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SS01-1 Machine Learning Aided SI, PI, EMC and EMI Session #1 (Sponsored by SC-3)

Special Session **10:30am - 12:00pm**

Room: 125AB

Chair: Lijun Jiang, *Missouri University of Science and Technology, Rolla, MO, USA*

Co-Chair: Sourajeet Roy, *Indian Institute of Technology Roorkee, Roorkee, India*

Session Abstract: Machine learning is having a profound effect on the landscape of every technology domain, including signal integrity, power integrity, EMC, and EMI engineering. This special session will present the state-of-the-art in our IEEE Society. It will focus on the paradigm shift of using machine learning to generate innovations in a way that's differentiate to traditional design and analysis approaches. The session will aim to draw deeper analysis and facilitate open discussions about the pros and cons of machine learning in EMC/EMI, SI and PI.

10:30am **Imitation Learning-Based Fast Optimization of SSD Interface for PCIe 6.0 considering Signal Integrity** 1

Seonguk Choi[1], Jihun Kim[1], Taein Shin[1], Jungmin Ahn[1], Keunwoo Kim[1], Keeyoung Son[1], Joonsang Park[1], Jinwook Song[2], Kyungsuk Kim[2], Sunghoon Chun[2], Joungho Kim[1]

[1]Korea Advanced Institute of Science and Technology, Korea; [2]Samsung Electronics, Korea

EMC BEST PAPER FINALIST

Abstract: In this paper, we propose an genetic algorithm (GA)-based imitation learning (IL) for fast optimization method of interface in the Peripheral Component Interconnect Express (PCIe) 6.0 system using Pulse Amplitude Modulation (PAM4) signaling. PCIe is the main interface standard for connection between CPU and GPU or solid-state drive (SSD) with a high data rate. However, issues related to signal integrity (SI) become severe as the data rate per lane has increased with each generation. Therefore, optimizing both the PCIe channel and equalizer is required. The proposed method trains the policy network to obtain immediately the optimal design of the channel and equalizer by using the imitation learning method. Based on the high-quality data obtained from the GA, the policy network learns the expert trajectories. Furthermore, the training process is implemented in several host systems. Hence, the trained policy network has reusability for an arbitrary electrical characteristic of the host systems. For verification, the proposed method is applied to the E1.L SSD interface design task. As a result, the superiority of the proposed method is validated by comparing conventional optimization algorithms in terms of optimal performance and computational time.

11:00am **High-Speed Link Transient Simulation based on Simple Recurrent Unit Method** 7

Hanzhi Ma, Jiarui Qiu, Ling Zhang, Da Li, Er-Ping Li

Zhejiang University, China

Abstract: Time-domain transient simulation is a crucial signal integrity modeling technique in high-speed link design. Recurrent Neural Network (RNN), a commonly used machine learning method for high-speed link transient simulation, faces a limitation in parallel operation during computation. This constraint presents challenges when analyzing high-speed links with long input bit patterns. In this paper, we introduce an effective and accurate transient simulation approach that utilizes the Simple Recurrent Unit (SRU) for assessing signal integrity in high-speed links. Applied to a nonlinear high-speed link example, the SRU model demonstrates both a faster training and improved accuracy in predicting output signals compared to the conventional RNN model.

11:30am **High-Speed Channel Simulator using Neural Language Models** 11

Hyunwook Park[1], Yifan Ding[1], Ling Zhang[2], Natalia Bondarenko[3], Hanqin Ye[3],
Brice Achkir[3], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]Zhejiang University, China;
[3]Cisco Systems Inc., USA

Abstract: In this paper, high-speed channel simulators using neural language models are proposed. Given the input sequence of geometry design parameters of differential channels, the proposed channel simulator predicts SI characteristic sequences such as insertion loss (IL) and far-end crosstalk (FEXT). Sequence-to-sequence (seq2seq) networks using a recurrent neural network (RNN) and a long short-term memory (LSTM) are utilized for the estimator. Moreover, a transformer network which is a recent neural engine of large language models (LLMs) is introduced for the first time. Compared to seq2seq networks, the transformer network-based simulator can achieve shorter computing time due to its parallel computation called an attention. The accuracy and training time of seq2seq and transformer networks are validated and compared. As a result, all the proposed simulators show ~1% error rates for both the IL and FEXT. However, for the training time, the transformer network achieves 75%–83% reduction compared to seq2seq networks.

TC2-1 EMC Measurements for PCBs and Memory Components (Sponsored by TC-2)

Technical Papers **10:30am - 12:00pm**

Room: 127B

Chair: Ghery Pettit, *Pettit EMC Consulting, Olympia, WA, USA*

Co-Chair: Ahalya Srikanth, *Ford Motor Company, Lasalle, ON, Canada*

10:30am **Octal-Input Zero-Span-Mode Analyzer using FPGA Boards** 17

Satoru Hatsukade[1], Keiji Wada[2]
[1]Railway Technical Research Institute, Japan; [2]Tokyo Metropolitan University, Japan

Abstract: Measuring leakage currents in the rolling stock is crucial to avoid electromagnetic interference (EMI). Particularly, tackling common-mode current paths at a given signal frequency at several locations simultaneously is essential because railway signaling equipment uses electromagnetic waves below 10 MHz to detect trains and for vehicle-to-ground communications. This paper presents a measurement instrument that can simultaneously record eight inputs in zero-span mode using two low-cost field-programmable gate array boards.

11:00am **Reactive Magnetic Near-Field to Far-Field Transformation based on Plane Wave Spectrum at PCB Level** 22

Dong-Hao Han, Ming-Jie Pang, Xing-Chang Wei
Zhejiang University, China

EMC BEST STUDENT PAPER SEMI-FINALIST

Abstract: This paper proposes a reactive magnetic near-field to far-field transformation method based on plane wave spectrum (PWS), aiming at electromagnetic radiation emission (RE) assessment at printed circuit board (PCB) level. Different from the antenna near-field measurement, the scanning plane is usually located in close vicinity of the device under test (DUT) in electromagnetic interference (EMI) near-field measurement, within the reactive region where evanescent waves are dominant. Additionally, in consideration of the presence of a ground plane on PCB, the tangential reactive electric near-field is minor, thus making it more common to measure the tangential reactive magnetic near-field. This further increases the difficulty of predicting far-field, which is commonly characterized by and . In this paper, the formula for magnetic near-field to far-field transformation is derived. Compared with the traditional dipole source reconstruction method, the proposed method eliminates the need for any intermediate steps and showcases an enhanced precision in predicting the far field of different examples. Additionally, the proposed method exhibits stronger robustness against noise interference, even in scenarios where the signal-to-noise (SNR) ratio is as low as 0 dB. Subsequently, numerical and experimental examples corroborate the effectiveness of the proposed mothed for reactive magnetic near-field to far-field transformation.

11:30am **Designing Spectrum Analyzer Measurements for EMI Analysis of Memory Components** 28
Praveen Gurrala, Todd Elson
Micron Technology Inc., USA

Abstract: Spectrum analyzers are widely used for peak emission power measurements in electromagnetic interference applications. For wideband input signals, the measured amplitudes must be corrected to account for the attenuating effect of small resolution bandwidths (RBW). We develop an analytical relationship between the peak amplitude and the RBW for bursty input signals of the type typically associated with DRAM memory operation and demonstrate its validity in emissions measurements. We also propose a method to improve the signal-to-noise ratio by repeating the test pattern periodically.

TC9-1 Modeling Techniques for Radiation (Sponsored by TC-9)

Technical Papers **10:30am - 12:00pm**
Room: 127C
Chair: Shubhankar Marathe, *Amazon Lab126, Santa Clara, CA, USA*

10:30am **Effects of the Asynchronous Differential Signals on Radiated Emissions** 29
Jaehoon Kim
Altair Engineering Inc., USA

Abstract: Asynchronous differential signals are studied in terms of how much their phase difference quantitatively contributes to electromagnetic noise radiated both from a PCB and a cable. A simulation setup, based on the CISPR 25 standard, is utilized to understand the EMI effect difference between the PCB and the cable. More importantly, it is estimated when the cable is closely coupled with the differential signal's clock frequencies and leads to the worst radiated emissions.

11:00am **Impact of Different Voltage Source Models on Radiated Field and Incident Power Density within the Boundary Element Method Formalism** 33
Anna Šušnjara Nejašmić, Dragan Poljak
University of Split, Croatia

Abstract: This paper deals with the impact of different voltage source models on computed radiated electromagnetic (EM) field and incident power density (IPD) in the framework of boundary element method formalism. Quarter, half and full wavelength dipole antennas are placed in free space. Antenna current is obtained by solving the Pocklington's integrodifferential equation via Galerkin-Bubnov Indirect Boundary Element Method (GB-IBEM). Delta gap (DG) and magnetic frill (MF) are used as excitation source models. Frequency, distance, antenna radius and segment number are varied. Relative errors in current, EM field and IPD values are computed for MF source with respect to DG source. It is found that definition of antenna radius plays an important role in the difference between the results obtained with DG and MF sources. The relative error does not depend on frequency nor on distance from the antenna for EM field and IPD.

TC10-12 High-Speed Interconnects and Noise Coupling (Sponsored by TC-10)

Technical Papers **10:30am - 12:00pm**

Room: 128A

Chair: Hanfeng Wang, *Google Inc, Mountain View, CA, USA*

Co-Chair: Chulsoon Hwang, *Missouri University of Science and Technology, Rolla, MO, USA*

10:30am **Vertical Interconnect Technology in Silicon, Package, and Printed Circuit Board (PCB) with Coaxial Structure** 39

Junyong Park[1], Chaofeng Li[1], Eddie Mok[2], Joe Dickson[2], Joan Tourné[3], Donghyun Kim[1]

[1]Missouri University of Science and Technology, USA; [2]Wus Printed Circuit (Kunshan) Co., Ltd, USA; [3]NextGin Technology, Netherlands

Abstract: This paper introduces vertical interconnect technology in silicon, package, and printed circuit board (PCB) levels with a coaxial structure, respectively. The coaxial structure has been known to be advantageous in terms of signal integrity (SI) compared to the non-coaxial structure. The coaxial structure is easy to control the characteristic impedance Z0 and robust to crosstalk. The silicon-level interconnect includes the wire bonding (WB) and through-silicon via (TSV) technology, the package-level interconnect includes an elastomer package test socket. The PCB-level interconnect includes the vias, and vertical conductive structure (VeCS). For each level, the non-coaxial and coaxial interconnects are compared with the measurement results in the frequency domain. In conclusion, this paper successfully shows the improvement of the coaxial structure at silicon, package, and PCB levels.

11:00am **Channel Budget Assessment of ENRZ and PAM4** 45

Francesco de Paulis[1], Sherman Shan Chen[2], Tim Wang-Lee[3], Luis Boluna[3], Mike Resso[3], Brandon Gore[4]

[1]University of L'Aquila, Italy; [2]Kandou Bus, United Kingdom; [3]Keysight Technologies, USA; [4]Samtec Corporation, USA

Abstract: The development of future interconnect technology will involve the exploration of different modulation or channel encoding schemes. This abstract deals with a one-toone comparison between the PAM4 and Ensemble NRZ (ENRZ) to verify their performances based on the same data throughput of 224 Gbps. The maximum length (loss) reached without equalization is investigated, and the receiver equalization (CTLE and DFE) required by the PAM4 based channel will be derived to obtain comparable results with the ENRZ without equalization in terms of eye height and width.

11:30am **Noise Reduction Technique to Meet Power Delivery Requirements for High Speed IPs** 46

Haijin Zhang[1], Jinsong Hu[1], Xiao Hu[1], Qing Zhou[2]

[1]Intel Corporation, China; [2]Intel Corporation, USA

Abstract: In multichip package (MCP) design, merging power rails is common to reduce costs. However, power noise often couples between different IPs via the power delivery network. High-speed IPs like PCIE gen5 require tight power noise control. This paper proposes an embedded low-pass filter in the package to attenuate high-frequency power noise coupling to high-speed IPs, reducing peak-to-peak noise on the power rail by 75%. Our approach is valuable for power design for high-speed IPs and MCPs.

TC10-S1 Crosstalk, Jitter, Noise Coupling, BER Analysis #1 (Sponsored by TC-10)

Technical Papers **10:30am - 12:00pm**

Room: 128B

Chair: Jianmin Zhang, *Google Inc., Mountain View, CA, USA*

Co-Chair: Francesco de Paulis, *University of L'Aquila, L'Aquila, Italy*

10:30am **Modeling of Ground-Bounce Induced Jitter for Rising Transition Edges in CMOS Inverters** 47

Anuj Kumar, Jai Narayan Tripathi

Indian Institute of Technology Jodhpur, India

SIPI BEST STUDENT PAPER SEMI-FINALIST

Abstract: An analytical modeling approach for ground-bounce noise (GBN) induced jitter in CMOS inverters for the rising transition edges at the output is presented in this paper. To estimate jitter at the inverter output, the device parameters of the transistors are used for a comprehensive analysis. A closed form expression for jitter is derived by establishing the input-output relationship of the CMOS inverter based on the different operating modes of the transistors. The proposed analytical method has been validated using several examples and for various process corners of 40 nm United Microelectronics Corporation (UMC) technology. The transient responses of the inverter with and without noise, as well as estimated jitter using the proposed method is closely matched with the results obtained from an SPICE based simulator.

11:00am **Modeling of Power Distribution Network (PDN) Noise Coupling Induced Clock Phase Noise** 52

Zhekun Peng[1], Junyong Park[1], Chaofeng Li[1], Joey Stecher[1], Srinivas Venkataraman[2], Xu Wang[2], Granthana Rangaswamy[2], DongHyun (Bill) Kim[1]

[1]Missouri University of Science and Technology, USA; [2]Meta Platforms Inc., USA

Abstract: Phase noise analysis is important to clock design. Noise sources of spurs shown on the phase noise result are challenging to find out due to the unknown source locations and coupling mechanisms. Noise from power distribution network (PDN) is one of the most troublesome sources. A behavioral modeling methodology is proposed to simulate the clock phase noise induced by PDN noise coupling for two different mechanisms : PDN-to-clock additive coupling and PDN-to-PDN up-conversion modulation. The thermal noise and 1/f flicker noise are simplified to provide a straightforward view of spur level. The model can be applied to both single-ended clock and differential clock. The result of the model can be used to compare the power spectral density of the potential noise sources and provides hypothesis on the potential noise source together with layout change simulation. The potential root cause of the spurs is analyzed. The mitigation methodologies of the phase noise are proposed and evaluated in the specific case, presenting a 34 dB suppression to the spurs shown on a differential clock phase noise.

11:30am **Modeling of Variability-Aware Supply-Induced Jitter in VMD Circuit Driving Long Transmission Lines** 58

Vinod Kumar Verma, Bhavani Sankar Challa, Jai Narayan Tripathi

Indian Institute of Technology Jodhpur, India

Abstract: This paper discusses the impact of variations in device parameters on power supply-induced jitter for a voltage-mode driver circuit driving long transmission lines. It aims to provide a comprehensive study on variability-aware modeling of power supply-induced jitter. Semi-analytical expressions are derived to estimate jitter, considering both power supply noise and variability issues. The mathematical expressions are validated by comparing the results obtained from the analytical approach with those obtained from the EDA simulations. Compared to the EDA simulator, the suggested method offers a notable speedup in jitter estimation.

SS01-2 Machine Learning Aided SI, PI, EMC and EMI Session #2 (Sponsored by SC-3)

Special Session **1:30pm - 3:00pm**

Room: 125AB

Co-Chair: Alistair Duffy, *De Montfort University, Loughborough, United Kingdom*

Co-Chair: Hanzhi Ma, *Zhejiang University, Hangzhou, China*

Session Abstract: Machine learning is having a profound effect on the landscape of every technology domain, including signal integrity, power integrity, EMC, and EMI engineering. This special session will present the state-of-the-art in our IEEE Society. It will focus on the paradigm shift of using machine learning to generate innovations in a way that's differentiate to traditional design and analysis approaches. The session will aim to draw deeper analysis and facilitate open discussions about the pros and cons of machine learning in EMC/EMI, SI and PI.

1:30pm **Efficient Distribution-Based Process Corner Identification using Machine Learning** 63

Andrew Page, Matteo Cocchini, Zhaoqing Chen

IBM Corp., USA

Abstract: This paper presents a novel method of open-area wire corner modeling for high-speed PCB's based on the statistics of transmission line performance calculated using a pair of neural network surrogate models. This approach requires significantly less data than a polynomial interpolation surrogate model or a brute-force sweep, the two predominant alternatives. This reduction in overhead allows the same problems to be solved in a fraction of the time and allows introduction of more complexity into corner model extraction. It is demonstrated for a differential stripline embedded in a low-loss material giving a 10-D design space, showing a 5x speedup over the previous methods while exhibiting excellent accuracy and providing statistical information. Correlation between a live training metric and ground-truth model performance is examined in a convergence study.

2:00pm **Machine Learning Model for a Trace Referenced to Meshed Ground Planes** 67

Jiyue Zhu, Xiaoyan Xiong, Gang Kang, Karthikeyan Mahadevan

Cadence Design Systems Inc., USA

Abstract: Transmission lines (TL) with meshed ground planes have been widely used in Flexible Printed Circuit Boards (FPCB) because of its physical flexibility and weight. Unfortunately, the introduction of the meshed ground plane increases the complexity of modeling for the signal integrity of TL, which is beyond the capability of TL theories and 2D numerical methods. Although 3D full wave methods can characterize the electric properties accurately, it costs time and computation resources heavily. In this paper, we propose a machine learning model to calculate the inductance and capacitance per unit length (PUL) of TL with meshed ground planes. In this model, multiple physical parameters which can affect the characteristic impedance are taken into account. Simulation samples are obtained using 3D full wave simulations as training and testing data. The testing results show that predictions of the machine learning model are in good agreement with the results of 3D full wave simulations.

