japan)*; Takeshi Sugawara *(Tohoku University, Sendai, Japan)*; Takaaki Mizuki *(Tohoku University, Sendai, Japan)*; Takafumi Aoki *(Tohoku University, Sendai, Japan)*; Hideaki Sone *(Tohoku University, Sendai, Japan)*

** Nominated for Best Symposium Paper Award*

Abstract–In this paper, we introduce a new type of intentional electromagnetic interference (IEMI) which causes information leakage in electrical devices without disrupting their operation or damaging their physical structure. Such IEMI could pose a severe threat to a large number of electrical devices with cryptographic modules since it can be used for performing fault injection attacks, which in turn allows for obtaining faulty outputs (i.e., ciphertexts) from cryptographic modules and exploiting them to reveal information about secret keys. Such faulty outputs are usually generated by inducing faults into target modules through modification or invasion of the modules themselves. In contrast, IEMI-based fault injection can be performed on the target modules from a distance by using an off-the-shelf injection probe without leaving any hard evidence of the attack. We demonstrate fault injection attacks based on the above IEMI through experiments using an Advanced Encryption Standard (AES) module implemented on a standard evaluation board (SASEBO). The experimental results indicate that generating effective faults is feasible and, therefore, such IEMI presents a tangible threat to many existing electrical devices and systems that use cryptographic modules for secure communication and transactions.

11:00 am **Practical Results of EM Cartography on a FPGA-Based RSA Hardware Implementation** 768
Laurent Sauvage *(Institut Télécom, Télécom ParisTech, Paris, France)*; Sylvain Guilley *(Institut Télécom, Télécom ParisTech, Paris, France)*; Jean-Luc Danger *(Institut Télécom, Télécom ParisTech, Paris, France)*; Naofumi Homma *(Tohoku University, Sendai, Japan)*; Yu-ichi Hayashi *(Tohoku University, Sendai, Japan)*

Abstract–Side channel attack is a powerful technique to extracting secret key from cryptographic applications of embedded systems. Best results are obtained by placing a small electromagnetic probe just over areas of an integrated circuit which are leaking the most information. To find such locations, some methods have been proposed in the past, but never used against asymmetric-key cryptosystems. In this paper, we target such cryptosystem, more precisely a FPGA-based RSA hardware implementation. We show that these methods are effective to locate the RSA cryptoprocessor.

11:30 am **Identification of Information Leakage Spots on a Cryptographic Device with an RSA Processor** 773
Olivier Meynard *(Telecom-ParisTech, Paris, France)*; Yu-ichi Hayashi *(Tohoku University, Sendai, Japan)*; Naofumi Homma *(Tohoku University, Sendai, Japan)*; Sylvain Guilley *(Telecom-ParisTech, Paris, France)*; Jean-Luc Danger *(Telecom-ParisTech, Paris, France)*

Abstract–This paper investigates the relation between the intensity of electromagnetic (EM) radiation and that of EM information leakage from a cryptographic device. For this purpose, we first acquire an EM field map of the cryptographic device with an EM scanning system, and then perform simple electromagnetic analysis of distinct points on the device, including over the module. The target device considered here is a Side-channel Attack Standard Evaluation Board (SASEBO) with RSA hardware implemented in a field-programmable gate array. Through the experiment, we evaluate which points and frequencies are effective for electromagnetic information leakage. The results suggest that the position of greatest EM field intensity is not always the most effective point in terms of EM information leakage.

THU-AM-5, Special Session: Full Channel Characterization and Link Path Analysis for High-Speed Interconnect (TC10), Room 103B

Chair: Zhiping Yang, Cisco Systems
Co-Chair: Amy Chen, Intel Corporation

8:30 am **High Speed Differential I/O Overview and Design Challenges on Intel Enterprise Server Platforms** 779
Beom-Taek Lee *(Intel Corporation, Santa Clara, CA, United States)*; Mohiuddin Mazumder *(Intel Corporation, Santa Clara, CA, United States)*; Richard Mellitz *(Intel Corporation, Columbia, SC, United States)*

Abstract–In this paper the high speed differential I/O buses are explored which are used on Intel server platforms. The characteristics of channel components are examined along with channel and I/O circuit design challenges. The statistical time domain and frequency domain methods are briefly discussed as the state-of-art simulation tools.

9:00 am **Signal Transition Structure Optimization for 16 Gbps SFP Cage and PCB Interface** 785
Jianmin Zhang *(Cisco Systems, Inc., San Jose, CA, United States)*; Hanfeng Wang *(Missouri University of Science and Technology, Rolla, MO, United States)*; Jane Lim *(Cisco Systems, Inc., San Jose, CA, United States)*; Kelvin Qiu *(Cisco Systems, Inc., San Jose, CA, United States)*; Rick Brooks *(Cisco Systems, Inc., San Jose, CA, United States)*; Bill Chen *(Yangtze Delta Region Institute of Tsinghua University, JiaXing, China)*

Abstract–SFP (Small Form-factor Pluggable) module and SFP cage form an interface between a network device and an optic cable or a copper cable for data communication and telecommunication. Data rate on such an interface for a high-speed channel varies from 1 Gbps (Gigabit per second) to 10 Gbps for the existing products, and products with the data rate of 16 Gbps are under development. Due to the differences of networking platform, data rate, and channel length, this interface can be directly driven by an ASIC (Application-Specific Integrated Circuit) or an EDC (Electric Dispersion Compensation) chip in electric domain. Compliance tests are enforced on the interface to fulfil the interoperability requirement, which makes the signal integrity work extremely challenge at 16 Gbps. Since the discontinuity on the interface of a PCB (Printed Circuit Board) and a SFP cage is dominant in the electric path, optimization such an interface structure is critical to meet the compliance specification and achieve system BER (Bit Error Rate). In this paper, a fast via tool is used initially for quick solution about the interface structure optimization. The optimized parameter is verified in a full-wave modelling, and the via structure related resonance is observed and identified. Based on the given SFP cage footprint and observed resonance, a new signal transition structure for the SFP cage and PCB interface is finally proposed, modelled and optimized.