2:30pm **A Hybrid Algorithm to Dual Sparse Sampling Measurement in Time-Resolved Electromagnetic Near-Field Scanning** 71

Yanming Zhang[1], Steven Gao[1], Lijun Jiang[2]

[1]The Chinese University of Hong Kong, China; [2]Missouri University of Science and Technology, USA

Abstract: Time-resolved electromagnetic near-field scanning is vital for antenna measurement and addressing complex electromagnetic interference and compatibility issues. However, the swift acquisition of high-resolution spatiotemporal data remains challenging due to physical constraints, such as moving the probe position and allowing sufficient time for sampling. This paper introduces a novel hybrid approach that combines Kriging for sparse spatial measurement, compressed sensing (CS) for sparse temporal sampling, and dynamic mode decomposition (DMD) for a comprehensive analysis of dual-sparse sampling electromagnetic near-field data. CS optimizes sparse sampling in the time domain, capitalizing on the inherent sparsity within electromagnetic radiated signals, resulting in reliable representation of time-domain signals and reducing the required time samples. Latin hypercube sampling guides the probe position, facilitating sparse measurement in the space domain. DMD extracts meaningful insights from the resulting sparse spatiotemporal data, producing sparse dynamic modes and temporal evolution information. Subsequently, Kriging is employed to infer missing spatial measurements for each sparse dynamic mode. Finally, the entire spatiotemporal signals are reconstructed based on interpolated dynamic modes and temporal evolution information. Validation of the proposed method is demonstrated with an example using crossed dipole antennas as the device under test. The Kriging-CS-DMD framework effectively reconstructs electromagnetic fields with precision while concurrently reducing the measurement workload in both the time and space domains. This methodology holds promise for various applications, including space-time-modulated electronic devices.

TC2-2 EMC Measurements for Wireless Communications, Pulsed Interference and Transistors (Sponsored by TC-2)

Technical Papers **1:30pm - 3:00pm**

Room: 127B

Chair: Tom Braxton, *Elite Electronic Engineering Inc, Bolingbrook, IL, USA*

1:30pm **Assessing Time-Scale-Dependent Interference Vulnerabilities in Wireless Communications** 76

Michelle Pirrone[1,2], Jordan Bernhardt[1], Adam Wunderlich[1]

[1]National Institute of Standards and Technology, USA; [2]University of Colorado Boulder, USA

EMC BEST STUDENT PAPER SEMI-FINALIST

Abstract: We demonstrate a general-purpose approach to evaluate interference immunity at the source (data payload origin) of a `closed-box' wireless communication system over different time-scales. Specifically, using a consumer off-the-shelf point-to-point microwave link operating in the unlicensed U-NII-5 6GHz band as the victim system, we assess the impact of injected pulse-modulated noise with various signal periods at the source of a communication link. Observed distributions of link throughput show performance degradation and multimodal behaviors that are problematic for critical applications where a minimum data throughput is desired or required to maintain a given quality of service. Particularly, impacts from pulse-modulated noise are observed to induce greater link degradation as compared to constant additive white Gaussian noise with the same average power, highlighting the need to re-evaluate current EMC test methods that use constant AWGN as a benchmark interference signal.

2:00pm **Cage-in-Cage Test Setup for Discontinuous Radiated Emissions from GaN Transistors in the Gigahertz Frequency Range** 82

Krzysztof Sieczkarek, Bartłomiej Nagórny, Adam Maćkowiak, Tomasz Warzyński, Michał Rokossowski, Radosław Szczepański

Łukasiewicz Research Network - Poznan Institute of Technology, Poland

Abstract: The article presents a method for measuring unwanted radio frequency emissions in the frequency range 30 MHz to (at least) 6 GHz coming from new types of transistors based on gallium nitride (GaN). A test set-up based on dedicated Faraday cage was designed to extract emissions passing only through the transistor housing. Secondary screening was achieved through the use of an anechoic chamber and fast broadband spectrum measurement was performed using a real-time EMI receiver.

2:30pm **A Device for the Detection of HPEM Interference based on an LPDA Antenna with Nonlinear Load** 88

R. Michels[1], M. Schaarschmidt[2], S. Fisahn[2], F. Gronwald[1]

[1]Universitat Siegen, Germany; [2]Bundeswehr Research Institute for Protective Technologies and CBRN Protection, Germany

Abstract: Antenna structures with nonlinear loads that are exposed to electromagnetic illumination may show responses that are difficult to predict. A remarkable effect can be observed if a diode is chosen as nonlinear load. In this case, the rectifying property of the diode can lead to an energy storage effect that appears as a rather long lasting voltage at the antenna port. Besides the fact that this energy storage effect might be a major issue regarding EMC it is also possible to use it for the detection of high power electromagnetic (HPEM) pulses without requiring advanced high frequency equipment. In this contribution it will be shown that the broadband characteristics of a common log-periodic dipole antenna (LPDA) combined with a nonlinear energy storage effect can be utilized to develop an efficient low-cost HPEM pulse detector.

TC9-2 Computational EM (Sponsored by TC-9)

Technical Papers **1:30pm - 3:00pm**

Room: 127C

Chair: Shaohui Yong, *Missouri University of Science and Technology, San Jose, CA, USA*

1:30pm **Efficient Crosstalk Evaluations for Electric Vehicles using FDTD and Transmission Line Simulations** 89

Kyle Elsasser, Karen Burnham

Electro Magnetic Applications, Inc., USA

Abstract: In electric vehicle (EV) architectures, a significant risk to electromagnetic self-compatibility is crosstalk between high voltage (HV) cables and low voltage (LV) signal lines such as the Controller Area Network (CAN) bus. Switching noise resulting from inverter or DC/DC conversion operations can be carried on HV lines and then couple into sensitive LV lines via a radiative crosstalk mechanism. When these threats are identified in advance, computational electromagnetic (CEM) modeling and simulation can be used to rapidly iterate through different design mitigations to arrive at a practical and cost-effective solution to ensure self-compatibility between the HV and LV systems. This paper presents a case study where this approach was used to improve the design of an EV mobile charging trailer to prevent likely threats to the CAN network.

2:00pm **3D Full Wave Finite Element Method for Advanced IC Pattern-Dependent Effects Analysis** 94

Baolong Li, Lei Yue

Cadence Design Systems Inc., USA

Abstract: During the sub-nanometer IC manufacturing process, the physical width, thickness, and sheet resistance of a wire generally depend on the surrounding wiring, called Pattern-Dependent Effects. The Pattern-Dependent effects can change resistance and capacitance values by up to 50%, so it is important to account for them in simulation and modeling. Luckily, some RFIC EM simulation software offered solutions in the past, but they are not 3D full-wave algorithms. This paper will describe the challenges of FEM for such type of problem and introduce a hybrid electromagnetic algorithm to solve this effect and verify the effectiveness of this approach with a simple transmission line example.

2:30pm **A Modal Network Representation of Complex Electrical Structures Suitable for an Overall EMC System Analysis** 98

Hannes Schreiber, Marco Leone

Otto von Guericke Universitat Magdeburg, Germany

Abstract: A novel efficient and versatile method for the modeling of electrical structures by an equivalent modal network is presented. Based on a modal full-wave solution, the network model can fully represent the system behavior and thus provides very good matches with conventional full-wave simulation even for complex examples. In contrast to black-box models, the presented approach provides physical insight into the system due to its modal description. This enables EMC analysis and optimization of the overall system by network simulation. The validity of the method is demonstrated by a computational example referring to an extensive Method-of-Moments full-wave solution.

TC10-13 Power Distribution Networks and Decoupling #1 (Sponsored by TC-10)

Technical Papers **1:30pm - 3:00pm**

Room: 128A

Chair: Kinger Cai, *Intel Corporation, San Jose, CA, USA*

Co-Chair: Jingook Kim, *Ulsan National Institute of Science and Technology (UNIST), Ulsan, Korea (the Republic of)*

1:30pm **Innovatiave Decoupling Capacitor Solutions for Power Delivery Improvement on Advanced FPGA Packages** 104

Wei Liu, Guang Chen, Jenny Xiaohong Jiang, Ed Milligan

Intel Corporation, USA

Abstract: In this paper, the innovative on-package decoupling capacitor (OPD) technique is presented for power delivery network (PDN) design optimizations with next generation Field- Programmable Gate Array (FPGA) for intensive power consumption usage. The paper introduces general on-package decoupling capacitor techniques, compares discrete multi-layer ceramic capacitors with deep trench capacitors, and demonstrates the advantage of deep trench capacitor (DTC) application in optimizing voltage noise in power delivery network. With the proposed DTC methodology, the voltage supply 1st droop at the package C4 bump can be reduced by 5mV in one example compared with MLCC (multi-layer ceramic capacitors) to reach design specifications. An accurate noise simulation methodology and package routing optimization strategy in noise optimization are essential to an efficient system evaluation and demonstrated in this paper.

2:00pm **Experimental Study of PCB Vibration Induced by MLCC Assembly Orientation and Process Variations** 110

Yifan Ding[1], Ming-Feng Xue[2], Jianmin Zhang[2], Xin Hua[2], Benjamin Leung[2], Eric A. MacIntosh[2], Chulsoon Hwang[1]

[1]Missouri University of Science and Technology, USA; [2]Google Inc., USA

SIPI BEST STUDENT PAPER SEMI-FINALIST

Abstract: The piezoelectric effect will cause the multilayer ceramic capacitor (MLCC) to deform in several directions. When it is soldered to the printed circuit board (PCB) and powered on, these deformations will exert a certain force on the PCB, causing the PCB to vibrate and emit acoustic noise at a certain frequency. Determining the dominant deformation direction that MLCC can affect the PCB is relevant and important for efficiently extracting the equivalent source of noise. This paper provides a method to determine the dominant deformation direction produced by MLCC, explores it through experimental measurement results, and finally provides a conclusion to the investigation.

2:30pm **Novel Interdigital Capacitor-Type Power Distribution Network Design for Power Noise Suppression in Redistribution Layer Interposer** 114

Haojie Wu[1], Xinglin Sun[2], Keeyoung Son[2], Jonghyun Hong[2], Yin Sun[3], Joungho Kim[2]

[1]Zhejiang University, China; [2]Korea Advanced Institute of Science and Technology, Korea; [3]Ningbo Detool Technology Co. Ltd, China

SIPI BEST PAPER FINALIST

Abstract: The interposer-based high bandwidth memory-graphic processing unit (HBM-GPU) module plays the key role for high-performance computing (HPC) with ultra high data bandwidth. Among different interposer structures, redistribution layer (RDL) interposer has exhibited outstanding signal integrity performance due to its low dielectric constant (Dk) substrate. However, the low-loss characteristic results in compromised power integrity performance and increased coupling of power noise. Conventional methods that center on the placement of decoupling capacitors and filter-type structures cannot be effectively implemented on the RDL interposer due to its passive characteristic and limited routing space. In contrast to these methods, our focus is on designing the RDL interposer structure itself. In this paper, we proposed a novel power distribution work (PDN) design featuring an interdigital capacitor (IDC)-type structure and a hybrid-substrate layer stack, obtaining a larger on-interposer capacitor. We conducted simulations and analyses to investigate the impact of the proposed PDN structural parameters on the PDN impedance profile. Finally, we validated the effectiveness of the proposed IDC-type PDN in improving the PDN impedance and achieving superior noise attenuation by comparing it with the conventional mesh-type PDN.

TC10-2 Material Characterization for SI (Sponsored by TC-10)

Technical Papers **1:30pm - 3:00pm**

Room: 128B

Chair: Tao Wang, *Missouri University of Science and Technology, San Diego, CA, USA*

Co-Chair: Wei Zhang, *Missouri University of Science and Technology, Fremont, CA, USA*

1:30pm **DK and DF Characterization of Low-Loss Dielectric Liquid by Cylindrical Cavity Resonator** 119

Chaofeng Li[1], Seyedmehdi Mousavi[1], Reza Asadi[1], Seyedmostafa Mousavi[1], Reza Vahdani[1], Xiaoning Ye[2], Kai Wang[2], DongHyun Kim[1]

[1]*Missouri University of Science and Technology, USA;* [2]*Intel Corporation, USA*

Abstract: A novel cylindrical cavity resonator-based measurement method was developed to characterize the dielectric property of the low-loss dielectric liquid in the paper. The proposed method can be used to accurately measure the dielectric constant (Dk) and the loss tangent (Df) of the low-loss coolant for signal integrity analysis. The cylindrical cavity resonator works at tangential magnetic (TM010) mode is used in the paper to demonstrate the proposed method. A cylindrical cavity resonator apparatus was designed and investigated using full-wave simulations at first. The relative error of Dk and Df extractions based on the designed apparatus are less than 1% and 5% from simulation results, respectively. In addition, the designed apparatus was manufactured to verify the proposed method through measurements. Measurements demonstrate the high accuracy and repeatability of the proposed method for low-loss dielectric liquid characterization. The measurement uncertainty for Dk could be less than 1%.

2:00pm **Design of the TM_{010} Mode Cylindrical Cavity Resonator for PCB Dielectric Characterization** 125

Reza Asadi[1], Chaofeng Li[1], Seyedmehdi Mousavi[1], Seyed Mostafa Mousavi[1], Reza Vahdani[1], Xiaoning Ye[2], DongHyun Kim[1]

[1]*Missouri University of Science and Technology, USA;* [2]*Intel Corporation, USA*

Abstract: This paper presents the study of the TM010 mode cylindrical resonator, which can be used for printed circuit board (PCB) material properties extraction, e.g., the dielectric constant (Dk) and the loss tangent (Df) extraction. The theoretical formulas of the resonance frequency and Q-factor of the resonator are presented. In real measurement, the TM010 mode cylindrical cavity resonator needs to be excited by the probe. The study emphasizes the impact of probe orientation, location, and field distribution on the accuracy of material property extraction. The relationship between cavity dimensions and resonance frequency is explored, highlighting the influence of cavity radius and height on material property characterization. Visual representations and simulations illustrate the significance of these dimensions in accurately determining Dk and Df. The paper also compares the efficiency of electric- (E-) and magnetic- (H-) probe feeding methods through full-wave simulations. Results indicate that the E probe exhibits superior accuracy, with relative errors below 0.2% for Dk and less than 2.2% for Df, while the H probe shows a relative error of 0.1% for Dk and 8% for Df. The presented analysis can help the development and the manufacture of the cavity resonator method, for characterizing the PCB material.

2:30pm **Analytical Modeling of Partially-Filled TM_{010}-Mode Dielectric Resonator for Accurate DK and DF Extraction** 130

Mehdi Mousavi[1], Chaofeng Li[1], Reza Asadi[1], Seyedmostafa Mousavi[1], Reza Vahdani[1], Xiaoning Ye[2], Mina Esmaeelpour[1], DongHyun Kim[1]

[1]*Missouri University of Science and Technology, USA;* [2]*Intel Corporation, USA*

Abstract: In high-speed printed circuit board (PCB) modeling, the accurate determination of the dielectric constant (DK) and dissipation factor (DF) is crucial for signal integrity analysis at design stage. This paper introduces an analytical approach using a partially filled TM010-mode dielectric resonator, an effective tool for DK and DF extraction of PCB material. We begin by discussing the theoretical underpinnings of TM010-mode dielectric resonators and their applicability in measuring the DK and DF of the material under test. A mathematical model is then presented, linking the resonant characteristics directly to the DK and DF of the dielectric material. The validity of this model is established through comprehensive simulations results, highlighting its precision in determining DK and DF values. Our research not only underscores the practicality of TM010-mode dielectric resonators in PCB design but also offers a robust analytical framework for advance electronic material analysis in high-speed applications.

ED05 Common Mode – Where Does It Come From and How Can It Go Away?

Experiment/Demonstration **2:00pm - 4:00pm**
Room: E&D Booth 1

Session Abstract: We hear about common mode currents. The question becomes how are they generated, and why are they a problem? If they exist in a product, how do we control it? What works and what does not work? Through both teaching and demonstration, Mr. Andre will demonstrate each of these points.

Common Mode – Where Does It Come From and How Can It Go Away?

Patrick G. Andre
Andre Consulting, Inc., USA

ED06 Visualization of Low Frequency EMI using a Smartphone

Experiment/Demonstration **2:00pm - 4:00pm**
Room: E&D Booth 2

Session Abstract: We will be demonstrating an application where we use a smartphone to map low frequency EMI. Data is captured through a magnetic sensor connected to the headphone jack and onboard GPS sensors. This data is then fused to provide a map of low frequency EMI up to 16 kHz. The map is dynamic and interactive, allowing one to view a heatmap of EMI or interrogate the EMI spectrum at a given point.

Visualization of Low Frequency EMI using a Smartphone

Kevin Claytor
Johns Hopkins University Applied Physics Laboratory, USA

ED07 The Challenge of Measuring a 40 uOhm (2000 Amp) PDN with a 2-Port Probe

Experiment/Demonstration **2:00pm - 4:00pm**
Room: E&D Booth 3

Session Abstract: The assessment of PDN impedance has become a well-published mantra. However, designing a power distribution network (PDN) for a scalable 2000 Amp power supply presents numerous challenges, one of which is measurement of the 2000A PDN.

Most of us are aware of the ground loop in the 2-port measurement. Most of us are also aware that we need to introduce a ground loop isolator to correct the error. If not, we've published plenty on the subject. But how much CMRR do you need to add? How does the use of a probe impact this requirement? The goal of this presentation is to demonstrate how one can effectively measure a 2000 Amp PDN or 40 uOhm using various VNAs. In addition to proving the need for CMRR rejection, discussion on how to calculate the minimum CMRR with a PDN impedance measurement using a 2-port probe will be shown. Lastly, it will be shown that it is possible to measure a sub-40 μΩ impedance using a 2-port probe, when using an isolator that has sufficient CMRR.

The Challenge of Measuring a 40 uOhm (2000 Amp) PDN with a 2-Port Probe

Steve Sandler
California Miramar University, USA

ED08 Wi-Fi 6E/7: Amazing New Frontiers and Challenges ...

Experiment/Demonstration **2:00pm - 4:00pm**
Room: E&D Booth 4

Session Abstract: Wireless connectivity has had such an impact on how we conduct our daily lives. With the wires removed, suddenly we are able to be connected to almost anyone, anywhere and anytime. According to a report released by IDC Research, 3.8 billion Wi-Fi devices were forecasted to be shipped in 2023. Over the last few years, the number and complexity of the Wi-Fi standards has grown. The U.S. opened up the 6 GHz band while the EU opened up about half of the 6 GHz bands for Wi-Fi 6E, and now Wi-Fi 7. Although the Wi-Fi 7 standard has yet to be formally adopted, manufacturers have released Wi-Fi 7 products already. Each new standard offers more.. more bandwidth, more data transfer, more capability. With that increase, however, comes more measurement challenges to address for regulatory approval. This presentation will review the changes and discuss the measurement challenges in achieving regulatory approval.

Presentation will include videos with examples and experimental results.

Wi-Fi 6E/7: Amazing New Frontiers and Challenges ...
Bill Koerner
Keysight Technologies Inc., USA

SS01-3 Machine Learning Aided SI, PI, EMC and EMI Session #3 (Sponsored by SC-3)

Special Session **3:30pm - 5:00pm**
Room: 125AB
Co-Chair: Jianfeng Zheng, *University of Houston, Houston, TX, USA*
Co-Chair: Matteo Cocchini, *International Business Machines Corp, New York, NY, USA*
Co-Chair: Mohamed Kheir, *SDU, Syddansk Universitet, Odense, Syddanmark, DK, Sonderborg, Denmark*

Session Abstract: Machine learning is having a profound effect on the landscape of every technology domain, including signal integrity, power integrity, EMC, and EMI engineering. This special session will present the state-of-the-art in our IEEE Society. It will focus on the paradigm shift of using machine learning to generate innovations in a way that's differentiate to traditional design and analysis approaches. The session will aim to draw deeper analysis and facilitate open discussions about the pros and cons of machine learning in EMC/EMI, SI and PI.

3:30pm **Active Machine Learning for Automatic High-Frequency EMI Source Localization** 135
Jinghai Guo[1,2], Ling Zhang[1], Xin Yan[3], Hanzhi Ma[3], Da Li[3], Er-Ping Li[1]
[1]Zhejiang University, China; [2]National Key Laboratory of Intense Pulsed Radiation Simulation and Effect, China; [3]Missouri University of Science and Technology, USA

Abstract: This paper proposes a sparse emission source microscopy (ESM) technique based on active machine learning to localize high-frequency electromagnetic interference (EMI) sources. The proposed method, which combines the query-by-committee (QBC) algorithm and a newly proposed entropy feedback (EF) technique, can significantly improve the efficiency of high-frequency EMI source location by reducing the number of scanning points. The results of simulation and measurement examples show that the proposed method is much more time-efficient compared with the full sampling method. Also, the method demonstrates a noticeable advantage over the uniform sampling and random sampling approaches, and has higher accuracy of EMI source location with the same number of sparse scanning samples.

4:00pm **A Fast Metalearning Algorithm for Neural Network Enabled Uncertainty Quantification of Graphene based Interconnects with Passive Shielding** 140

Asha Kumari Jakhar, Dyuti Basu, Km Dimple, Surila Guglani, Avirup Dasgupta, Sourajeet Roy
Indian Institute of Technology Roorkee, India

EMC BEST PAPER FINALIST AND BEST STUDENT PAPER SEMI-FINALIST

Abstract: Inserting passive shield lines in between the active and victim conductors has become a standard approach for mitigating the crosstalk effects in multi-walled carbon nanotube (MWCNT) and multilayer graphene nanoribbon (MLGNR) interconnect networks. However, the insertion of the shield lines augments the number of conductors of the network, thereby making the training of artificial neural network (ANN) surrogate models of such networks from SPICE simulations a time-consuming process. In this paper, this problem is addressed using a novel multistage metalearning algorithm. In the proposed algorithm, an additional ANN is trained using data extracted from SPICE simulations of the network where the active and victim lines are represented using the rigorous multiconductor circuit (MCC) model and the shield lines are represented using the compact but approximate equivalent single conductor (ESC) model. Finally, the metadata extracted from this additional ANN is leveraged to achieve higher training efficiency not possible using standard metalearning algorithms. Validation examples of MWCNT and MLGNR interconnect networks at 7-nm technology node are presented in this paper.

4:30pm **Graph Convolutional Neural Network Assisted Genetic Algorithm for PDN Decap Optimization** 146

Haran Manoharan[1], Jack Juang[1], Ling Zhang[3], Hanfeng Wang[2], Jingnan Pan[2], Kelvin Qiu[2], Xu Gao[2], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]Google LLC, USA; [3]Zhejiang University, China

SIPI BEST STUDENT PAPER SEMI-FINALIST

Abstract: This paper proposes a hybrid algorithm combining reinforcement learning (RL) and a genetic algorithm (GA) for PDN decap optimization. The trained RL agent uses a graph convolutional neural network as a policy network and predicts the decap solution for a given PDN impedance and target impedance, which is seeded as an initial population to the GA. The trained RL agent is scalable regarding the number of decap ports. The main goal is to save computation time and find the near global minimum or global minimum. Generalization of the algorithm to different decap libraries is achieved through transfer learning, eventually reducing the training time of the RL agent. The proposed algorithm finds a decap solution satisfying target impedance twice as fast compared with genetic algorithms.

TC2-3 EMC Measurements – Probes (Sponsored by TC-2)

Technical Papers **3:30pm - 5:00pm**

Room: 127B

Chair: Ghery Pettit, *Pettit EMC Consulting, Olympia, WA, USA*

Co-Chair: Monrad Monsen, *Oracle, Broomfield, CO, USA*

3:30pm **On the Feasibility of a Direct Injection Probe with a Capacitively Coupled Return and Integrated Voltage Monitor** 151

Aaron Harmon, Daniel Szanto, Victor Khilkevich, Daryl Beetner
Missouri University of Science and Technology, USA

EMC BEST PAPER FINALIST

Abstract: Characterizing the susceptibility of an IC while it is integrated within a system can be challenging. Characterization is even harder if one wants to know the waveform at the target IC pin when injecting a signal on the pin. In this work, the feasibility of a direct injection probe with a capacitively coupled return and integrated voltage monitor is proposed. This probe is advantageous because it does not need to be soldered to the test device and its ability to provide a measurement of the waveform on the target IC pin during the injection. Methods for reconstructing the pin waveform based on probe measurements are discussed. Initial results indicate that the presented probe is generally insensitive to landing position variations and can accurately provide the waveform at the target IC during an injection. Future work is focused on further validation of the presented probe.

4:00pm **Design of Waveguide Probe for EMI Characterization of DDR5 SODIMM** 157
Xiangrui Su[1], Junho Joo[1], Minsu Lee[2], Jeongho Ju[2], Hyunsik Kim[2],
Taeil Bae[2], Haekang Jung[2], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]SK hynix Inc., Korea

Abstract: In the latest portable electronic devices, 5th generation double data rate small outline dual in-line memory modules (DDR5 SODIMMs) are more and more used and have been identified as one of the critical electromagnetic interference (EMI) noise sources that could cause RF desensitization. In this paper, the radiation mechanism of DDR5 SODIMM deployed in a laptop is identified and investigated based on near-field scanning. It was found that a cavity formed by the SODIMM and the main board can generate strong radiation around 2.4 GHz due to their dimensions, which overlap with the Wi-Fi band. To quantify the radiation from the cavity, a waveguide probe was designed to perform quick measurements. The performance of the proposed probe showed better sensitivity compared to conventional loop probes. The designed probe was built and used to characterize 4 different SODIMMs from 3 manufacturers. The waveguide probe-measured noise was proportional to the coupled power on the Wi-Fi antenna with an accuracy of 3 dB.

4:30pm **Full Modal-Admittance Matrix In-Circuit Measurement by Multiple Inductive Probes** 162
Simone Negri, Giordano Spadacini, Flavia Grassi, Sergio A. Pignari
Politecnico di Milano, Italy

EMC BEST PAPER FINALIST

Abstract: In past years, the use of clamp-on inductive probes was proposed for measuring the impedance or admittance at radio frequencies while the equipment under test (e.g., power electronic converters) is in operation. However, previous one-port methods (involving either one or two probes) allow only an approximate determination of the common-mode (CM) or differential-mode (DM) self-impedance, depending on how the probe/s is/are clamped on wires, and requesting (for DM) the disconnection of the CM return wire. Furthermore, with a single port it is not possible to determine the mutual-modal impedance parameter related to mode conversion. In this paper, a recently proposed multiport measurement method, originally intended for physical admittance measurement, is adapted to modal admittance measurements, resulting in a fast and effective solution for the characterization of full admittance matrices in the modal domain. By experimental tests on passive test networks, it is shown that the proposed method provides accurate results of the true CM/DM self and mutual admittances.

TC9-3 Multi-Physics Modeling (Sponsored by TC-9)

Technical Papers **3:30pm - 5:00pm**
Room: 127C
Chair: Shaowu Huang, *Marvell Semiconductor Inc, Cupertino, CA, USA*

3:30pm **The Study on How Model Selection Propagates in High Frequency Electromagnetic-Thermal Dosimetry** 167
Mario Cvetković, Dragan Poljak, Hrvoje Dodig
University of Split, Croatia

Abstract: This paper is on the electromagnetic (EM)-thermal dosimetry workflow in GHz frequency range. The hybrid boundary element method/finite element method (BEM/FEM) is used to calculate the induced electric field due to exposure to plane EM wave at 0.9 GHz, 1.8 GHz, 3.5 GHz, and 6 GHz. Two simplified human head models are considered, homogeneous one and non-homogeneous one. The output of two EM models is used as input to the thermal model based on Pennes' bioheat equation solved by means of FEM. The numerical results for the induced electric field, the specific absorption rate, the temperature increase and the heating factor, respectively, are compared point-wise along the propagation axis. By representing the human head with simplified geometry such as a sphere, the influence of geometry on the calculated metrics can be minimized, while focusing on the results along the diameter of the spherical head, the effect of the plane wave polarization can be neglected. As the frequency increases toward the transition frequency of 6 GHz, similar results are obtained with both homogeneous and non-homogeneous models, respectively. The results suggest that if we are interested in the thermal response, the homogeneous EM model of biological tissue might prove sufficient.

4:00pm **Modeling Non-Linearity in Laplace Domain** 173
Naomi de Mejanes, Olivier Maurice
ArianeGroup, France

Abstract: In this work a technic is proposed in order to model non-linearity in the Laplace Domain. The main idea is to set the non linearity by its parametric impedance function and to divide the source in temporal subdomains. The method is applied to study the voltage across a Spark Gap knowing its voltage breakdown. The main interest of the technic is its versatility. It can be used to analyze any EMC measurement in the frequency domain.

TC8&TC2 Aerospace EMC and Shielding (Sponsored by TC-8 and TC-2)

Technical Papers **3:30pm - 5:00pm**
Room: 128A
Chair: Jen Dimov, *NASA, Greenbelt, MD, USA*
Co-Chair: Jim Lukash, *Lockheed Martin Space Systems, Palo Alto, CA, USA*
Co-Chair: John Kraemer, *Kraemer EMC, Marion, IA, USA*

3:30pm **HIRF Avoidance Approach for Advanced Air Mobility Vehicles** 177
Truong X. Nguyen
NASA Langley Research Center, USA

Abstract: Advanced Air Mobility (AAM), including Urban Air Mobility (UAM) and Unmanned Aerial Systems (UAS), vehicles may fly in similar airspace to Transport Category Rotorcraft, thereby requiring meeting the same stringent High-Intensity Radiated Fields (HIRF) certification requirements. This effort proposes a map-based approach to avoid high-power transmitters based on the vehicle tolerance level. In addition, a minimum threshold level is suggested for vehicles operating in an urban area. As a result, a vehicle can tolerate common lower-power transmitters by default, and transmitter maps are only needed to avoid high-power transmitters which are far less common. Transmitter data are analyzed for New York City representing an urban area.

4:00pm **Broad Band Measurement of the Shielding Effectiveness of Carbon Fiber Composite Panels for Aerospace Applications** 178
Jinsoo Kim, Pablo Trejo, Jonathan Wang, Ju Hui Yoo, Jason Ehrich, Daniel Dijamco, Kattris Lee, Clifton Courtney, Leonardo Gutierrez Sierra
Lockheed Martin Aeronautics, USA

TC10-3 Simulation and Modeling Techniques #1 (Sponsored by TC-10)

Technical Papers **3:30pm - 5:00pm**
Room: 128B
Chair: Zhen Zhou, *Intel Corporation, Chandler, AZ, USA*
Co-Chair: Tao Wang, *Teradyne Inc, Thousand Oaks, CA, USA*

3:30pm **Truncated Gaussian Monte Carlo Circuit Simulation using an Extracted Resistor Model with Randomized Power Loads** 183
Jeffrey L. Cutcher
Ford Motor Company, USA

Abstract: EMC requirements span many different types of electronics, including those found in automobiles. These requirements cover areas such as radiated emissions, immunity and susceptibility to external emissions, and voltage fluctuations. DC battery voltage transients presented to the electronics, often lumped into EMC requirements in the Automotive Industry, could cause damage or an undesirable user experience. This paper covers the simulation and modeling steps utilized in estimating the input voltage margin to a battery voltage transient. The end goal is to have some level of confidence that the electronics under consideration can be adequately powered and functional during such a transient.

4:00pm **Far Power Referencing Impact on High-Speed Memory Interface** 184
Yanjie Zhu, Rishik Bazaz
Intel Corporation, USA

Abstract: To maintain the best signal performance, a solid ground plane on both referencing layers for high-speed memory interfaces is recommended in Printed Circuit Board (PCB) design. Some customers and cost reduction platform designs may choose a far plane power referencing strategy to limit board layer count and meet the PCB design budget. In this paper, using a customer board as an example, memory interface margin impact due to violation of referencing recommendations is analyzed and quantified. A new signal integrity analysis method with a power referencing effect is proposed and correlated with the test platform result. The paper also discusses the future platform power referencing risk projection and mitigation proposals.

4:30pm **AMI DLL Hook: A Novel IBIS-AMI Simulation Debugging Method for Model Users** 189
Chuanyu Li, Alaeddin A. Aydiner, Sleiman Bou-sleiman, Xinjun Zhang
Intel Corporation, USA

Abstract: With the growing complexity of Serializer / Deserializer (SerDes) Physical Layer (PHY) architecture, the I/O Buffer Information Specification (IBIS) Algorithmic Modeling Interface (AMI) standard has gained widespread acceptance among model developers. However, simulations using IBIS-AMI models can yield varying results across different electronic design automation (EDA) software. As the speed of SerDes continues to escalate, these differences become increasingly unacceptable. The reasons for these discrepancies are varied and challenging to identify, particularly for model users. This paper presents the "AMI DLL hook" method, a debugging tool for IBIS-AMI channel simulations that do not align across EDAs. In its application in a recent SerDes AMI model alternative EDA enabling project, five inappropriate user settings or unexpected EDA behaviors were identified within a single week. This method can reduce the time spent on each parameter or setting adjustment to mere minutes or seconds, as opposed to running a full-channel simulation for hours.

WEDNESDAY – AUGUST 7, 2024

WT13 EMC Testing Basics (Sponsored by TC-2)

Tutorial **8:30am - 12:00pm**
Room: 125AB
Chair: Jack McFadden, *ETS-Lindgren, Cedar Park, TX, USA*
Co-Chair: Bob Mitchell, *TUV Rheinland AG, Littleton, MA, USA*

Session Abstract: Due to the popularity of this tutorial when it was presented in the IEEE EMC+SIPI Symposia held virtually in 2020 and 2021 as well as in person in 2022 and 2023, we have brought it back with many of the original topics and speakers! This tutorial will cover basic topics in EMC testing – from bench top analysis to designing a new laboratory/test capability. Presentations will provide practical information and real-world knowledge that can be implemented immediately. While the topics may be basic to EMC testing, we will also discuss nuances that can challenge even the most experienced EMC test practitioner. Speakers include experts who are actively involved in designing, managing, or supporting EMC test facilities. Attendees will quickly learn the best practices in each topic area.

What are Emissions Tests Actually Measuring?
Todd Hubing
LearnEMC, USA

Abstract: This presentation reviews the physics of conducted and radiated emissions measurements. It discusses set-up parameters, as well as product design features, that have a significant impact on these measurements.