9:30 am **Intentional and Un-Intentional Far End Crosstalk Cancellation in High Speed Differential Link** 791
Xiaoning Ye *(Intel Corporation, Hillsboro, OR, United States)*

Abstract–In this paper, a new type of differential far end crosstalk cancellation mechanism for high speed differential link is reported. By implementing design change on the PCB routing, or enforcing specific differential pin-out pattern, the crosstalk contribution from different component or different section of the link can cancel each other, and results in a significant crosstalk reduction at receiver can end. On the other hand, this paper also addresses another aspect of this type of crosstalk cancellation scheme: the crosstalk contribution from different link components may be un-intentionally cancelled out in full link simulation, and results in favorable but wrong simulation results. Suggestions on how to avoid this type of problem is given in the paper.

10:30 am **Statistical Link Analysis and In-Situ Characterization of High-Speed Memory Bus in 3D Package Systems** 797
Dan Oh *(Rambus Inc., Sunnyvale, CA, United States)*; Sam Chang *(Rambus Inc., Sunnyvale, CA, United States)*; Jihong Ren *(Rambus Inc., Sunnyvale, CA, United States)*; Ling Yang *(Rambus Inc., Sunnyvale, CA, United States)*; Hai Lan *(Rambus Inc., Sunnyvale, CA, United States)*; Chris Madden *(Rambus Inc., Sunnyvale, CA, United States)*; Ralf Schmitt *(Rambus Inc., Sunnyvale, CA, United States)*

Abstract–High-speed link design in a 3D package system poses unique challenges due to the fact that it provides limited visibility to signal quality and that supply noise induced jitter is large due to a poor power distribution network in a small form factor. This paper outlines a statistical link simulation flow to accurately capture the impact of timing jitter due to power supply noise in 3D systems. The analysis includes on-chip jitter accumulation and link-level jitter tracking by considering both passive channel and on-chip signal path. On-chip measurement techniques which allow in-situ testing of the overall link margin are also described.

11:00 am **Full Link Impedance Optimization for Serial IOs** 803
Chunfei Ye *(Intel, Dupont, WA, United States)*; Xiaoning Ye *(Intel, Dupont, WA, United States)*; Edgar J. Vargas *(Intel Tecnologia de Mexico SA de CV, Tlaquepaque, Mexico)*; Odilon Argueta *(Intel Tecnologia de Mexico SA de CV, Tlaquepaque, Mexico)*

Abstract–In this paper optimal impedance for interconnects and buffer design is studied to improve link performance for high-speed differential signalling. Impedance lower than 100Ω for interconnect improves performance even when the rest components such as buffer, connector, cable, etc, are designed at 100Ω. The link performance can be further improved if TX and RX buffers can have options of other impedance values in addition to 100Ω. The study is supported by simulation and measurement for 6Gbps and by simulation for 12Gbps. Based on the study 85Ω is a good candidate as optimal impedance.

11:30 am **25 Gbps Backplane Links Frequency and Time Domain Characterization – Correlation Study between Test and Full-Wave 3D EM Field Simulation** 809
Peerouz Amleshi *(Molex Inc., Lisle, IL, United States)*; Vivek Shah *(Molex Inc., Lisle, IL, United States)*; Zhiping Yang *(Cisco Systems Inc., San Jose, CA, United States)*; Jitendra Mohan *(National Semiconductor Corp., Santa Clara, CA, United States)*; Tonmoy Mukherjee *(National Semiconductor Corp., Santa Clara, CA, United States)*

Abstract–Designing backplane links at such high data rates requires the consideration of the interaction between active and passive components. The degree of interaction at 25 Gbps data rates requires a co-design approach with respect to active and passive blocks. In this paper, we start with modelling a 25 Gbps backplane channel in frequency domain and establish the correlation between results obtained from passive channel model and measurement. We further extend this analysis to establish correlation between chip test and chip-based simulation. In this study, we focus on the transmission performance of a 0.6-meter backplane channel operating at 25 Gbps, and expect similar performance in the presence of crosstalk with sufficiently isolated TX/RX grouping within the multi-lane backplane system.

THU-AM-6, Special Session: EMC in Space, Room 103C

Chair: Ray Perez, Jet Propulsion Laboratory
Co-Chair: James Lukash, Lockheed Martin

8:30 am **Crew Quarters (CQ) and Electromagnetic Interference (EMI) Measurement Facility Combined Impedance Study** 814
Robert C. Scully *(NASA Johnson Space Center, Houston, TX, United States)*

Abstract–This report documents an investigation into observed anomalous behavior associated with conducted susceptibility testing of Crew Quarters (CQ) hardware in the Johnson Space Center (JSC) Electromagnetic Interference (EMI) Measurement Facility, and the work accomplished to identify the source of the observed behavior. Investigation led to the conclusion that the hardware power input impedance was interacting with the facility power impedance leading to instability at the observed frequencies of susceptibility. Testing performed in other facilities did not demonstrate this same behavior, pointing back to the EMI Measurement Facility power as the location of the potential root cause. Ultimately, a Line Impedance Simulation Network (LISN) emulating the Station power bus impedance was inserted into the power circuit, and the anomalous behavior was eliminated from the measurements.