Understanding and using EMC Antennas
Alistair Duffy
De Montfort University, United Kingdom

Abstract: This talk discusses some key factors that are important in the selection and use of antennas for EMC measurements. It discusses some of the different antennas specified in EMC Standards and provides an overview some of their important characteristics in a non-mathematical way.

Calibration of EMC Test Equipment an Introduction to Calibration for EMC Testing

Ross Carlton
Gibbs and Cox Inc., USA

Abstract: An introduction to calibration for EMC testing.

EMC Basics – Test Plan

Jack McFadden
ETS-Lindgren, USA

Abstract: The tutorial will demonstrate how to manage test resources, improve test efficiencies and understand risk. There will be one test cases study: MIL-STD-461 testing. The Presentation will give insights areas to consider and consequences of test order. What is testing elements you need to create an effective test plan?

EMC Lab Design: An Overview of the Process, Possibilities, and Issues

Bob Mitchell
TUV Rheinland, USA

Abstract: This presentation covers some of the details to think about wile setting up a new lab or facility. There are many things that get overlooked while you are evaluating the project. No matter if you are considering a basic bench setup, building a small shield room or a large facility, there are many aspects of the layouts and designs that are often overlooked. Parts one and tow will cover the various aspects of some things to consider while you are trying to optimize your setup for your needs.

WT14 Streamlined Power Integrity Model (SPIM) Workshop (Sponsored by TC-10)

Workshop **8:30am - 12:00pm**
Room: 127A
Chair: Kinger Cai, *Intel Corporation, San Jose, CA, USA*
Expert: Chi-te Chen, *Intel Corporation, Folsom, CA, USA*
Co-Chair: Ji Zheng, *Aurora-system, San Jose, CA, USA*
Organizer: Baolong Li, *Cadence Design Systems Inc, San Jose, CA, USA*

Session Abstract: IBIS Open Forum has approved BIRD223.1: Add Support SPIM in IBIS for platform power delivery network design review/sign-off and optimization, which uses the same philosophy as that for the invention of original IBIS for platform SI analysis, through providing minimum IP sensitivity information from chip vendors while sufficient for platform designs.

This workshop starts with an introduction to SPIM background, architecture, Tree structure in .spim file, and its linkage with .ibs. It is followed by the SPIM creation cookbook, which includes major steps of (1) Pre-modeling setups; (2) AC S parameter model generation & correlation, (3) DC R-network model generation & Correlation; and (4) SPIM creation in BIRD223.1 syntax and validation in FastPI.

The workshop will have the demo of two SPIM model creations and applications in supporting platform PDN design review/sign-off and optimization, one for Package-less power rails in industry-standard LPDDR5X devices, and the other for chip (PKG) level power rails in a SOC design. The workshop will wrap up with SPIM in FastPI Roadmap.

Platform PI Design Status Quo

Kinger Cai[1], Chi-te Chen[1], Baolong Li[2], Ji Zheng[3]
[1]Intel Corporation, USA; [2]Cadence Design System Inc., USA; [3]Aurora-System, USA

Abstract: The SPIM workshop comprises four main segments: (1) Presenting the current status of Platform PI design; (2) Introducing the addition of SPIM support in IBIS with the approved BIRD 223.1; (3) Providing a SPIM creation cookbook; (4) Exploring how FastPI supports SPIM. The workshop aims to tackle Platform PI design challenges by introducing a new FastPI platform PI architecture that backs a streamlined PI model (SPIM) and a unified PI design target (UPIT). This approach enables effective and efficient review, approval, and optimization of board level PDN designs, even for electrical design engineers or board designers with limited power integrity expertise. Participants will receive detailed guidance on creating a SPIM for a chip and utilizing FastPI for reviewing, approving, and optimizing board level PDNs. Key takeaways from the SPIM workshop include a solid foundation in SPIM principles, understanding SPIM creation, validation, and its application in optimizing platform PDN designs for review and approval.

IBIS-Approved BIRD223.1: Add Support for SPIM in IBIS

Kinger Cai[1], Chi-te Chen[1], Baolong Li[2], Ji Zheng[3]
[1]Intel Corporation, USA; [2]Cadence Design System Inc., USA; [3]Aurora-System, USA

Abstract: The SPIM workshop comprises four main segments: (1) Presenting the current status of Platform PI design; (2) Introducing the addition of SPIM support in IBIS with the approved BIRD 223.1; (3) Providing a SPIM creation cookbook; (4) Exploring how FastPI supports SPIM. The workshop aims to tackle Platform PI design challenges by introducing a new FastPI platform PI architecture that backs a streamlined PI model (SPIM) and a unified PI design target (UPIT). This approach enables effective and efficient review, approval, and optimization of board level PDN designs, even for electrical design engineers or board designers with limited power integrity expertise. Participants will receive detailed guidance on creating a SPIM for a chip and utilizing FastPI for reviewing, approving, and optimizing board level PDNs. Key takeaways from the SPIM workshop include a solid foundation in SPIM principles, understanding SPIM creation, validation, and its application in optimizing platform PDN designs for review and approval.

SPIM Cookbook

Kinger Cai[1], Chi-te Chen[1], Baolong Li[2], Ji Zheng[3]
[1]Intel Corporation, USA; [2]Cadence Design System Inc., USA; [3]Aurora-System, USA

Abstract: The SPIM workshop comprises four main segments: (1) Presenting the current status of Platform PI design; (2) Introducing the addition of SPIM support in IBIS with the approved BIRD 223.1; (3) Providing a SPIM creation cookbook; (4) Exploring how FastPI supports SPIM. The workshop aims to tackle Platform PI design challenges by introducing a new FastPI platform PI architecture that backs a streamlined PI model (SPIM) and a unified PI design target (UPIT). This approach enables effective and efficient review, approval, and optimization of board level PDN designs, even for electrical design engineers or board designers with limited power integrity expertise. Participants will receive detailed guidance on creating a SPIM for a chip and utilizing FastPI for reviewing, approving, and optimizing board level PDNs. Key takeaways from the SPIM workshop include a solid foundation in SPIM principles, understanding SPIM creation, validation, and its application in optimizing platform PDN designs for review and approval.

FastPI Supports SPIM

Kinger Cai[1], Chi-te Chen[1], Baolong Li[2], Ji Zheng[3]
[1]Intel Corporation, USA; [2]Cadence Design System Inc., USA; [3]Aurora-System, USA

Abstract: The SPIM workshop comprises four main segments: (1) Presenting the current status of Platform PI design; (2) Introducing the addition of SPIM support in IBIS with the approved BIRD 223.1; (3) Providing a SPIM creation cookbook; (4) Exploring how FastPI supports SPIM. The workshop aims to tackle Platform PI design challenges by introducing a new FastPI platform PI architecture that backs a streamlined PI model (SPIM) and a unified PI design target (UPIT). This approach enables effective and efficient review, approval, and optimization of board level PDN designs, even for electrical design engineers or board designers with limited power integrity expertise. Participants will receive detailed guidance on creating a SPIM for a chip and utilizing FastPI for reviewing, approving, and optimizing board level PDNs. Key takeaways from the SPIM workshop include a solid foundation in SPIM principles, understanding SPIM creation, validation, and its application in optimizing platform PDN designs for review and approval.

WT15 ESD/EMC Needs in Automotive High-Speed Links (including Ethernet): Optimizing Semiconductor Robustness

Tutorial **8:30am - 12:00pm**

Room: 127B

Co-Chair: Sudhama Shastri, *Nexperia, Phoenix, AZ, USA*

Co-Chair: Patrick DeRoy, *Analog Devices Inc, Norwood, MA, USA*

Session Abstract: High-speed data-links (10 to 1000Mbps & into the10Gbps range) are popular in automotive applications. Ethernet (single pair) is preferred due to bi-directional communication, prevention of vendor lock-in, etc. Traditional CAN networks may be supplanted by 10-50Mbps protocols such as 10BaseT1S Ethernet, and the 100Mbps A2B 2.0 network. Automotive Ethernet enables zonal architecture with high-performance compute, on-board telematics, and sensor networks (LiDAR and RADAR). A2B is a bi-directional digital audio bus for next-gen, low-latency audio/infotainment. ESD requirements are in the range of +/-15kV contact discharge under certain OEM specifications, which reference ISO 10605 as well as IEC 61000-4-2. Another requirement is to maintain communication and signal integrity in the noisy vehicle environment. The OPEN Alliance standardization effort has recommendations for high-speed IVNs, while Tier1s and OEMs have the freedom to deviate. We will present challenges of maintaining data/signal integrity and the concept of external ESD protection as an elegant solution to signal-integrity + ESD needs for UTP cables. SEED models can be used to accurately simulate the ESD strike in a very non-linear system. Optimal placement of protection devices is explored.

Automotive E/E Architecture and Signal Integrity of In-Vehicle Networks – Part 1

Ajeya Gupta

Ford Motor Corporation, USA

Abstract: This presentation aims to introduce the participants to the progression of Electrical/Electronic Architecture over the years, and the corresponding sophistication within in-vehicle networks. Network Communications play an integral part in the vehicle's architecture, enhancing and advancing the vehicle's electronic operation. Traditional vehicle architectures mainly consisted of Controller Area Network (CAN) and Local Interconnect Network (LIN) buses, both of which run at relatively slow bit rates and low bandwidth. With the advancement of next-generation architectures (e.g., connectivity, high-resolution surround view cameras, high-resolution displays, etc.), today's vehicles require higher bandwidth networking solutions. The data rate required to support these features can range from 100 Mbps (e.g. Automotive Ethernet) to multiple gigabits (e.g. MultiGig Automotive Ethernet, Automotive SerDes Alliance-ASA, LVDS, etc.). and is accompanied by increased challenges including vehicle integration since vehicles have more challenging EMC, Electrical, and Environmental requirements than consumer electronics. Participants attending this session will be able to take away the differences within architecture types, and the evolving industry trends influencing the direction. In addition, we will also cover the networking that is required to achieve the latest architectural requirements. This presentation will also incorporate the signal integrity characteristics, and cable-connector assembly evaluation, to meet automotive's stringent EMC/EMI requirements.

Taming the 3-Headed Dragon: Unpowered ESD Survivability, Powered ESD Resilience and RF/Transient Immunity Robustness

Patrick DeRoy

Analog Devices Inc., USA

Off-Chip (Standalone) ESD Protection Solutions for Maintaining Robustness and Signal-Integrity

Sudhama Shastri[1], Andreas Hardock[2], Sergej Bub[2], Taimoor Ahmed[3]

[1]Nexperia, USA; [2]Nexperia, Germany; [3]Nexperia BV, Netherlands

Abstract: The OPEN Alliance standardization effort has recommendations for high-speed IVNs, while Tier1s and OEMs have the freedom to deviate. We present challenges of maintaining data/signal integrity and the concept of external ESD protection as an elegant solution to signal-integrity + ESD needs for UTP cables. SEED models can be used to accurately simulate the ESD strike in a very non-linear system. Optimal placement of protection devices is explored.

Panel Discussion with All Speakers

Sudhama Shastri[1], Patrick DeRoy[2]
[1]*Nexperia, USA;* [2]*Analog Devices Inc., USA*

Abstract: Panel discussion between all authors who are present.

WT16 Introduction to Machine Learning for Electromagnetic Compatibility and Signal Integrity (Sponsored by SC-3)

Workshop **8:30am - 12:00pm**
Room: 127C
Co-Chair: Zhong Chen, *ETS-Lindgren, Cedar Park, TX, USA*
Co-Chair: Janet O'Neil, *ETS-Lindgren, Cedar Park, TX, USA*

Session Abstract: This workshop offers an accessible introduction to machine learning (ML) in the context of Electromagnetic Compatibility (EMC) and Signal Integrity (SI), with a special focus on various ML techniques, including compressed sensing. Tailored for newcomers, the workshop aims to provide an entry point for understanding how ML applies to EMC and SI.

Speakers will present basic concepts such as learning sparse representations and the principles of compressive sensing, as well as reinforcement learning and other ML techniques. Additionally, interactive and graph-based ML approaches will be introduced to demonstrate how they can address challenges in EMC and SI. While real-world examples will be used to illustrate concepts, the main goal is to foster a solid understanding of ML principles.

By the end of the workshop, participants will have been introduced to ML concepts relevant to EMC and SI, including techniques such as compressed sensing and reinforcement learning, and their potential applications. Further exploration may be needed, but attendees will have gained valuable insights to start exploring the application of ML in EMC and SI contexts.

Compressed Sensing Applications in EMC Chamber Evaluations

Zhong Chen
ETS-Lindgren, USA

Learning Sparse Representations

Doug Cochran
Arizona State University, USA

Abstract: Key elements of compressive sensing are summarized with emphasis on the essential role that sparsity plays in enabling this efficient measurement methodology. Examples of effective application of compressive sensing in EMC/SIPI applications are noted. Sparse Dictionary Learning, a type of machine learning, is introduced as a mechanism for obtaining a dictionary to enable sparse representation from a large corpus of training data.

Reinforcement Learning for PDN Optimization

Chulsoon Hwang
Missouri University of Science and Technology, USA

Advancements in Artificial Intelligence for Antenna based EMC Measurement Optimization

Dennis Lewis
The Boeing Company, USA

Abstract: Traditional antenna test facilities are typically designed with a specific measurement application in mind, and as a result these facilities tend to be comprised of single fixed measurement geometry. However, modern antenna measurement ranges employing multi-axis robotic positioners provide a near limitless degree of re-configurability in terms of measurement types and scan geometries. This drives an ongoing need to evaluate each unique setup and application. This previously unimaginable flexibility offers new opportunities for the improvement of safety, measurement quality and reduction of measurement uncertainties. These new robotic systems are capable of acquiring large amounts of data allowing for the implementation of advanced post processing techniques. Model based Systems Engineering and development (MBSE/MBD) approaches can be employed to dramatically reduce the time, effort and cost associated with the test development and validation phases of a given program. MBSE tools can also be used to optimize test configurations to greatly reduce measurement uncertainties and simulate measurements. This presentation provides an overview of how these engineering techniques are being harnessed during the implementation of a new dual multi-axis robotic antenna test system and how they can enable utilization of AI/MI to improve measurement accuracy.

Harnessing Interactive and Graph-Based Machine Learning for EMC

Gautam Dasarathy
Arizona State University, USA

Abstract: As the complexity of interacting systems in electronic environments grows, addressing Electromagnetic Compatibility (EMC) and Electromagnetic Interference (EMI) challenges has become increasingly critical. This talk explores leveraging graph-based machine learning strategies to tackle these tasks. In the first part of the talk, we consider the general problem of using graph-based models for signal localization which is relevant to a range of applications including EMI source localization. We will formalize this problem and propose novel interactive machine learning techniques for efficiently and quickly localizing the signal of interest. In the second part of the talk, we consider the problem of learning network topologies from node measurements. This general problem is increasingly applicable in management, communication, and anomaly detections tasks in complex wireless sensor networks.

WT17 Introduction to Modeling Techniques for EMC+SIPI Problems (Sponsored by TC-9)

Tutorial **8:30am - 12:00pm**

Room: 128A

Chair: Giulio Antonini, *Universita degli Studi dell'Aquila, L'Aquila, Italy*
Expert: Chuck Bunting, *Oklahoma State University, Stillwater, OK, USA*
Expert: Lijun Jiang, *Missouri University of Science and Technology, Rolla, MO, USA*
Expert: Bruce Archambeault, *Missouri University of Science and Technology, Rolla, MO, USA*
Expert: Jonas Ekman, *Luleå University of Technology, Sweden*

Session Abstract: This tutorial will provide an introduction to commonly used numerical modeling techniques for EMC+SIPI problems without the need for detailed math. Practicing modelers will also benefit from learning the fundamentals of modeling techniques they are currently not using. Each technique will be presented along with its strengths and weaknesses, so engineers can decide which techniques are appropriate for their types of problems.

Introduction to the Finite Element Method

Chuck Bunting
Oklahoma State University, USA

Abstract: An introduction to the finite element method. Applications in quasi-statics and reverberation chambers.

Modeling with the Method of Moments

Lijun Jiang, James Drewniak, Daryl Beetner
Missouri University of Science and Technology, USA

Abstract: The Method of Moments is one of the fundamental numerical methods for electromagnetic analysis and parasitic extraction in signal intensity, power integrity and EMC engineering practices. This talk intends to present basics of method of moments, issues with using it, and example applications of applying MOM to solve practical problems. The takeaway for attendees is to understand the most effective and reliable way to use MOM based methods and tools.

Introduction to FDTD

Bruce Archambeault[1,2]
[1]Missouri University of Science and Technology, USA; [2]IBM Corp., USA

Abstract: FDTD is straight forward and easy to use.

Introduction to the Partial Element Equivalent Circuit (PEEC) Approach Applied to EMC+SI/PI Problems

Giulio Antonini[1], Daniele Romano[1], Jonas Ekman[2], Albert E. Ruehli[3]
[1]University of L'Aquila; [2]Luleå University of Technology, Sweden;
[3]Missouri University of Science and Technology, USA

Abstract: An introduction to the Partial Element Equivalent Circuit (PEEC) method is given. The PEEC method is well suited to be adopted to analyze mixed electromagnetic and circuit problems which arises in the EMC, SI and PI areas. Building PEEC model requires computing partial element, including partial inductances, coefficients of potential, describing the magnetic and electric couplings, which account for power dissipation in conductive materials. One of the main advantage of the PEEC method is that it relies in the easy incorporation of linear and non-linear lumped elements.

Efficient and High-Fidelity Full Wave Methods for Large Platform EMC Analysis

A. Mori[1], M. Bercigli[1], M. Bandinelli[1], D. Romano[2], G. Antonini[2]
[1]IDS, Italy; [2]University of L'Aquila, Italy

Abstract: The presentation aims to illustrate the use of the surface formulation of the PEEC method to address EMC problems arising aboard of aircraft made in composite materials due either to the imperfect current return networks and direct lightning.

WT18 SIPI Challenges and Innovations in High-Speed System and Device Interconnects (Sponsored by TC-10)

Tutorial **8:30am - 12:00pm**

Room: 128B

Chair: Thanh Tran, *Rice University, Houston, TX, USA*

Session Abstract: Today's fastest serial digital interconnects of systems or devices run at data rates in multi-gigahertz range, and these fast switching signals can generate considerable noise and radiation which degrade and limit system performance. Maintaining good signal integrity of these signals is very challenging as interconnecting traces on a printed circuit board (PCB) or interconnecting cables in AI/cloud computing servers become very lossy which causes major issues related digital timing margin, clock recovery, inter-symbol interference, and electromagnetic radiation, etc. This tutorial session consists of presentations from experts in different industries to discuss challenges and innovations in signal and power integrity to advance next generation compute such as AI servers, aerospace and defense electronics. The main topics covered in this tutorial session are: 1. Challenges in high-speed system and device interconnects 2. Innovations in high-speed SERDES enabling data higher than 112Gbps

Enabling High-Speed Interconnects for Future High Performance Computer Applications

Walker Turner

Nvidia Corporation, USA

Abstract: The ever-increasing demand for high performance computers (HPC) for applications using artificial intelligence has led to HPC performance doubling every 2.5 years. One of the key enablers to this growth is the high-speed wireline links that interconnect these board- and rack-scale systems, which must provide increased bandwidth every generation while consuming a fraction of total system power. A holistic approach to link design needs to be embraced through co-optimization of the high-speed circuitry and signaling channels to simplify the signal paths and meet future bandwidth and energy targets. This includes improvements in channel signal integrity to alleviate circuit-design challenges, the use of single-ended signaling techniques to minimize per-pin symbol rates, and delay-matched clock forwarding architectures to reduce link power while improving robustness to power-supply induced jitter.

Methodology for Designing Accurate High-Speed Interconnects of ASICs/FPGAs on a Printed Circuit Board

Wendel Williamson, Thanh T. Tran

Raytheon Technologies, USA

Abstract: Designing embedded system with high-speed, low skew interconnects is very challenging as there is not one development tool that enables analyzing complex transmission line effects while measuring accurate skew resolution in the range of 1 picosecond. In this tutorial shown in the simplified architecture below, we demonstrate a new methodology that uses one tool to accurately extract printed circuit board parasitics and generate s-parameter models and another tool to perform high precision skew simulations, including signal integrity and crosstalk.

PCB Compensation Techniques for Wideband Analog Filter Designs

Thanh Tran

Rice University, USA

Abstract: Designing wideband analog filters to reconstruct analog waveforms or to filter frequency noise has increasingly become more challenging as the filter bandwidth gets higher and higher. The good news is there are many RF filter synthesizer tools on the market to use today, but these tools do not have ways for engineers to compensate for PCB effects. In this talk, we will demonstrate the following. Synthesizing a high order filter design Simulating the filter with and without PCB layout Tuning the circuit to compensate for frequency shifting due to layout effects

EMI Noise Mitigation in High-Frequency GaN-Based Converters

Qiang Li
Virginia Polytechnic Institute and State University, USA

Abstract: The majority of power electronic equipment, with few exceptions, has traditionally been designed and constructed using discrete active and passive components. The power electronics industry has reached a level of maturity where enhancing one performance attribute often comes at the expense of others. Moreover, manufacturing practices have remained labor-intensive and largely unchanged for decades. The emergence of the new generation of wide-band-gap power semiconductor devices, such as SiC and GaN, presents a significant reduction in both conduction and switching losses when compared with their silicon counterparts. Current design practices involving these Wide Band Gap (WBG) devices often adhere to a 'plug-and-play' concept, resulting in incremental improvements in efficiency and power density. However, this approach fails to fully unlock the potential for a transformative paradigm shift in the design and manufacturing process. Recent demonstrations have highlighted the potential of combining PCB-based magnetics with Wide Band Gap (WBG) power devices to bring about a fundamental shift in design and manufacturing practices. This holistic approach has the capability to simultaneously enhance all performance attributes, encompassing efficiency, power density, cost, and electromagnetic compatibility (EMC) This presentation will begin by discussing how to use PCB-based inductors to implement balancing techniques for reducing CM EMI noise in AC/DC converters. It will then introduce a unique shield design in a PCB winding transformer to help minimize CM noise as well as reduce winding loss in DC/DC converters. Finally, it will address the near-field coupling problem between power stage and EMI filter and present an effective solution using shield design in PCB-winding inductors.

ED09 Automated SI Verification Methods for Optimal Design of DDR Systems

Experiment/Demonstration **10:00am - 12:00pm**
Room: E&D Booth 1

Session Abstract: This software demo presents the automatic SI verification method for DDR systems and provides background knowledge on the proposed approach. In this demo, the verification method consists of two parts. The first utilizes numerical analysis-related solvers for simulations, including transmission line analysis, characteristic impedance analysis, and crosstalk analysis. It particularly explains how automatic DDR compliance simulation for high-speed DDR systems is structured. The second part is an SI design rule checker based on geometric algorithms. These rules are developed through iterative simulation results and expert knowledge, representing a type of site-dependent Intellectual Property (IP). This enables SI engineers to detect design faults/defects that may violate electrical issues at the early design stage.

While conventional DDR system SI verification methods heavily rely on CAE engineering teams, the proposed approach allows circuit designers to directly detect electrical problems in high-speed DDR designs without the need for prior simulation setup or specialized knowledge of its standard. This helps reduce design iterations caused by SI problems during the development period.

For this demo, Altair PollEx simulation tools are used to analyze high-speed signal waveform data of LPDDR buses and present a methodology to find the optimal net topology. The results showed that compliant waveforms satisfying the signal integrity criteria were found within the simulation run time reduced by up to 60%, demonstrating that the proposed method was valid for automated SI verification. A live demo of the software will be shown during the presentation..

Automated SI Verification Methods for Optimal Design of DDR Systems

Junesang Lee
Altair, USA

ED10 Transmission Lines

Experiment/Demonstration **10:00am - 12:00pm**
Room: E&D Booth 2

Session Abstract: The proper functioning of any electronic system is ultimately determined by the quality of its interconnections between its circuits. Any interconnections whose length is a significant fraction of a wavelength must be treated as a transmission line. This demonstration shows 1) the importance of proper terminations of transmission lines in their characteristic impedance, and 2) impacts of improper terminations.

Transmission Lines
John C. McCloskey
NASA Johnson Space Center, USA

Transmission Lines
Jen Dimov
NASA Johnson Space Center, USA

ED11 Common-Impedance Coupling

Experiment/Demonstration **10:00am - 12:00pm**
Room: E&D Booth 3

Session Abstract: This hardware experiment demonstrates the impact of the return path impedance and the return current level on common-impedance coupling between circuits. The measurements are performed on a custom PCB, containing audio, video, and high current circuitry where the return paths for each circuit can be selectively shared with other circuits.

Common-Impedance Coupling
Nicklas Koeller
E3 Compliance, USA

Common-Impedance Coupling
Bogdan Adamczyk
Grand Valley State University, USA

ED12 EMC Pre-Compliance Test – Do I Need It?

Experiment/Demonstration **10:00am - 12:00pm**
Room: E&D Booth 4

Session Abstract: Slide Presentation containing video of experimental results

To ensure safe operation, and to guarantee quality and accuracy, compliance testing is necessary to sell your device. A compliance test failure can delay produce introduction and add unplanned development expense. Pre-compliance testing allows you to cost-effectively reduce your time to market by maximizing the success your product passing final compliance testing

EMC Pre-Compliance Test – Do I Need It?
Steve Narciso
Keysight Technologies Loveland, USA

ED13 IEC 61000-6-3 Spectral Density – IVL Method

Experiment/Demonstration **12:00pm - 2:00pm**
Room: E&D Booth 2

Session Abstract: IEC 61000-6-3 Spectral Density - IVL method

IEC 61000-6-3 Spectral Density – IVL Method

Jacob Dixon
International Business Machines Corp, USA

Abstract: IEC JWG6 has developed a generic standard of emissions limits in the 9-150 kHz frequency range (IEC 61000-6-3/A1/F2/Ed3). The need for these additional conducted emissions limits are based on observed sensitivity of equipment such as powerline communication devices, smart meters, and clocks being disrupted by emitting devices such as switching mode power supplies and PV inverters.

This technical demonstration will include an overview of measurements to implement Integral Voltage Level (IVL) following informative annex guidance, as well as live demonstrations of emissions from various suspected emissions sources (both 6-3 residential and 6-8 commercial/industrial equipment) and how their results compare to the proposed limits.

WT19 Future EMC/EMI/SI/PI Technologies with Machine Learning and Artificial Intelligence (Sponsored by SC-3)

Workshop **1:30pm - 5:00pm**
Room: 127C
Chair: Lijun Jiang, *Missouri University of Science and Technology, Rolla, MO, USA*
Co-Chair: Alistair Duffy, *De Montfort University, Loughborough, United Kingdom*

Session Abstract: Machine learning (ML) and artificial intelligence (AI) are heavily investigated with the good will to advance technologies into a new age. No matter if we like it or doubt it, ML and AI will be part of the future and EMC Society has to consider how to work with ML and AI technologies.

This workshop intends to picture the potential future that we could vision or would like to have for EMC/EMI/SI/PI technologies with the augmentation of ML and AI. Experts from industries and academia are invited to present their ideas and exchange opinions. Instead of focusing on technical details, this workshop focuses on visions. It does not applaud or criticize ML and AI. It presents possible merits and potential concerns to the EMC society.

This workshop is part of EMC SC3 “ML and AI in EMC and SIPI” initiatives. After all presentations, a discussion forum will be open to all audiences for opinion exchanges.

EMC SC3 ML and AI in EMC and SIPI

Alistair Duffy
De Montfort University, United Kingdom

Abstract: In introducing the Special Committee (SC3) on AI and Machine Learning in EMC + SIPI, this talk will start with the author's view of five key trends in AI that could have notable impact on the EMC and SIPI community over next few years. After a summary of the current research fronts within our community, the activities of SC3 will be introduced.

Large Language (LLM) and Machine Learning based Design for Signal Integrity and Power Integrity

Joungho Kim, Keunwoo Kim
Korea Advanced Institute of Science and Technology (KAIST), Korea

Creating an SI/PI Database for ML Applications!?

Christian Schuster, Morten Schierholz, Til Hillebrecht
Hamburg University of Technology, Germany

Abstract: In this workshop contribution we address "the missing link" in the machine learning (ML) ecosystem for SI/PI applications: large-scale, meaningful, and easily accessible data. We present our solution to this issue by giving an overview of our "SI/PI Database" that was published 2021 in IEEE Access (DOI: 10.1109/ACCESS.2021.3061788). We discuss the physics-based modeling tool for printed circuit boards that we used to create the data, give an overview of currently available data, explain how to access/use the data and present open tasks and challenges.

AI for Integrated Chiplets Electromagnetic Integrity Design and Simulation

ErPing Li
Zhejiang University, China

Abstract: The this presentation entitled as AI for Integrated Chiplets Electromagnetic Integrity Design and Simulation, is given at the workshop of Future EMC/EMI/SI/PI Technologies with Machine Learning and Artificial Intelligence held on August 7, 2024 organised by Lijun Jiang.

Outlook of AI and ML Assisted Signal Integrity and Power Integrity Engineering

Matteo Cocchini
IBM Corp., USA

Abstract: AI, and Machine Learning in particular, applied to signal and power integrity already has a large literature within IEEE. In these slides, some real ML for SI applications will be discussed, as well as what other people in the SI-PI community are focusing on.

Perspective and Challenges in the Integration and Co-Design of Brain-Inspired Systems for Artificial General Intelligence

Jose Schutt-Aine
University of Illinois at Urbana-Champaign, USA

AI/ML Augmentation of Hardware Compliance Processes

Samuel Connor
IBM Corp., USA

Abstract: Hardware compliance engineers perform a number of tasks that can be streamlined by using artificial intelligence and machine learning techniques. From reviewing new country regulations to determine scope and applicability, to classifying vendor documents and extracting key data elements for paper qualifications, AI/ML can eliminate some of the tedious, manual effort and enable engineers to focus on their value-add reviews and decision-making.

Neural Network for the Prediction of Electric Field Intensity Applied to a Simple Scenario

Sebastian Salas Laurens, Anne Roc'h
Eindhoven University of Technology, Netherlands

Abstract: In this workshop, we will delve into the development and evaluation of a Neural Network (NN) tailored for such predictions. We begin with the creation of a dataset through simulations, while addressing the scarcity of ready-made datasets for this task. Our dataset encompasses the EM fields of simple scenarios with light changes. Through the training of the model, we explore different configurations of NN architectures, focusing on fully connected layers. We evaluate these architectures based on their performance in training and generalization, identifying an optimal architecture for further testing. Subsequently, we deploy the trained NN on new data to assess its predictive capabilities, highlighting its proficiency in approximating electric field behaviors while acknowledging challenges in capturing complex patterns. The findings underscore the importance of refining sampling methodologies and exploring alternative architectures to enhance model robustness and predictive accuracy. This workshop offers insights into the application of NNs for predicting electromagnetic field behaviors, paving the way for advancements in this vital area of research.

LLM, ChatGPT, and GPT as the SI and PI Assistant

Lijun Jiang
Missouri University of Science and Technology, USA

Abstract: This talk intends to demonstrate the latest investigation of the power of LLM based AI tool for electromagnetics analysis, transmission line designs, and electronic engineering practice. It provides a systematic evaluation of the application potential of chatGPT and possible application scenarios based on what we can find today.

Using AI/ML for Lightning Direct Effects

Philipp Boettcher, Jason S. Damazo, Benjamin A. Westin, Brian A. Carpenter, Louisa Michael, Sofia Gaham, Stefani Mokalled, Derek R. Tuck, Brain P. Justusson, Hunter B. Johnston
The Boeing Company, USA

Poster Poster Sessions

Poster Session **1:30pm - 3:30pm**
Room: Exhibit Floor

Bongjoon Lee, Michael Trebisovski, John Timmerman
Henkel Corporation, USA

Abstract: Due to miniaturization, modern electronics are prone to electromagnetic interference by cavity resonance and crosstalk. Also, as more computation power is needed to improve performance, more heat is generated, requiring enhanced heat dissipation. In this paper, we report the first silicone-free thermally conductive and EM absorbing gap filler for high frequency (77GHz) ADAS application. Multi-functional fillers enable high dispensability and processability despite the moderate thermal conductivity (4.0W/mK) and EM attenuation (90dB/cm) at 77GHz. The silicone-free matrix provides advantages for sensitive applications including camera and ADAS modules. This study shows, through simulation and direct material testing, that a multi-functional EM absorbing thermal gap filler dramatically reduces the power coupling between an antenna and an IC chip in a model ADAS application.

Tong Liang[1], Weijia Wu[1], Yu Liu[2], Xu Wang[2], Zhiyong Liu[1]
[1]China Mobile Group Design Institute Co., Ltd, China; [2]China Mobile Communications Group Co., Ltd, China

Abstract: With the progressing and developing of 5G voice services, to provide users with better voice calling services in complex electromagnetic environments, an effective method to evaluate the Voice over New Radio (VoNR) service quality is necessary. In this paper, a method to evaluate the voice service quality based on an AI algorithm is proposed, in which the mean opinion score (MOS) of VONR calls can be calculated with the network-side indicators as input based on a model trained with the drive test score, which is verified in the session-level voice quality scoring and can be used in cell-level voice quality scoring. This method is helpful to discover cells with poor voice service quality and verify the network optimization effects so as to increase the network quality.

Jong Hwa Kwon[1], Hyun Ho Park[2]
[1]Electronics and Telecommunications Research Institute, Korea; [2]The University of Suwon, Korea

Abstract: This paper analyzes the electromagnetic shielding property of a bent slot filled with absorbing materials by an analytic modal solution for transverse magnetic (TM) wave incidence. The penetrated fields are calculated in terms of the size of bent slot and the types of absorbing materials.

TC5-1 Electrostatic Discharge (Sponsored by TC-5)

Technical Papers **1:30pm - 3:00pm**

Room: 125AB

Chair: Michael McInerney, *Consultant, Champaign, IL, USA*

Co-Chair: William Radasky, *Metatech Corporation, Goleta, CA, USA*

1:30pm **A Model for Corona Streamer Propagation on Glass during an Air Discharge** 284

Zhekun Peng[1], Jianchi Zhou[2], Darryl Kostka[2], David Pommerenke[3], Daryl Beetner[1]

[1]Missouri University of Science and Technology, USA; [2]Apple Inc., USA; [3]Technische Universitat Graz, Austria

EMC BEST PAPER FINALIST AND BEST STUDENT PAPER SEMI-FINALIST

Abstract: Corona discharge to a glass surface is challenging to model due to a poorly understood air and surface ionization process. A modeling methodology based on the transmission line modeling (TLM) approach is proposed to simulate the streamer propagation process. The time-changing corona streamer resistance is estimated using the Rompe and Weizel spark model. The streamer is represented using small segments consisting of the arc resistance, per unit length (PUL) capacitance of the streamer, PUL inductance, a switch representing streamer formation, and a surface discharge gap voltage representing the voltage drop caused by ions within the streamer length. The propagation of the corona streamer depends on the tangential electric field strength at the streamer tip being higher or lower than the breakdown threshold for streamer formation. This preliminary 1D model shows plausible results for the current waveform shape, Lichtenburg dust figure diameter and streamer propagation velocity for a positive surface discharge to the glass. Although the model requires further improvement to predict propagation of multiple corona streamers, it provides a basis for simulation of a corona discharge on a glass surface which is related to the behavior of the underlying physics.