9:00 am **Tailoring MIL-STD-464A and MIL-STD-461F Requirements for Space Systems Applications** 819
David Brumbaugh *(The Boeing Company, Seattle, WA, United States)*; Joseph Chott *(Orbital Sciences Corporation, Gilbert, AZ, United States)*; Ken Javor *(EMC Compliance, Huntsville, AL, United States)*; James Lukash *(Lockheed Martin Space Systems Company, Sunnyvale, CA, United States)*

Abstract–MIL-STD-464 and MIL-STD-461 are the basis for electromagnetic effects requirements for military procurements for all platforms. Tailoring of requirements is essential to that process so that it applies to the special needs of spaceflight. AIAA S-121-2009, "Electromagnetic Compatibility Requirements for Space Equipment and Systems", was developed during a three year effort by a government/industry committee. This paper describes how MIL-STD-464 and MIL-STD-461 were tailored for space applications.

THU-PM-1, Immunity (TC2), Room 101A

Chair: Galen Koepke, NIST
Co-Chair: Ghery Pettit, Intel Corporation

2:30 pm **20V-High Speed Low Cost Arbitrary Waveform Generator for ICs Immunity Test** 846
Xu Gao *(Missouri University of Science and Technology, Rolla, MO, United States)*; Tianqi Li *(Missouri University of Science and Technology, Rolla, MO, United States)*; Nicholas Bennett Mentesana *(Missouri University of Science and Technology, Rolla, MO, United States)*; Zhenwei Yu *(Missouri University of Science and Technology, Rolla, MO, United States)*; Aleksandr Yakubovich Gafarov *(Missouri University of Science and Technology, Rolla, MO, United States)*; Liehui Ren *(Missouri University of Science and Technology, Rolla, MO, United States)*; Hongyu An *(Missouri University of Science and Technology, Rolla, MO, United States)*; David Pommerenke *(Missouri University of Science and Technology, Rolla, MO, United States)*

Abstract–A 20V high speed, low resolution and low cost arbitrary waveform generator has been prototyped. It uses FPGA transceivers and resistive weighting networks and broadband power amplification. The sampling rate of this arbitrary waveform generator is 6.25 Gsps, allowing rise times down to 130 ps. As 4 transceiver channels are used a 4 bit resolution is achieved. The generator is combined with a wide band (20MHz – 6 GHz) power amplifier allowing 20V at 50-Ohm load. The intended application is IC immunity testing. Here different waveforms and exact timing is needed. Using different FPGAs the concept can be extended to higher resolution and faster sampling rates. The project was completed in a 400 level RF design class during only one semester.

3:00 pm **A Method to Determine the Injected Real Power into an IC Pin in Case of a Conducted Immunity EMC Test** 850
Marco Frick *(Robert Bosch GmbH, Reutlingen, Germany)*; Robert Weigel *(University of Erlangen-Nuremberg, Erlangen, Germany)*; Roland Eidher *(Robert Bosch GmbH, Reutlingen, Germany)*

Abstract–The direct power injection (DPI) measurement method is an internationally accepted technique to verify the robustness of an integrated circuit (IC) against an injected RF signal. The requirements of this measurement method respecting the setup is fixed in the international standard IEC 62132-4 [1]. In this paper a method is presented which allows to determine the real power injection into the IC pin by considering the influence of the required test printed circuit board (PCB). To apply this method only the transmitted and reflected RF power, the voltage standing wave ratio (VSWR), which are already locked during the DPI test, and the scattering parameters (S-parameters) of the PCB injection path are needed. How to use the available measurement results and how to determine the required Sparameters of the PCB injection path is described in this paper

4:00 pm **Low-Frequency Characterization of Composite Panels from a Near-Field Magnetic Shielding Effectiveness Measurement** 855
Guillaume Andrieu *(University of Limoges, Limoges, France)*; Johan Panh *(CNES, Toulouse, France)*; Alain Reineix *(University of Limoges, Limoges, France)*; Patrice Pelissou *(Axessim, Strasbourg, France)*; Christophe Girard *(Axessim, Strasbourg, France)*; Xavier Romeuf *(Axessim, Strasbourg, France)*; Dominique Schmitt *(ESA/ESTEC, Noordwijk, Netherlands)*

Abstract–This paper presents a simple method allowing to obtain an homogeneous model from an inhomogeneous composite panel thanks to a near-field magnetic shielding effectiveness in the low frequency range (f 1 MHz). Consequently, the method which does not require the knowledge of the detailed internal geometry of the sample consists in defining an equivalent conductivity to the homogeneous model. After the validation of the measurement setup on a copper plate of known conductivity, results obtained on 3 different samples are presented. Finally, the possibility to homogenize samples made of different inhomogeneous layers previously characterized separately is presented and validated on different samples.

4:30 pm **Fast and Accurate Radiated Susceptibility Testing by using the Reverberation Chamber** 861
Magnus Höijer *(Swedish Defence Research Agency FOI, Linköping, Sweden)*

** Nominated for Best Symposium Paper Award*

Abstract–The reverberation chamber is a good tool to perform high level radiated susceptibility testing. The accuracy and repeatability is good, and the testing time is short. However, the susceptibility of electronic equipment depends on from which direction the equipment is irradiated. It has generally been assumed that that effect can not be included when performing a radiated susceptibility test in the reverberation chamber. In this paper we show the opposite, that it actually can be included.

5:00 pm **System Throughput and Immunity Analysis of a 802.11n WLAN in a Large Reverberation Chamber** 865

Valter Mariani Primiani *(Università Politecnica delle Marche, Ancona, Italy)*;
Franco Moglie *(Università Politecnica delle Marche, Ancona, Italy)*;
Renzo Recanatini *(Università Politecnica delle Marche, Ancona, Italy)*

Abstract–The paper presents some results concerning the use of a reverberation chamber (RC) to test a wireless local area network (WLAN) system based on 802.11n standard. The whole link (root and non-root bridge) operates inside the RC under different chamber loading conditions and varying the stirrer rotating speed. The effects of this multipath environment on system performances are checked measuring three transmission quality estimators: the ping average round trip time, the number of cyclic redundancy check (CRC) error, and the number of data retries. The behavior of these parameters is also analyzed changing the modulation and coding scheme (MCS) index using both one spatial stream and two spatial streams (MIMO). The same RC is used to carry out a radiated immunity test. The undesired signal is both a modulated and continuous wave injected into the active channel and into adjacent channels. The modulated wave is that prescribed by the IEC 61000-4-3 standard. Results reveal the high robustness of the 802.11n standard with respect to b and g standards when it operates in a hostile environment reproduced by an RC.

THU-PM-2, Signal Integrity-5 (TC10), Room 101B

Chair: Giulio Antonini, Univeirsity of L'Aquila
Co-Chair: Al Ruehli, Missouri University of Science and Technology

2:30 pm **Pseudo-Balanced Signaling using Power Transmission Lines for Parallel Links** 871

Suzanne Huh *(Georgia Institute of Technology, Atlanta, GA, United States)*;
Madhavan Swaminathan *(Georgia Institute of Technology, Atlanta, GA, United States)*;
David Keezer *(Georgia Institute of Technology, Atlanta, GA, United States)*

Abstract–Power integrity has become an indispensable part to ensure signal integrity in high-speed systems. Simultaneous switching noise (SSN) in the power delivery network (PDN) is now one of major factors to place the limit on the noise margin for off-chip communication so that a great emphasis is being laid on controlling SSN. Accordingly, power transmission line (PTL) has been suggested as a new PDN design. In this paper, a new signaling scheme is proposed to address the issues associated with PTL, and yield a synergetic improvement in signal integrity.

3:00 pm **A Passive Analytical Per-Unit-Length Internal Impedance Matrix Model for Multiconductor Interconnections** 877

Frédéric Broydé *(Tekcem, Maule, France)*; Evelyne Clavelier *(Tekcem, Maule, France)*

Abstract–Based on multiconductor transmission line (MTL) theory, we describe a technique for a simple computation of the high-frequency (h.f.) current distribution in a multiconductor interconnection and of the h.f. per-unit-length (p.u.l.) resistance matrix of the interconnection. This result is used in a model for the p.u.l. internal impedance matrix of the interconnection. We show that this model is passive, hence causal.

4:00 pm **A Novel Imaging Method for the Impedance Calculation of Power and Ground Planes** 883

De-Cao Yang *(Zhejiang University, HangZhou, China)*; Xing-Chang Wei *(Zhejiang University, HangZhou, China)*; Er-Ping Li *(Zhejiang University, HangZhou, China)*

** Nominated for Best Symposium Paper Award*

Abstract–Power and ground planes are the major noise sources in the electronic package and multi-layered printed circuit boards. We propose a novel imaging method to simulate the impedance of power and ground planes. In the proposed method, the noise propagation between the power and ground planes is equivalent to a two-dimensional transverse magnetic problem. The electromagnetic wave multi reflections from the periphery of the power and ground planes are represented by the images of the source current, then a two-dimensional Green's function is used to efficiently calculate the contributions from the source and all its images. The major advantages of the proposed imaging method over the available mode expansion method are that it converges quickly at high frequencies, and it can be easily extended to simulate power and ground planes with arbitrary shapes. By the comparison with the full-wave method and measurement results, the accuracy and efficiency of the proposed imaging method are validated.

4:30 pm **A Novel Common Mode Choke and Its Application for 5 Gbps USB 3.0** 888
Chung-Hao Tsai *(National Taiwan University, Taipei, Taiwan)*; Jing-Zuei Hsu *(National Taiwan University, Taipei, Taiwan)*; Iat-In Ao Ieong *(National Taiwan University, Taipei, Taiwan)*; Tzong-Lin Wu *(National Taiwan University, Taipei, Taiwan)*

** Nominated for Best Symposium Paper Award*

Abstract–A novel compact common mode choke is proposed and realized without using ferrite materials. It is fabricated on LTCC substrate and possesses a small size of 1.2 mm 2.0 mm. It provides over 10 dB common mode suppression from 1.4 GHz to 3.7 GHz and still maintains the differential signal transmission up to 8 GHz. To validate the common mode choke on USB 3.0 cable, a series of experimental tests are executed, including eye diagram for differential signal, common mode noise suppression, and elimination of common mode current on cables. The eye diagram for the filter board keeps obvious eye width and eye height and almost the same result with that for the reference board. About 57 % common mode suppression is achieved after placing the common mode filter on the board with 8 mm skew line. Moreover, the common mode current on cables related to far field radiation is also measured by current probe and eliminated over 10 dB within designed stopband by using the common mode choke.