2:00pm **Metamaterial-Enabled Localization of Electrostatic Discharges using Time Reversal** 290

Elias Le Boudec[1], David Martinez[2], Nicolas Mora[3], Marcos Rubinstein[4], Felix Vega[2], Islem Yahi[2]

[1]Ecole Polytechnique Federale de Lausanne, Switzerland; [2]Technology Innovation Institute, United Arab Emirates; [3]Universidad Nacional de Colombia, Colombia; [4]University of Applied Sciences and Arts Western Switzerland, Switzerland

Abstract: Protection against electrostatic discharges requires knowledge of the discharge-current path. Thanks to the time-reversal technique combined with a GHz-range resonant metalens, we present an experimental gateway to imaging subwavelength interference sources.

2:30pm **Time-Dependent Resistance-Based Dynamic Behavior Model of Spark Gap Device under ESD Pulse** 291

Mingming Yang, Guangxiao Luo, Jianfang Dang, Zhaolong Xue, Weidong Zhang

North China Electric Power University, China

EMC BEST STUDENT PAPER SEMI-FINALIST

Abstract: This paper investigates the dynamic response characteristics of spark gap structures on printed circuit boards (PCB) under electrostatic discharge (ESD). A gas discharge tube (GDT) is selected as the research subject. Initially, voltage and current signals at the device ports are measured under transmission line pulse (TLP) excitation, and the variation in the time lag of the spark gap structures with different voltage levels is analyzed. Subsequently, a dynamic behavior model, based on a time-dependent typical arc resistance model, is developed to predict the response of the GDT to TLP pulses. This system-level model is further validated through experiments using an electrostatic generator excitation.

TC4-1 Control of Electromagnetic Interference: Shielding, Filtering, Modeling and Prediction #1 (Sponsored by TC-4)

Technical Papers **1:30pm - 3:00pm**

Room: 127A

Chair: Daryl Beetner, *Missouri University of Science and Technology, Rolla, MO, USA*

Co-Chair: Charles Jullien, *Safran Electrical and Power, Blagnac, France*

Co-Chair: Victor Khilkevich, *Missouri University of Science and Technology, Rolla, MO, USA*

1:30pm **Operation of the Bifilar Common-Mode Voltage Suppressor** 296

James McLean

TDK Corp., USA

EMC BEST PAPER FINALIST

Abstract: The common-mode (CM) voltage suppressor (CMVS) is essentially a tightly-coupled, center-grounded inductor. While the CM choke ideally presents an open circuit impedance to CM current, the CM voltage suppressor presents a short circuit to CM voltage. The efficacy of the CM voltage suppression depends on the magnetic coupling coefficient between the two symmetrical halves of the inductor. Bifilar winding is typically necessary in order to effect sufficiently tight magnetic coupling. However, bifilar winding causes the device to behave in a distributed sense. This, in turn, hard limits the bandwidth of the device–when the winding is one-half of the odd-mode wavelength (in the bifilar transmission line) long, it acts as a CM open circuit and a differential mode (DM) short circuit. It is further shown that the effective upper operating frequency limit is about one octave below the half wavelength frequency. These assertions are supported by an analytical model, finite element numerical simulations, and experimental data. The author believes the model and the predictions of bandwidth limitations in the bifilar CM voltage suppressor have not previously been published.

2:00pm **Analysis of Common-Mode Filter Effect for Induced Voltage by Bulk Current Injection using Chain Parameter Matrix** 302

Nobuo Kuwabara, Tohlu Matsushima, Yuki Fukumoto

Kyushu Instiute of Technology, Japan

Abstract: Telecommunications equipment should be designed to maintain performance in electromagnetic environments. The common-mode filter (CMF) is one of the significant devices to improve immunity against electromagnetic disturbances. In this paper, the induced voltage by the bulk current injection was calculated using a chain parameter matrix, and we evaluated the CMF effect from the induced voltage. The equipment was replaced by a balun, and the matrix elements of the balun, the CMF, the injection probe, and an unshielded twisted pair cable were determined from the measurement. The relation between the source voltage of the injecting signal and the induced voltage was calculated using these matrixes in the frequency range from 1 MHz to 400 MHz, and they were compared to the measured value. The results showed that the calculated value agreed well with the measured value for the induced common-mode voltage, and the countermeasure effect of CMF could be analyzed using the proposed method. Results also showed that the induced differential-mode voltage was affected by the Scd21 of CMF.

2:30pm **Evaluating Electromagnetic Interference Effects on GNSS Receivers** 308

Giorgi Tsintsadze[1], Haran Manoharan[1], Arushi Sahai[1], Daryl Beetner[1], Brian Booth[2]

[1]Missouri University of Science and Technology, USA; [2]Deere and Company, USA

Abstract: Electromagnetic interference can be highly disruptive to global navigation satellite system (GNSS) receivers. Interference can be intentional, but can also occur from electronics modules placed within the same system, where these modules may create sufficient unintended radiated emissions to disrupt GNSS operation. In this paper, GNSS receiver performance is evaluated in the presence of multi-tone interference. An expression for the GNSS correlator output in the presence of continuous wave interference (CWI) is derived and is extended to predict the carrier to noise density ratio, C/N_0, of the receiver in the presence of multi-tone interference. C/N_0 is widely used for characterizing interference with GNSS receivers. Analytical estimates of C/N_0 are compared to results from measurements performed on a commercially available GNSS unit. The value of C/N_0 was predicted within a standard deviation of 0.97\ dB when the noise type and level was varied, demonstrating the accuracy of the derived equations. These equations will be used in the future to develop more intelligent guidelines for evaluating the impact of interference from electronic modules placed in the same system as a GNSS receiver.

TC9-4 Modeling Techniques for Radiated and Conducted Susceptibility (Sponsored by TC-9)

Technical Papers **1:30pm - 3:00pm**

Room: 127B

Chair: Ying Cao, *Apple Inc, Santa Clara, CA, USA*

1:30pm **Radiated Susceptibility Simulations from 40-100 GHz (A New Frontier)** 313

David Norte, Rachel Lumnitzer

BAE Systems, Inc., USA

Abstract: EMC standards, such as the RS103 standard, subject hardware to electric fields of varying strengths over the frequency range from 2 MHz and 40 GHz [1]. However, some programs have extended this frequency range up to 100 GHz, where many EMC test facilities don't have the equipment or the capital to complete this testing. In these cases, it is necessary to simulate the performance of the hardware in the presence of the RS103 environment through computational resources. This paper highlights the results of such an effort when two chassis are interconnected by a double shielded 1.0 m long cable. The inner shield contains a single 100 Ω differential circuit that is terminated at both ends with 100 Ω resistances, and where the common-mode and differential-mode currents are extracted from 40 GHz to 100 GHz. The impacts of the induced DM interference on a 5 Gbps digital interconnect are extracted with respect to the received differential eye patterns, as well as the associated degradations on the bit-error-rates (BERs).

2:00pm **RS103 Nonuniform Exposure of Shielded Cables** 319

David Norte, Rachel Lumnitzer

BAE Systems, Inc., USA

Abstract: The RS103 standard requires exposing electrical systems to E fields from 2 MHz to 40 GHz, where the system must perform as intended during this exposure. This paper addresses the induced currents on cable shields that are not uniformly exposed to the E fields due to the 3 dB beamwidths from practical antennas, as well as the location of the antenna along the shield. The impact of these currents on a received differential signal for a digital link at 1.6 Gbps is addressed.

2:30pm **The Impact of the CS115 Excitation on the Performance of Digital Interconnects – A Time and Frequency Domain Approach** 320

David Norte, Rachel Lumnitzer

BAE Systems, Inc., USA

Abstract: Conductive susceptibility requirements for many programs require that the hardware demonstrate full functionality in the presence of the expected conductive noise environment that is subjected to the hardware. The CS115 standard attempts to simulate such environments by subjecting cables to conductive interference signals. These signals simulate repetitive short duration impulse events that may arise in the case of switched inductive loads that are nearby the hardware. It is of interest to understand how this conductive interference signal manifests itself as common-mode and differential-mode currents and voltages that can degrade the performance of high-speed digital interconnects. This paper addresses the performance of a 5.0 Gbps differential digital interconnect in the presence of the CS115 standard and attempts to disclose how this interference degrades the received differential signal.

TC10-4 Simulation and Modeling Techniques #2
(Sponsored by TC-10)

Technical Papers **1:30pm - 3:00pm**

Room: 128A

Chair: Yuandong Guo, *Missouri University of Science and Technology, Foster City, CA, USA*

Co-Chair: Zhichao Zhang, *IEEE, Chandler, AZ, USA*

1:30pm **The Worst-Case Eye Prediction Algorithm for MIPI C-PHY Signaling on Mobile Artificial Intelligence (AI) Chips** 326

Yu-Ying Cheng[1], Suani-Kai Yang[2], Shih-Hsien Wu[2], Tzong-Lin Wu[3]

[1]National Taiwan University, Taiwan; [2]Industrial Technology Research Institute, Taiwan; [3]National Taiwan University, Taiwan

Abstract: This paper presents a novel method for efficiently estimating the worst-case eye diagram in MIPI C-PHY signaling. Conventional approaches for generating an eye diagram on this three-channel (four-conductor) transmission interface with particular three-phase encoding are time-intensive. To address this challenge, a novel greedy algorithm is proposed that predicts the worst-case eye based on the single state response (SSR). In addition, the combination of the C-PHY interface and the AI-chip provides a better high-resolution display. Therefore, the method is applied successfully to predict C-PHY signaling on AI chips, with the results aligning well with the transient eye.

2:00pm **Modelling Weave Effect in PCBs using 2D Cross-Sectional Analysis** 330

Victor Khilkevich[1], Scott Hinaga[2]

[1]Missouri University of Science and Technology, USA; [2]Cisco Systems, Inc., USA

Abstract: Printed circuit board dielectric substrates are composite materials produced by embedding fiber glass fabrics into epoxy resin. Because of this the medium in the PCB transmission lines is inhomogeneous which often leads to degradation of the signal integrity performance of the lines, particularly due to the differential skew. The detrimental effect of the fiber weave can be modeled relatively accurately using full-wave analysis, but at a high computational cost. Alternative modelling techniques are less demanding, but often lack accuracy. This article investigates a possibility of using the 2D cross-sectional analysis for the fiber weave effect modeling, which considerably decreases the computational cost of modeling while retaining the accuracy inherent to the field solvers.

2:30pm **A Sub-Channel based Chord™ Signaling Channel Analysis Method** 336

Sherman S. Chen[1], Nithin VM[1], Bob Xu[2], Francesco de Paulis[3]

[1]Kandou Bus, United Kingdom; [2]Analogix semiconductor Inc., USA; [3]University of L'Aquila, Italy

Abstract: A novel sub-channel-based frequency domain analysis method is proposed for analyzing the performance of the ChordTM signaling. The algorithm of converting a channel s-parameter into a ChordTM signaling sub-channel matrix is presented and validated. In the context of Ensemble Non-Return-to-Zero (ENRZ), which is the 4-wire member of ChordTM signaling, the sub-channel matrices based reflection/transmission/crosstalk parameters including the 1st/2nd/.../nth-order adjacent crosstalk, power-sum crosstalk (PSXT), and integrated crosstalk noise (ICN) are calculated and analyzed. The proposed method is then applied to three transmission line based ENRZ channels with similar return loss and insertion loss, but different crosstalk and uniformity levels. ENRZ channel simulations running at 64 Gbps are performed and the obtained eye diagrams well align with the predictions made using the recommended sub-channel based metrics, evidencing the effectiveness of the proposed method. The study also reveals that uniformity across the subchannels is crucial for the optimal performance of a ChordTM signaling system. To facilitate the assessment of the uniformity of sub-channel eye diagrams, three evenness metrics RHM, RWM, and REM are defined and can be applied for the performance evaluation of a ChordTM signaling system.

TC10-6 SI/PI/EMI Co-Design (Sponsored by TC-10)

Technical Papers **1:30pm - 3:00pm**

Room: 128B

Chair: Ling Zhang, *Zhejiang University, Hangzhou, China*

Co-Chair: Baolong Li, *Cadence Design Systems Inc, San Jose, CA, USA*

1:30pm **Reducing EMI in Wire-Bond BGA IC-Chips through Magnetic Dipole Moment Control** 342

Satoshi Tago, Keita Sasaki, Yasuhiro Ochiai

Sony Semiconductor Solutions Corporation, Japan

SIPI BEST PAPER FINALIST

Abstract: The proportion of IC-Chips in the components of electronic devices is increasing year by year. IC-Chips can be a noise source of Electro-Magnetic Interference (EMI), which should be minimized. IC-Chip suppliers require the development of low-cost and low-noise IC-Chips to enhance product value. This paper introduces a method for reducing EMI radiation (herein after referred to as EMI) from IC-Chips each packaged in a wire-bond Ball Grid Array (BGA). EMI was measured using near-field scanning and analyzed using magnetic dipole moments. Based on the results, current sources and current paths of the noise were predicted and validated through simulations. We prove that the magnetic dipole moments accurately represent EMI from the bonding wires (hereinafter referred to as wires) and balls in the IC-Chip package and propose a method for reducing EMI. The method greatly reduces EMI by mutually inverting vectors of EMI from wires and vectors of EMI from balls. This method is referred to as EMI cancellation in this paper. Finally, we demonstrate the effectiveness of the method through simulations and measurements, confirming that changing ball arrangements in existing IC-Chips reduces EMI by 4 dB. Moreover, the ball arrangement change is minimal, reducing EMI at very low cost is feasible.

2:00pm **Porous Absorber for Electromagnetic Radiation Suppression in Chip-Packages** 348

Chaolong Lin, Jiaqi Xing, Da Li, Ling Zhang, Hanzhi Ma, Er-Ping Li

Zhejiang University, China

SIPI BEST STUDENT PAPER SEMI-FINALIST

Abstract: In this paper, a low profile absorber for suppressing the electromagnetic radiation in the chip packages is proposed. The incorporation of porosity reduces the dielectric constant of the absorbing material which makes it easier to meet the impedance matching condition. Additionally, the porosity causes incident electromagnetic waves to undergo multiple reflections within the pores, effectively lengthening their propagation path within the absorber and enhancing the absorption capability. The simulated results in the chip-package model demonstrate an effective absorption of -14 dB within 20.3-29.8 GHz by adding the proposed absorber into the package. The detailed working mechanism of this structure is explained through the effective medium theory. Finally, the porous absorber is fabricated and experimental measured within a real chip-package inside a reverberation chamber, where the measured results bring out a -12 dB absorption effect covering 20-30 GHz.

2:30pm **DIE-PKG-PCB Co-Design Methodology for High-Speed Interfaces for Complex Automotive SoCs** 354

Rishi Bhooshan[1], Swapnil Tiwari[1], Sanamdeep Singh[1], Bihua He[2], Ajay Kumar Sharma[1], Sachin Kumar[1], Osvaldo Romero[3], Jesus Armando Sanchez Carranza[4]

[1]NXP Semiconductor, India; [2]NXP Semiconductors, China; [3]NXP Semiconductors, Germany; [4]NXP Semiconductors, Mexico

Abstract: With shrinking technology, increasing functionality and performance including high speed interfaces imposes major challenges for DIE, Package and PCB Co-design to meet overall system level electrical specifications (e.g. Power, Performance, Area, Timing, PISI, IR Drop, Thermal, EMI/EMC) and BOM Cost (e.g. DIE, PKG, PCB Cost). In this paper, we present DIE-PKG-PCB Co-Design Methodology for high speed interfaces to optimize DIE, PKG and PCB overall to meet system level electrical specifications as well as to optimize the overall system cost for complex Automotive SoCs.

ED14 EMC Society EMC PCB Experiments Kit

Experiment/Demonstration **2:00pm - 4:00pm**
Room: E&D Booth 1

Session Abstract: The EMC Society has created a set of nine PCBs that are each constructed to illustrate a particular principle of EMC engineering. At this demonstration we will put them through their paces, demonstrating the boards (and the Nano VNA that comes with them). In addition we will be showing how simulations of each board can help with demonstrations and education.

Hardware Demonstration

Karen Burnham
Electro Magnetic Applications, Inc., USA

Simulation Demonstration

Jason Bommer
Ansys, USA

ED15 EMC Workshop for Power Supply Designers

Experiment/Demonstration **2:00pm - 4:00pm**
Room: E&D Booth 2

Session Abstract: I plan to show a portable conducted emissions test setup that utilizes low voltage (<60VDC) to demonstrate fundamental EMC troubleshooting in a practical way by using a lecture style that includes first the explanation of theory, then the simulation, then a live test to prove empirically how the theory holds true on a real design. Our test board separates out common mode and differential mode noise so that the exact source of the EMI can be understood more fully and therefore a better solution can be implemented. It is common to see engineers using a guess and check method by just grabbing whatever components are available nearby, testing and then deciding what the next step is based on the test results. Although this iterative method sometimes works, as engineers, we should strive to better understand the underlying phenomena to be able to implement a more precise solution and resolve EMC issues with less time and effort. I hope to accomplish this in my session by focusing on practical tips and tricks. Topics include CMC selection, Xcap, and Ycap selection.