THU-PM-3, PCB Simulations (TC9), Room 102BC

Chair: Jun Fan, Missouri University of S & T
Co-Chair: Marina Koledintseva, Missouri University of S & T

2:30 pm **The Convolutional PML for FDTD Analysis: Transient Electromagnetic Absorption from DC to Daylight** 892
J. Alan Roden *(The Aerospace Corporation, Chantilly, VA, United States)*; Tyler Kramer *(The Aerospace Corporation, Chantilly, VA, United States)*

Abstract–The convolutional PML (CPML) was introduced ten years ago as an efficient implementation of Berenger's PML absorbing boundary within FDTD simulations. Numerous researchers and practitioners have demonstrated the benefits of the CPML for grid termination across a broad spectrum of electromagnetic applications. In this paper the basic formulation as well as a recently introduced high order implementation is revisited and its advantages to the EMC community are demonstrated.

3:00 pm **Analysis of via Impedance Variations with a Polynomial Chaos Method** 899
Jianxiang Shen *(University of Houston, Houston, TX, United States)*; Hanfeng Wang *(Missouri University of Science and Technology, Rolla, MO, United States)*; Ji Chen *(University of Houston, Houston, TX, United States)*; Jun Fan *(Missouri University of Science and Technology, Rolla, MO, United States)*

Abstract–In this paper, we propose a systematic framework for the optimization and analysis of the equivalent characteristic impedance of practical via structures. The framework consists of (a) optimizing via structures for impedance matching using a Genetic algorithm, and (b) numerically characterize, by Polynomial Chaos (PC) method, the sensitivity of the equivalent characteristic impedance to the manufacturing uncertainties in the various geometrical parameters of a via structure. The PC method can be effectively used to compute important statistical information, such as moments, probabilities and sensitivities with respect to the design variables. The PC method is straightforward to implement, and can be orders of magnitude faster than the traditional Monte Carlo (MC) method. The proposed framework naturally leads to a rigorous methodology for EM design/control in the presence of multiple sources of uncertainty.

4:00 pm **Minimizing the Number of Basis Functions in Chip-Package Co-Simulation using Lauerre-FDTD** 905
Myunghyun Ha *(Georgia Institute of Technology, Atlanta, GA, United States)*; Madhavan Swaminathan *(Georgia Institute of Technology, Atlanta, GA, United States)*

Abstract–Interaction between the chip and package at the system level needs to be predicted in the design process for saving time and cost, which requires chip-package co-simulation. Laguerre-FDTD is an unconditionally stable FDTD scheme which is attractive for chip-package co-simulation since its time-step is not limited by the Courant condition. In Laguerre-FDTD, the transient waveform of the field of interest is represented as the weighted sum of Laguerre basis functions. Therefore, the number of basis functions used in the simulation is directly related to both the simulation run time and the accuracy. Normally, there is a tradeoff between simulation run time and the accuracy. . However, this paper proposes a novel solution to minimize the number of basis functions while increasing the accuracy of the output transient waveform of interest. The method of maximizing the efficiency in terms of run time and improving the accuracy of simulation described in this paper is a key step for the automation and practical use of the transient simulation technique using Laguerre polynomials.

4:30 pm **Application of Integrated Transmission Line Modeling and Behavioural Modeling on Electromagnetic Immunity Synthesis** 910

Xian-Ke Gao *(Institute of High Performance Computing, Singapore, Singapore)*;
Eng-Kee Chua *(Institute of High Performance Computing, Singapore, Singapore)*;
Er-Ping Li *(Institute of High Performance Computing, Singapore, Singapore)*

Abstract–The paper presents an integrated electromagnetic immunity modeling, design and diagnosis system for EMI/EMC scenarios assessment and analysis of electronic devices/equipments. With extracting the intrinsic electric characteristic of PCB, a new modeling method which integrates transmission line modeling and behavioural modeling is proposed to be employed. The system is thus capable of modeling and analyzing electromagnetic interference therefore to evaluate the immunity level of electronic systems. It will also be customized so that it can be used for the design verification, parameter calculation and optimization.

5:00 pm **Equivalent Circuit Model Order Reduction by Real-Coefficient AFS** 916

Sungtek Kahng *(University of Incheon, Incheon, Republic of Korea)*;
Raj Mittra *(Pennsylvania State University, State College, PA, United States)*

Abstract–In this paper, the Adaptive Frequency Sampling (AFS) technique for Model Order Reduction is modified to macromodel the RF components. The conventional AFS can just express the frequency response as a rational function, but ends up with inefficiency in macromodelling So the proposed scheme here enables the AFS to macromodel the problem by finding the equivalent circuit of the frequency response, since the coefficients of the rational function are made real-valued and easily arranged to the well-known configurations of resistors, capacitors and inductors. The validity of the proposed technique is watched by showing the accuracy of the equivalent circuit compared to the original data and vector fit curve of an RF DGS filter as an instance.

THU-PM-4, Information Leakage (TC5), Room 103A

Chair: Tetsuya Tominaga
Co-Chair: William Radasky

2:30 pm **Suppression of Information Leakage from Electronic Devices based on SNR** 920

Taishi Ikematsu *(Tohoku University, Sendai, Japan)*; Yu-ichi Hayashi *(Tohoku University, Sendai, Japan)*; Takaaki Mizuki *(Tohoku University, Sendai, Japan)*; Naofumi Homma *(Tohoku University, Sendai, Japan)*; Takafumi Aoki *(Tohoku University, Sendai, Japan)*; Hideaki Sone *(Tohoku University, Sendai, Japan)*

Abstract–Recently, the issue of information leakage through electromagnetic radiation has increasingly attracted attention. Using accumulated knowledge and experience, EMC-related committees have established guidelines on standardized acceptable values of EM radiation during device operation. Current electronic devices are usually designed so as to satisfy these EMC standards. However, the main aim of these standards is to reduce EM radiation that disturbs other devices, not radiation that leaks secret information. Even for EM radiation below the value specified in the guidelines, extraction of secret key information remains a possibility. Unlike noise radiation in the field of EMC, however, there are no definite criteria regarding EM information leakage. Therefore, uncertainty remains as to whether conventional noise suppression techniques are applicable to the suppression of information leakage. This paper discusses the difference between using electromagnetic field suppression techniques for noise and for information by using a quantitative approach. Information leakage and effective countermeasures are investigated, based on a quantitative evaluation of the signal and noise components of the leakage.

3:00 pm **On-Board Decoupling of Cryptographic FPGA to Improve Tolerance to Side-Channel Attacks** 925

Kengo Iokibe *(Okayama University, Okayama, Japan)*; Tetsuo Amano *(Okayama University, Okayama, Japan)*; Yoshitaka Toyota *(Okayama University, Okayama, Japan)*

Abstract–One of PI/EMC design techniques, on-board decoupling, was proved its usefulness as a countermeasure against cryptographic side-channel analysis attack. The on-board decoupling was applied to a side-channel attack standard evaluation board (SASEBO-G) involving a cryptographic FPGA that operated an AES-128 encryption process. Three decoupling conditions available to realize with SASEBO-G were examined. Radio frequency (RF) power current was detected as voltage variations with a current probe that was probed on the power cable for the cryptographic FPGA. Traces of the voltage variation were recorded on a digital oscilloscope until 30,000 traces were acquired in each decoupling condition. The traces were analyzed statistically by using the correlation power analysis (CPA). Results show that necessary traces for revealing the secret key significantly increased in its number when amplitude of trace was attenuated by decoupling. The decoupling technique could be useful as a countermeasure of side-channel attacks to cryptographic modules.

4:00 pm **Compromising Emanations of LCD TV Sets** 931

Markus G. Kuhn *(University of Cambridge, Cambridge, United Kingdom)*

Abstract–This study attempts to characterize the radiated compromising emanations from four typical LCD TV sets, in particular the predictability of format and timing parameters. Three were found to emit clear UHF RF signals visually related to the displayed image, from the LVDS link between display controller and LCD panel. Although the input signals to all four products followed the same TV standard, the timing parameters of their emanations differed substantially. Some also frequency-modulate their pixel clock to improve EMI compliance. All digitally rescale the input image to the respective display size. The frame rate at which the display panel is driven is, if at all, only loosely phase locked to the input signal. These observations have implications for eavesdroppers, for the design of test standards to limit compromising emanations from video displays, and for the practicality of detecting the mere presence of an active television receiver by correlating the emanations of the circuitry driving its display panel with a known broadcast TV input signal.

4:30 pm **Towards Large-Scale EM-Leakage Evaluation by means of Automated TOE Synchronization** 937

Takashi Watanabe *(Hitachi Ltd., Tokyo, Japan)*; Katrin Franke *(Gjøvik University College, Gjøvik, Norway)*; Hiroshi Sako *(Hitachi Ltd., Tokyo, Japan)*

Abstract–The security problem of screen image leakage from a display unit has received wide interest of security researchers since the Van Eck's paper. To investigate the risk of EM-information leakage, we want to analyse as many devices as possible. However, during the evaluation, we face the problem of necessity on extraction of the target devices' synchronization parameters. Even though limited numbers of timings are used in the field, slight differences among devices introduced during production require an evaluator to search for the actual timings for each of them. The search has been done by human heuristics and many trial and errors; which prevents analysis of massive amount of target of evaluation (TOE). We propose a technique to automate the search by using a classification method, which is carried out on a computer, to help EM-leakage evaluation.

5:00 pm **Estimation of Receivable Distance for Radiated Disturbance Containing Information Signal from Information Technology Equipment** 942

Hidenori Sekiguchi *(Osaka University, Osaka, Japan)*;
Shinji Seto *(Mitsubishi Electric Corp., Hyogo, Japan)*

Abstract–The present study was conducted to evaluate a leakage threat of information that can be reconstructed using radiated electromagnetic disturbance of information technology equipment. In this paper, the information leakage threat was estimated from a viewpoint of the receivable distance from the information technology equipment. The radiated electromagnetic disturbance of the information technology equipment is then based on the limits of the radiated disturbance for the information technology equipment of class B provided in CISPR 22. The estimation result reveals that the receivable distance exceeds hundreds of meters from the information technology equipment, taking account of the receivable capacity of a receiver with an antenna assumed in this paper. In addition, when the receiving frequency is higher, the receivable distance is shorter, in the defined frequency range with the constant limit value defined in CISPR 22. However, the receivable distance is stepped up at the receiving frequency of 230 [MHz], because at which the limit values of the radiated disturbance for the ITE of class B is stepped up.