EMC Workshop for Power Supply Designers

Jared Quenzer
Würth Elektronik, USA

ED16 Experimental Demonstration of the Noise Attenuation Performance of an Active EMI Filter with EMIC

Experiment/Demonstration **2:00pm - 4:00pm**

Room: E&D Booth 3

Session Abstract: Electromagnetic interference (EMI) from power converters during switching operations has become a significant problem due to increased demand for high-power products. EMI filters are commonly implemented on AC powerlines in power systems to suppress conducted emissions (CE) noise. A conventional passive EMI filter typically consists of a low-pass L-C topology with Y-capacitors, common-mode (CM) chokes, and X-capacitors. However, in high-power appliances or industrial systems, the size and cost of CM chokes can be prohibitive considering several practical issues.

Active EMI filters (AEFs) are a practical solution for high-power applications to effectively reduce the size and number of CM chokes in passive filters. In previous studies, the topologies and implementations of analog AEFs are demonstrated, and design guidelines for stability, reliability, and noise attenuation performance have been proposed. Also, recently, AEFs have been implemented as EMI management-integrated circuits (EMIC) to reduce CE noise.

In this proposal for Experiments & Demonstrations, we would like to demonstrate the performance of the AEF with EMIC using a simplified experimental setup. The EMIC is the active EMI filter IC for high-voltage and high-current application. An evaluation board has been designed to help designers to evaluate the operation and performance of the EMIC with three-phase four-line ac utility. The evaluation board can be used for small signal testing as well as real application testing. The proposed AEF is designed as a fully-isolated structure using magnetic core components of the sensing and injection transformers. It can operate with 12V supply.

Experimental Demonstration of the Noise Attenuation Performance of an Active EMI Filter with EMIC

Jingook Kim
Ulsan National Institute of Science and Technology (UNIST), Korea

ED17 Measuring Power Distribution Network Noise and Impedance Effects on SIgnal Integrity

Experiment/Demonstration **2:00pm - 4:00pm**

Room: E&D Booth 4

Session Abstract: Power integrity including power distribution network (PDN) impedance and noise is one of the primary sources of signal integrity issues in digital transmission systems. Sources of noise can include power supply switching harmonics, high speed clocks, EMI and even nearby RF signals. The impedance of the PDN often varies widely with frequency resulting in ranges within which the impedance is higher allowing increased noise ingress. This demonstration will show how jitter analysis using an oscilloscope can reveal specific source of periodic jitter leading to higher oiverall peak to peak jitter. Further analysis of the PDN impedance, again using an oscilloscope, will be shown to reveal the specific frequency ranges corresponding to the periodic jitter sources where the impedance is higher. The resulting analysis is then used to provide a solution for mitigating the PDN noise and, along with it, the peak to peak jitter.

Measuring Power Distribution Network Noise and Impedance Effects on Signal Integrity

Michael Schnecker
Rohde&schwarz, USA

SS02 Medical Device EMC

Special Session **3:30pm - 5:00pm**

Room: 125AB

Chair: Ji Chen, *University of Houston, Houston, TX, USA*

Co-Chair: Ananda Kumar, *US Food and Drug Administration, Baltimore, MD, USA*

Moderator: Jianfeng Zheng, *University of Houston, Houston, TX, USA*

Session Abstract: With the continuous advancement of electrical and electronic medical instruments, there is an increasing prevalence of medical devices that can be implanted inside the human body or operated in close proximity to humans. However, the operation of these devices introduces the emission of electromagnetic signals, raising safety concerns for individuals. Moreover, the potential interaction of these devices with nearby medical equipment poses risks of device interference and malfunctions, especially in scenarios involving multiple electronic devices implanted within human bodies. Addressing these challenges requires the establishment of comprehensive scientific standards for both human safety and product safety assessment methodologies. Further advancements in computation and measurement techniques are crucial to achieve this objective. This special issue aims to delve into various critical aspects of Electromagnetic Compatibility (EMC) concerning electromagnetic safety and its application in biomedicine.

The areas to be covered in this **Special Session include:**

- Computational Methods for Interaction with Biological Bodies
- Human Exposure Safety and Compliance Assessment
- EMC in Biomedicine

This special issue aims to contribute to the ongoing discourse in the field by exploring these diverse and crucial topics in EMC, fostering the development of advanced scientific standards and methodologies for enhanced safety in the rapidly evolving landscape of medical electronics.

3:30pm **A Measurement Method for Magnetic Field Characteristics of Inductive Wireless Power Transfer Chargers for Consumer Electronics** 359

Yasaman Ardeshirpour, Joshua Guag, Jeffrey L. Silberberg, Seth J. Seidman

US Food and Drug Administration, USA

Abstract: The use of wireless power transfer (WPT) for charging consumer electronics has grown in recent years owing to its convenience. However, due to inadequate information regarding the emissions characteristics of commercially available WPT systems, the electromagnetic (EM) immunity test protocols of many current consensus standards applicable to medical devices have not been assessed for their appropriateness in evaluating interference caused by such WPT systems. In this paper, we present a methodology for measuring the EM disturbances of these WPT devices and provide some preliminary results, aiming to address this critical knowledge gap.

4:00pm **Safety Assessment of Pulsed Electromagnetic Field Pelvic Floor Therapies with Implanted Sacral Neuromodulation Devices** 365

Xuechen Huang[1], Shanie Scoles[1], Paul Nguyen[1], Jeff Chen[1], Jeremie Wisniewski[2], Yuqing Wan[1], Guangqiang Jiang[1]

[1]Axonics, Inc., USA; [2]CentraleSupelec, France

Abstract: Patients with Sacral Neuromodulation (SNM) implantable systems may seek Pulsed Electromagnetic Field (PEMF) therapy in pelvic floor muscle training due to symptoms of stress urinary incontinence. However, the use of PEMF therapy may raise safety concerns for these patients. Patients implanted with Axonics SNM implants are currently prohibited from receiving this PEMF treatment. In this study, the induced risks to patients implanted with Axonics SNM systems from the BTL EMSELLA pelvic floor muscle training system were investigated. The potential risks include heating, device malfunction, and unintended nerve stimulation. The results demonstrate that the PEMF therapy under investigation is a safe therapeutic option for patients with Axonics SNM implants under specific use conditions, potentially broadening patients' therapeutic choices. The results of this study have been submitted to the U.S. Food and Drug Administration (FDA), and the safety claim of PEMF therapy for patients with implanted Axonics SNM systems is currently under review.

4:30pm **The Effect of Lead Winding Near IPG on AIMD Models under MR RF Exposure** 369
Ziyu Zuo[1], Qingyan Wang[1], Jianfeng Zheng[1], Hongbae Jeong[2], Ananda Kumar[2], Ji Chen[1]
[1]University of Houston, USA; [2]US Food and Drug Administration, USA

Abstract: This paper explores the effects of lead winding near an Implantable Pulse Generator (IPG) on a Transfer Function (TF) model under Magnetic Resonance Imaging (MRI) Radio Frequency (RF) exposure. Three commercial AIMD systems are used in the study. Multiple sets of measurement are carefully conducted. Revealing that the TF model remains unchanged for one AIMD, while it undergoes significant changes for the other two systems. Upon closer examination of the leads' structure, it is observed that leads with thicker insulation layer tend to preserve the TF model. This observation is in agreement with the transmission line theory, wherein the AIMD with a thick insulation layer can preserve a low lossy transmission line mode in contrast to the other two devices.

TC4-2 Control of Electromagnetic Interference: Shielding, Filtering, Modeling and Prediction #2 (Sponsored by TC-4)

Technical Papers **3:30pm - 5:00pm**

Room: 127A

Chair: Daryl Beetner, *Missouri University of Science and Technology, Rolla, MO, USA*

Co-Chair: Charles Jullien, *Safran Electrical and Power, Blagnac, France*

Co-Chair: Victor Khilkevich, *Missouri University of Science and Technology, Rolla, MO, USA*

3:30pm **Use of Embedded Ferrites for Routing under Inductors in Compact Printed Circuit Boards** 374
Sami Heinisuo, Kari Mansukoski, Anil Kumar
Intel Corporation, USA

Abstract: Routing signals on a Printed Circuit Board (PCB) under inductors and other electromagnetic interference (EMI)-emitting components, such as switching field-effect transistors (FET), can be challenging since they induce noise to other signals. For example, using current methods, many high-speed signals cannot be routed under an inductor on any layer of the PCB stack up. By implementing embedded ferrite material in the PCB as described here, the routing constraints can be relaxed, which can enable signal routing under these devices. In this solution, ferrite is laminated as part of the PCB stack-up structure to either replace copper or dielectric insulation or both. Ferrite placement within the PCB is defined during the PCB layout design phase, so it can be placed exactly where the application requires it. This ferrite layer, or layers, may be local or may consist of the whole PCB area within the applicable layer(s) depending on application needs. Simulations of embedded ferrite placed under the typical power delivery inductor, with ferrite on dielectric layers between layers 1, 2, and 3 and traces on layer 4 of the PCB, showed up to 25-55% reduction in common mode noise when compared to a design without the embedded ferrite. By laminating ferromagnetic material as part of PCB structure to act as magnetic shield within the PCB, we can enable high speed signal routing under inductors, or free up this space to decrease the board size, increase customer product's battery size and capacity, and reduce the overall costs. All these create compelling new products and product categories for customer systems with longer battery life. Keywords—Embedded Ferrite, Routing Under Inductors, Printed Circuit Board stack-up, Noise Coupling.

4:00pm **Feasibility of Coherent Perfect Absorption based on Spoof Surface Plasmon Polaritons** 380
Jiaqi Xing, Da Li, Ling Zhang, Er-Ping Li
Zhejiang University, China

Abstract: The coherent perfect absorption (CPA) technology has gained extensive attention in recent years. This study explores strips array configurations based on Spoof Surface Plasmon Polaritons (SSPP) to demonstrate their feasibility in achieving electromagnetic CPA by simulations. Leveraging the dispersion characteristics of metal strips of specific dimensions, electromagnetic absorption can be achieved at the corresponding frequency points. The SSPP absorptive structure is strategically positioned within the standing wave field formed by two counter-propagating coherent waves. Manipulating the phase of the control wave facilitates dynamic adjustment of the absorber's location within the standing wave field, thereby selectively enhancing or attenuating the coherent absorption effect. Particularly, the control wave's phases of 0° and 180° correspond to the two extremes for the coherent absorption. Furthermore, the frequency of the absorption peak can be manipulated by varying the size of the metal strips. Based on the above findings, this paper further presents a dual-polarized SSPP-based coherent absorber and a multi-frequency SSPP-based coherent absorber.

TC9-5 Statistical and Surrogate Models (Sponsored by TC-9)

Technical Papers **3:30pm - 5:00pm**
Room: 127B
Chair: Yansheng Wang, *Rivos Inc., Santa Clara, CA, USA*

3:30pm **Estimating Effects of Residual Physics with Machine Learning for Earbud Performance Prediction** 386
Srinivasa Mohan[1], Jingchen Liang[1], Mingfeng Xue[2], Krishna Mellachervu[1], Pavani Gottipati[1], Jianmin Zhang[2]
[1]Ansys, Inc., USA; [2]Google Inc., USA

EMC BEST PAPER FINALIST

Abstract: Consumer electronics devices like earbuds include small components like the voice coil speaker. The damping coefficient of the voice coil speaker system and the acoustic resistance of the mesh at the aperture used in Finite Element Analysis (FEA) based simulation needs to be tuned to match predictions with measurements. In this paper, a machine learning method is proposed to combine experimental data with simulation data, that accounts for uncertainties in model and parameters to obtain a hybrid analytics model that can predict the performance of the speaker for unmeasured parameter values.

4:00pm **Fusion of Parameterized and Physics-Oriented Statistical Surrogate Models for EM Coupling on Wires in Complex Electronic Enclosures** 392
Shen Lin[1], Sangrui Luo[1], Yang Shao[1], Zhen Peng[1], Bisrat D. Addissie[2], Zachary B. Drikas[2]
[1]University of Illinois at Urbana-Champaign, USA; [2]U.S. Naval Research Laboratory, USA

EMC BEST PAPER FINALIST

Abstract: In this paper, we explore a novel approach in the domain of statistical electromagnetics for high-frequency coupling on wires installed in complex electronic enclosures. The study involves the integration of two distinct types of statistical surrogate models: parameterized models, which are based on predefined parameter spaces for internal wire/cable components, and physics-oriented statistical models, which leverage statistical representations of cavity eigenfunctions and eigenvalues. The fusion of parameterized and physics-oriented statistical surrogate models allows for a comprehensive and versatile statistical analysis, accommodating the complex details and variability present in real-world electronic systems. The proposed work has been validated numerically, including the commercial software and traditional Monte Carlo simulation.

TC10-5 Simulation and Modeling Techniques #3 (Sponsored by TC-10)

Technical Papers **3:30pm - 5:00pm**
Room: 128A
Co-Chair: Shaohui Yong, *Missouri University of Science and Technology, San Jose, CA, USA*
Chair: Yuandong Guo, *Missouri University of Science and Technology, Foster City, CA, USA*

3:30pm **Linear Equalizer Effect-Included Worst Eye Diagram Estimation Method for PCIe 6.0** 398
Seonghi Lee, Hyunwoong Kim, Seunghun Ryu, Jiseong Kim, Seongho Woo, Seungyoung Ahn
Korea Advanced Institute of Science and Technology, Korea

SIPI BEST STUDENT PAPER SEMI-FINALIST

Abstract: In this paper, linear equalizer effect-included eye estimation method was proposed for Peripheral component in- terconnect express (PCIe) Gen 6. To reflect the equalizer effect, the overall transfer function was calculated by combining the transfer function of the channel and the equalizer. The worst eye contour was predicted using the pulse amplitude modulation- 4 (PAM-4) peak distortion analysis (PDA) method. For the verification, the feed forward equalizer (FFE) and continuous time linear equalizer (CTLE) were used. For channels, 9 channel cases with different loss values were assumed. The proposed method was compared with circuit simulation by eye diagram results and simulation time. The proposed method predicted the worst contours well, including the linear equalizer effect, and significantly reduced the simulation time, down to 93% faster, which is approximately 0.86 seconds.

4:00pm **SI Impact and Modeling Accuracy of Non-Ideal Signal Routing over GND Void** 404
Sungjoo Kim, Esha Kondapuram, Benjamin P. Silva
Intel Corporation, USA

4:30pm **COM Qualification of 100Gbps and 200Gbps High Speed Channels** 409
Tao Wang, Brian Brecht, Benjamin Harding
Technoprobe S.p.A, Taiwan

Abstract: High speed links are favored by industries as necessary hardware that supports machine learning and data center. In this work, we present using COM (Channel Operation Margin) to evaluate physical channel's performance in IC testers. First, 100 Gbps link was studied by simulation and measurement correlations to verify our COM assessment. Then by extending the design to 200 Gbps, we apply simulated data in COM to assess the crosstalk impact from via holes in the layout. It effectively avoids over design and helps us to quickly debug the channel.

TC10-7 Power Distribution Networks and Decoupling #2 (Sponsored by TC-10)

Technical Papers **3:30pm - 5:00pm**
Room: 128B
Co-Chair: Junyong Park, *Missouri University of Science and Technology, Rolla, MO, USA*
Chair: Shaowu Huang, *Marvell Semiconductor Inc, Cupertino, CA, USA*

3:30pm **Efficient Optimization of Decoupling Capacitors using Iterative Inversion Technique** 410
Sriram Hariharan, Dinesh Junjariya, Jai Narayan Tripathi
Indian Institute of Technology Jodhpur, India

Abstract: To maintain Power Integrity (PI) in a high-speed electronic system, the Power Delivery Network (PDN) needs to be optimized with respect to its impedance. To minimize power supply noise, decoupling capacitors are used in a PDN. By selecting appropriate decoupling capacitors (decaps) and placing them on optimal locations on board/package, the overall impedance of a power delivery network can be effectively reduced to a desired level to minimize the variationa in supply voltage due to varying load current. In this paper, a time-efficient matrix inversion approach is used for impedance calculation within Particle Swarm Algorithm (PSO) algorithm which helps to enhance the efficiency of the optimization proces. The proposed approach is demonstrated through a practical case study. The applied technique significantly reduces the overall runtime of the algorithm, enhancing computational efficiency. A comparative evaluation of the performance of the proposed approach with the conventional algorithm is presented.

4:00pm **IBIS-Approved Streamlined Power Integrity Model (SPIM) for Platform Power Integrity Analysis** 414
Xingjian Kinger Cai, Chi-te Chen, Ei Jun Cheng
Intel Corporation, USA

Abstract: The Streamlined Power Integrity Model (SPIM) has received approval from the IBIS Open Forum. After a comprehensive overview of the structure, SPIM is elaborated with its generation, correlation, validation, and practical application in the context of the actual design, review, sign-off, and optimization of platform Power Delivery Networks (PDN).