THU-PM-5, EMC Environment (TC3), Room 103B

Chair: Fred Heather, US Navy

2:30 pm **Hazards of Electromagnetic Radiation to Ordnance (HERO) Assessment of Electro-Explosive Devices and Validation of Extrapolation Method for Estimation of the Safety Margin at HERO Electromagnetic Environments** 946

Rakesh Kichouliya *(Research Centre Imarat (DRDO), Hyderabad, India)*; Devender *(Research Centre Imarat (DRDO), Hyderabad, India)*; V.V. Ramasarma *(Research Centre Imarat (DRDO), Hyderabad, India)*; D.S. Reddy *(Research Centre Imarat (DRDO), Hyderabad, India)*; V.G. Borkar *(Research Centre Imarat (DRDO), Hyderabad, India)*

Abstract–HERO is one of the critical electromagnetic environmental effects as defined in the MIL-STD-464A. The HERO electromagnetic environment is very severe for the ship born systems, as it contains the sources of EME (Radars, HF Transmitters and VHF communication systems etc.) and ordnance systems on the same platforms. Necessarily most of the ordnance system contains the EEDs/EIDs, and these are fired as and when the operation of the ordnance system is desired. HERO environment has the potential threat to cause an inadvertent actuation or firing of these ordnance systems by inducing the sufficient current in the EEDs/EIDs circuits. This results into a disaster and causing the loss of ordnance system along with collateral effects, platform, cost and human being. So it has now become essential to certify every ordnance system to be HERO safe and reliable, when it is on board or when it moving in the stock-pile to safe operation. The HERO environment defined in MIL-STD-464A calls for generation of very high field strength (i.e. 2620 V/m @ 2.7-3.6 GHz), which is really a challenge to generate inside the laboratory. So to overcome this practical difficulty the MIL-HDBK-240 suggested to use extrapolation method for high fields, provided the bridge wire should exhibit the linear characteristics. The aim of this paper is to demonstrate the extrapolation method (MIL-HDBK-240) for assessing the induced current on the bridge wires at very high fields. The induced current measurement system on bridge-wire consists of Fibre-optic temperature (FOT-HERO) sensor and the signal conditioner, which works on the principle of Fabry-Parot Interferometery (FPI). To verify the extrapolation FOT-HERO sensor mounted bridge-wire will be exposed to the different electromagnetic field levels at specified spot HERO test frequencies. The measured induced currents at the lower field levels will be extrapolated to higher field level to compute the induced currents at high field levels, and then it will be compared to the actual measured results and finally with the safety margin (i.e. 15% of the Maximum No Fire Current) of the ordnance system.

3:00 pm **"Good-but-Imperfect" Electromagnetic Reverberation in a VIRC** 954

Ramiro Serra *(University of Twente, Enschede, Netherlands)*; Frank Leferink *(Thales Nederland B.V., Hengelo, Netherlands)*; Flavio Canavero *(Politecnico di Torino, Turin, Italy)*

Abstract–Novel theoretical probability density functions (PDF) of electromagnetic fields inside reverberation chambers operating in a "good-but-imperfect" regime have been recently reported. The present work reports on the application and assessment of these PDFs using a non-conventional type of reverberation chamber, namely the Vibrating Intrinsic Reverberation Chamber (VIRC). Measurements confirm the fact that the novel PDFs are able to describe the occurrence of anomalous statistics in the VIRC.

4:00 pm **Industrial Environment Characterization for Future M2M Applications** 960

Javier Ferrer Coll *(University of Gävle, Gävle, Sweden)*; Per Ängskog *(University of Gävle, Gävle, Sweden)*; José Chilo *(University of Gävle, Gävle, Sweden)*; Peter Stenumgaard *(University of Gävle, Gävle, Sweden)*

Abstract–Combining electronics, telecommunications, and information technology to connect devices and remote systems is perhaps the best feature of the future Machine-to-Machine (M2M) technology. Wireless communication technologies for managing future M2M applications are becoming mature, but electromagnetic interference and time dispersion in industrial environments can limit the successful functioning of these wireless systems, leading to a failure in the control of critical functions. The characterization of these environments is necessary for collecting and specifying M2M requirements. In this paper, we present the conclusions from measurements carried out in three different industrial environments in the last three years

4:30 pm **Effect on Digital TV of Disturbances from Electrical Equipment Evaluated using an Actual Broadcasting Signal** 964

Nobuo Kuwabara *(Kyushu Institute of Technology, Kitakyushu, Japan)*;
Shohei Yanagi *(Kyushu Institute of Technology, Kitakyushu, Japan)*;
Hiroyuki Miyake *(Kyushu Institute of Technology, Kitakyushu, Japan)*

Abstract–The effect that disturbances from electrical equipment have on a digital TV signal was evaluated using an actual broadcasting signal. Various types of disturbance from equipment were measured by an oscilloscope and then the measured waveforms were generated by an arbitrary waveform generator. The TV signal and the disturbance level were evaluated using the quasi-peak value, amplitude probability distribution (APD), and average power. The effect on received images was evaluated using mean opinion score (MOS) and bit error rate (BER). The relation between MOS and the ratio of desired and undesired signal levels (DU ratio) was investigated for actual digital TV and analogue TV signals. Results suggest that evaluation using the APD or the average power is appropriate because these methods are less affected by the type of disturbance. The relation between the MOS and the BER indicates that image quality can be roughly estimated from the BER

5:00 pm **Empirical Estimation of Probability Distribution for Electric Field Strength in Automotive Cabin** 970

Noboru Maeda *(Nippon Soken, Inc., Aichi, Japan)*; Shinji Fukui *(Nippon Soken, Inc., Aichi, Japan)*;
Nobuyuki Ishihara *(Toyota Motor Corporation, Aichi, Japan)*; Takayuki Naito *(Toyota Motor Corporation, Aichi, Japan)*

Abstract–A novel model of the probability distribution for electric field strength in automotive cabin is proposed in the form of a mixture distribution of a linear Rayleigh distribution for low-value data and a log generalized extreme value (GEV) distribution for high-value data. A sample model is estimated from the data measured in a horizontal two-dimensional area above main battery in a hybrid vehicle. For the probability distribution model of the ensemble data of different transmitter antenna directions and all target frequencies, the mixture weights and the parameters for each component distribution are estimated using expectation-maximization (EM) algorithm. The result model showed good fitting to the measured data in probability density function plot and quantile-quantile (Q-Q) plot. Based on the ensemble data distribution model, the probability distribution models for individual conditions of frequencies and antenna-directions are also estimated applying linear transformation. Results are tested using Q-Q plot, which shows good fitting with slight overestimation in very high-value region. Kolmogorov-Smirnov (K-S) goodness of fit test at the 1% significance level also accepts this method for all the data measured above 600MHz.

THU-PM-6, EMC Management (TC1), Room 103C

Chair: Kimball Williams, Denso International America
Co-Chair: Doug Kraemer, Rockwerll-Collins

2:30 pm **The Education of EMC – The Strategy and Teaching Overview at the UWB** 976

Vaclav Kus *(University of West Bohemia, Pilsen, Czech Republic)*;
Pavel Drabek *(University of West Bohemia, Pilsen, Czech Republic)*

Abstract–This contribution introduces the education of EMC at the University of West Bohemia in Pilsen (UWB). The phenomenon of Electromagnetic compatibility (EMC) has been taken into account almost at the all faculties of electrical engineering in the Czech Republic. However there are very often only partial mentions of EMC in frame of individual electrical engineering subjects and the education is focused on the one specific EMC area. At the Faculty of electrical engineering at the UWB we have paid attention to these questions in several special subjects in the bachelor and master studying program. In this paper the education system of the Faculty of electrical engineering has been presented. The main attention has been given to the low frequency interference of power electronic converters.

3:00 pm **Managing Engineers for Success** 982

Scott Mee *(Johnson Controls, Inc., Cergy, France)*;
James Teune *(Gentex Corporation, Zeeland, MI, United States)*

Abstract–To be successful as a manager of engineers, there are three parties that should benefit: Employer, Engineer, and the manager. Without all three, long term success will not be assured. While the advice given in this paper could apply to managing a wide range of personnel, the focus will be placed on engineering personnel. The authors have spent most of their career working in electromagnetic compatibility positions that include: EMC Test Engineer, EMC Design Engineer, Lead Engineer and Laboratory Manager Roles. Over twenty-five combined years spent managing technicians and engineers. Much of what is covered in this paper is lessons learned from working for various managers and our own success and failures as managers.

Abstract–It is not an exaggeration to say that we are witnessing the birth of a brand new industry – Risk Management of EMC – which will be needed in many safety-related and high-reliability applications/industries. But at the moment there are (effectively) no resources available that can satisfy its requirements, either from EMC test laboratories or functional safety assessors. A great deal of work needs to be done to prepare manufacturing industry, test laboratories and safety assessors for these requirements, for which a large demand will build up by 2021. The new opportunities now available include: Academic teaching at all levels; Academic research; Vocational training courses; Computer-aided simulation; Test methods and specialized test equipment; Verification/validation techniques other than testing; Development of policies and procedures; Safety Assessor services; Accreditation services. This paper briefly introduces the rapidly growing need for the above, and discusses each of these opportunities in turn.

Abstract–VLAC, a Japanese laboratory accreditation body mainly in the field of EMC testing, has organized PT (Proficiency Testing) program of EMI measurement six times since 2005. The program has been performed with the type of inter-laboratory comparison by circulating an artifact. Based on the evaluation result of programs, the SCU (standards compliance uncertainty) of radiated emission measurement was estimated from the group interval of the collected data. Each test site carried out the measurement of radiated electromagnetic interference from the artifact under the conditions specified in the program including the use of the accompanying VHF LISN (Line Impedance Stabilization Network) to specify the common mode impedance of AC power supply of each participated test site. This paper discusses the calculation value of SCU which resulted in no greater than 6.9dB if EUT (Equipment under Test) has a simple operating condition and makes a simple test arrangement, and if the terminating condition of AC mains power supply is specified with using a stabilization device such as VHF-LISN.

Abstract–Existing immunity test methods can be developed to cost-effectively provide greater "coverage" of real-world electromagnetic environments, and such techniques are now needed to aid in effective risk management of electromagnetic compatibility (EMC) because of the increasing automation of society and industry. The reliability of electronic technologies (including their software and firmware) becomes critical when the consequences of errors, malfunctions or other types of failure include significant financial loss, mission loss, loss of security, or harm to people, domestic animals or property (known as "functional safety"). Electromagnetic interference (EMI) can be a cause of unreliability in all electronic technologies, so EMC must be taken into account when the risks caused by malfunctioning electronics need to be controlled. Unfortunately, it is not practicable to achieve the levels of confidence required for critical systems, over their entire lifetime, by EMC testing alone – no matter by how much the test level is increased above the maximum levels obtaining in the environment. A variety of additional verification and validation techniques are required. The subject of this paper, is developing existing radiated and conducted radio-frequency immunity test methods to cover the real-life possibilities for intermodulation, that at the time of writing are ignored by all standardized test methods.