4:30pm **Enhanced S-Parameter Rational Function (SRF) Model Revolutionizing Power Delivery Analysis** 415
Mohammad Islam, Kinger Cai, Sophia Alvarez, You Zhang Tan, Yihong Yang,
Vijay Govindarajan, Thim Khuen Wong, Julio Soto
Intel Corporation, USA

Abstract: The S-parameter model with abundant ports, extracted from the routing of power delivery network (PDN), is enhanced by reducing model complexity and enforcing passivity and causality, when transformed into a broadband S-parameter rational function (SRF) model. The enhanced SRF model is integrated into power integrity (PI) and power delivery (PD) simulations flow with HSPICE, resulting in accurate AC impedance analysis rectifying the anomalies in the sub-MHz frequency range, and more efficient transient simulation with further High Precision Parallel (HPP) boosting efficiency, making simulation runtime 50 times faster than that using IFFT of a conventional macro-model of the original S-parameter.

THURSDAY – AUGUST 8, 2024

TC2-4 EMC Measurements – VHF-LISN Termination, Current Coupling and Capacitive Coupling (Sponsored by TC-2)

Technical Papers **8:30am - 10:00am**

Room: 125AB

Chair: Monrad Monsen, *Oracle, Broomfield, CO, USA*

Co-Chair: Ahalya Srikanth, *Ford Motor Company, Lasalle, ON, Canada*

8:30am **Justification and Background for Terminating AC Mains Cable with Balanced VHF-LISN to Radiated Emission Measurement** 416

Kunihiro Osabe[1], Nobuo Kuwabara[2], Hidenori Muramatsu[1]

[1]VCCI Council, Japan; [2]Kyushu Institute of Technology, Japan

Abstract: This document provides a background for proposing a balanced Very High Frequency–Line Impedance Stabilization Network (VHF-LISN). The device is designed to terminate the Alternating Current (AC) mains cable of the Equipment Under Test (EUT) with 50 ohms balanced for radiated emission measurements. In 2017, Joint Ad-hoc Group 6 (JAHG6) of CISPR began discussing this proposal. The deliberation is ongoing towards international standardization. Throughout the discussions and studies, several findings were originally presented in this paper and requested to be summarized including the past studies as archives for future reference.

9:00am **Visualization of Common Mode Current Coupling to Attached Cables of Power Converters** 422

Daniel Lyngby Commerou[1], Kasper Mayntz Paasch[1], Morten Sørensen[2]

[1]University of Southern Denmark, Denmark; [2]FORCE Technology, Denmark

Abstract: Common mode currents on attached cables are often the dominant source of unwanted emissions at frequencies below 400 MHz as the cables act as unwanted antennas. High coupling to these cables combined with strong nearfields are seen as two conditions for radiated emission. This paper introduces a novel method and workflow to use nearfield scanning results to visualize areas with high coupling to attached cables from a device. The method is successfully demonstrated on a simple device and thereafter in a case study.

9:30am **Industrial EFT Capacitive Coupling Analysis** 429

Mohit Gopalraj, Sachinkumar Goudnoor, Michael Donaruma, Thane Sanford

Analog Devices Inc., USA

Abstract: This paper talks about the transient coupling analysis during industrial EFT (Electrical Fast Transients) tests using the Capacitive Coupling Clamp based on IEC 61000-4-4. The energy coupled onto to tested and untested ports on a DUT PCB are analyzed. This provides better insight on how much the untested ports are affected during the actual EFT tests.

TC7 Low Frequency EMC (Sponsored by TC-7)

Technical Papers **8:30am - 10:00am**

Room: 127A

Chair: Flavia Grassi, *Politecnico di Milano, Milano, Italy*

8:30am **Identification of Internal Impedance of Brush Motor in Operation using AMN** 430

Akito Mashino, Shohei Kan, Kengo Iokibe, Yoshitaka Toyota
Okayama University, Japan

EMC BEST STUDENT PAPER SEMI-FINALIST

Abstract: In brush motor drive systems, electromagnetic interference (EMI) due to brush noise can cause problems, thus it is essential to design an appropriate EMI filter built into the brush motor. Since the cable length also affects EMI, we are studying a multi-purpose design method for EMI filters that includes the cable length. In this study, it is important to identify the internal impedance of the brush motor with high accuracy. In EMI problems, not only differential mode (DM) but also common mode (CM) should be noted, and the identification of equivalent circuit models of noise sources in brush motors should cover the internal impedances of both DM and CM. More importantly, since brush noise arises during motor operation, it is necessary to identify the internal impedance during operation. A method using a vector network analyzer (VNA) and two current probes has been proposed to identify the internal impedance, but it is effective only up to 30 MHz. Therefore, this paper identifies the internal impedance in operation up to 100 MHz while using an artificial mains network (AMN) to supply power to a brush motor. Here, the impedance of the AMN is removed by de-embedding. Comparing the internal impedance at rest and in operation, the impedance related to DM was only slightly different, but the impedance related to CM changed significantly. On the other hand, the internal impedance characteristics changed little with the DC voltage applied to the brush motor or the load torque.

9:00am **Using the Wavelet Packet Transform to Evaluate Parameters of Harmonics Clustered in Quadruples using Linear Systems** 436

Ileana Diana Nicolae, Petre-Marian Nicolae, Marian-Ştefan Nicolae
University of Craiova, Romania

Abstract: The paper presents an original technique used to evaluate the parameters of quadruples of harmonics clustered in an almost exclusive manner to quadruples of nodes from the bottom level of a Wavelet Packet Tree. The harmonic signal (RHS) generated by harmonics from a quadruple can be deduced with approximation from the analyzed signal by using original computational techniques. Linear systems were conceived based on the harmonics superposition and randomly chosen components of RHC (the approximated version of RHS). Their solving yields sets of possible solutions, that are afterward refined to exclude values with non-zero imaginary parts or deviant values. Averages over refined values are used. The indetermination relative to phase-shifts is solved considering the criterion of "best approximation" of RHC by the signal obtained through the superposition of the computed clustered harmonics. The harmonics from the studied quadruples are: (11, 13, 19, 21), (23,25,39,41) and (27,29,35,37). This paper provides the complementary technique for the odd harmonic identification within the range 3…41 (the odd harmonics not belonging to quadruples are coupled in pairs and were approached in a previous publication).

9:30am **Black-Box Model of a Single-Phase Industrial Variable Frequency Drive** 441

Dusan Kostic[1], Lu Wan[2], Abduselam Hamid Beshir[2], Iurie Nuca[1], Petre-Marian Nicolae[1], Flavia Grassi[1]
[1]University of Craiova, Romania; [2]Aalborg University, Denmark; [3]Politecnico di Milano, Italy

Abstract: When an electrical device is power quality compliant, it means that its efficiency and coexistence within an energy system satisfies the standards that cover the harmonic range up to order of 40 (2/3 kHz), or in the electromagnetic compatibility (EMC) frequency (frequency higher than 150 kHz). Low-frequency (LF) EMC range, which covers the frequency range from 2kHz to 150kHz, is a grey area in standards for energy systems and the measurement of emissions in this range. Line impedance stabilization networks (LISNs) are the devices used to measure the EMC of devices. LISN standards cover only part of the LF EMC range (usually above 9kHz), thus making this range especially interesting for research. In this paper, measurements were made on a variable frequency drive (VFD) systems in the low-frequency electromagnetic compatibility range, where the switching frequency of the converter varied in steps from 5kHz to 15kHz, a common range for VFD and photo-voltaic inverters switching frequency, which corresponds to the LF EMC range. This research focuses firstly on common mode (CM) current measurements for a single-phase system where a VFD driving a motor without load is connected to two one-phase LISNs, where the active and passive part of the converter were computed to derive its black-box model. Because the results are different for each frequency, the authors found it convenient to derive a black-box model for 10kHz frequency, as it is also in the range of LISN standards.

SS03 EMC and EMF Safety of Wireless Power Transfer Systems

Special Session **8:30am - 10:00am**

Room: 127C

Co-Chair: Francescaromana Maradei, *University of Rome La Sapeinza, Rome, Italy*

Co-Chair: Mauro Feliziani, *Univerisity of Aquila, L'Aquila, Italy*

Session Abstract: Wireless Power Transfer (WPT) technology is poised to revolutionize electric mobility in the near future. This technology facilitates the transmission of electrical energy from a power source to an electric vehicle (EV) without the need for physical connections, making it a crucial component for the advancement of electric transportation. Unlike traditional plug connections, WPT offers several advantages: it enhances safety by eliminating the need for cables that users must connect to the vehicle, and it improves convenience by automating the charging process. Both stationary and dynamic WPT systems, based on inductive coupling, are an intentional source of strong magnetic fields in the environment. These fields pose potential health risks to individuals exposed to them and may interfere with the operation of electronic systems in vehicle and on roads, including cardiac implanted electronic devices (CIEDs) worn by passengers and pedestrians. Addressing electromagnetic compatibility (EMC), electromagnetic fields (EMF) safety, and electromagnetic interference (EMI) in CIEDs is a critical challenge for the widespread deployment of WPT systems. This special session focuses on models, methods, technologies and applications for the characterization and mitigation of the electromagnetic field emission produced by stationary and dynamic WPT systems for e-mobility. The assessment of compliance with EMC, EMF safety, and CIED standards is also a central theme of the special session.

8:30am **Design of a Shielding Coil for Fiber Composite Electric Vehicles with a SAE J2954 WPT System** 446

Tommaso Campi[1], Silvano Cruciani[2], Francescaromana Maradei[1], Mauro Feliziani[3]

[1]Sapienza University of Rome, Italy; [2]Tor Vergata University of Rome, Italy; [3]University of L'Aquila, Italy

Abstract: This work deals with the mitigation of magnetic field levels produced by an automotive wireless power transfer (WPT) system. For this purpose, a 1-turn passive shielding coil is adopted, positioned on the underneath of the vehicle, around the receiving coil and terminated on a tuning capacitor. The design of an efficient shielding coil is detailed in terms of dimensions, shape, and position, along with a methodology for selecting an optimal terminal capacitance. The shielding effectiveness (SE) during stationary wireless charging of an electric city car with a carbon fiber reinforced polymer (CFRP) chassis is calculated numerically. The proposed mitigation technique allows compliance with the limits set for electromagnetic field (EMF) safety and demonstrates how a correct design of a shielding coil does not degrade WPT system performance.

9:00am **Determination of Optimal Current Phase Difference between Transmitter and Receiver Coils for Minimizing Leakage Magnetic Field in Wireless Power Transfer Systems** 450

Seongho Woo[1], Yujun Shin[2], Sungryul Huh[1], Hyunsoo Lee[1], Seungyoung Ahn[1]

[1]Korea Advanced Institute of Science and Technology, Korea; [2]Keimyung University, Korea

Abstract: This paper proposes a method for determining the optimal phase difference between transmitter and receiver coils for suppressing leakage magnetic field in wireless power transfer (WPT) systems. As the power level of WPT systems increases, the leakage in the magnetic field also increases. As a result, the possibility of electromagnetic field (EMF) or electromagnetic interference (EMI) issues also increases. There are various shielding methods for reducing leakage magnetic field, but all the methods need additional materials or power sources. In contrast, the proposed method can suppress leakage magnetic field by determining the phase difference between TX and RX coils current without additional materials. So, the proposed method also can reduce the weight and cost of the WPT systems.

9:30am **Thermal-Aware Wireless Charging System Design and Optimization for Wearable Devices with Magnetic Shielding** 455
Jingchen Liang, Kamyar Keikhosravy, Mehdi Abarham, Pavani Gottipati
Ansys, Inc., USA

Abstract: Design of wireless chargers has become an increasingly complex subject in recent years due to the demand for reduced footprint of the wireless charger, increasing operating frequency and addition of permanent magnets for improved alignment. This paper presents a complete simulation workflow to address end-to-end design challenges for the wireless charging system of a smart watch including an integrated electromagnetic and thermal analyses and experimental validation of wireless charging coils, magnetic shielding to reduce electromagnetic interference, and system analysis with power electronics for efficiency calculation. Spatial power and temperature distributions are shared between the electromagnetics and thermal solutions and temperature dependent materials are considered for calculations to make this workflow unique and accurate. This provides engineers with a comprehensive wireless charging design and optimization workflow for consumer electronics applications.

SC3 Machine Learning and Artificial Intelligence Technologies (Sponsored by SC-3)

Technical Papers **8:30am - 10:00am**
Room: 128A
Co-Chair: Ling Zhang, *Zhejiang University, Hangzhou, China*

8:30am **Unsupervised Anomaly Detection of a Home Appliance by Monitoring EMI Data** 460
Hyeonwoo Yu[1], Sangyeong Jeong[2,3], Jingook Kim[2,3]
[1]Sungkunkwan University, Korea; [2]Ulsan National Institute of Science and Technology, Korea; [3]EMcoretech, Co., Korea

Abstract: We propose an anomaly detection method by approximating the system state using electromagnetic interference (EMI) data. Since the harmonics of switching frequency cause characteristic patterns in conducted emission (CE) currents, understanding CE patterns can be exploited to detect an anomaly state caused by physical or functional defects in the system. To capture the CE patterns that follow an intractable distribution, we introduce a method based on a variational generative model. The anomaly data in a real-world scenario is challenging to obtain, and as such, we determined an approximated distribution for the normal states of a system to detect an outlier. Further, we designed a manifold space with a multi-modal prior distribution, thus our method can be extended to consider the entire system. To evaluate our approach, we manually collected normal and anomaly EMI data from the outdoor unit of an air conditioner. Using the EMI data from a normal state, we approximated the manifold distribution that follows an tractable distribution and demonstrate the possibilities for outlier detection. While common-mode (CM) CE EMI noise are mainly used for configuring the state of a system, we also apply our approach to the differential-mode (DM) as well as for direct power line noise.

9:00am **Machine Learning based Radiation Source Reconstruction in Terms of Spherical Wave Expansion Coefficients** 466
Carlo Olivieri, Lino Di Leonardo, Francesco de Paulis
University of L'Aquila, Italy

Abstract: Modern high-end electronic systems require accurate control of unwanted electromagnetic radiation. This paper proposes a novel source reconstruction method based on the combined use of Spherical Wave Expansion theory and Machine Learning techniques. The proposed method aims to estimate the equivalent spherical wave expansion coefficients describing the radiation from a generic source starting from the knowledge of its field magnitude information only (measured or simulated). The main details of the proposed method and preliminary results are summarized in the paper.

TC10-8 Simulation and Modeling Techniques #4 (Sponsored by TC-10)

Technical Papers **8:30am - 10:00am**

Room: 128B

Chair: Jianquan Lou, *Cisco Systems (China) R&D Co., Ltd., Shanghai, China*

Co-Chair: Di Hu, *General Motors Company, Sunnyvale, CA, USA*

8:30am **Novel Formulation for Generalization of Mixed-Mode S-Parameters for Coupled Differential High-Speed Digital Channels** 467

Manish K. Mathew[1], Kevin Cai[2], Chaofeng Li[1], Mehdi Mousavi[1], Shameem Ahmed[2], DongHyun Kim[1]
[1]Missouri University of Science and Technology, USA; [2]Cisco Systems, Inc., USA

Abstract: As the demand for higher data rates intensifies, achieving accurate S-parameter calculation becomes increasingly critical. The conventional single-ended to mixed-mode S-parameter conversion formulation assumes uncoupled structures, which may not be true for high-speed digital channels. This work introduces a novel, generalized formulation for mixed-mode S-parameters and their corresponding transformation matrices [M_1] and [M_2], enabling comprehensive analysis of multi-pair coupled differential traces. An intra-pair crosstalk analysis of a tightly coupled stripline and microstrip line verifies and highlights the difference between the proposed and old formulations. A loosely coupled case is analyzed as an additional validation of the proposed formulation. Finally, the generalized conversion formulation is used to perform an inter-pair crosstalk analysis which compares the old and the new conversion formulation.

9:00am **Fast Macromodeling of Large-Scale Multiports with Guaranteed Stability** 472

Tommaso Bradde[1], Ion Victor Gosea[2], Stefano Grivet-Talocia[1]
[1]Politecnico di Torino, Italy; [2]Max Planck Institute for Dynamics of Complex Technical Systems, Germany

Abstract: This contribution introduces a novel approach for generating guaranteed stable macromodels of large multiport structures in a completely automated and efficient manner. The presented method is based on the Adaptive Antoulas-Anderson (AAA) algorithm for rational fitting of scalar transfer functions. We propose a computationally cheap multi-input multi-output extension of the AAA, and we combine the resulting algorithm with a novel post-processing stability enforcement step that is formulated in terms of a small-size convex program. Applying the resulting framework to a large Power Delivery Network (PDN), we show a significant computational cost reduction with respect to commonly employed state-of-the-art methods. The proposed scheme fits naturally as a bridge between electromagnetic and circuit simulation, enabling the representation of high-frequency phenomena and parasitics as low-order equivalent circuits synthesized from the computed macromodels.

9:30am **Reassessing the FER3 of the IEEE 370 Standard** 478

Chiu-Chih Chou
National Central University, Taiwan

Abstract: This paper reassesses the third fixture electrical requirements (FER3) in the IEEE 370 Standard. The link with the problem of spectrum truncation is explained, and through a simulated test case, it is shown that by properly handling the truncation, accurate de-embedding could be achieved even at frequencies significantly violating FER3. The results therefore suggest that the FER3 may be relaxed to avoid overdesign.

ED18 On the Application of FFTs for Accelerated Time Domain Scan to Reduce EMI Measurement Time

Experiment/Demonstration **10:00am - 12:00pm**
Room: E&D Booth 1

Session Abstract: EMC testing is required for just about any product that has digital and radio components. With the growth of those products, time to complete EMC testing typically takes longer, due to competition for lab time, and for the surprises in tracking down short-burst or impulse-type emissions. The automotive industry, for example, requires exacting methodologies to measure all emissions accurately. Long test times impact test facility availability and potentially reduces the number of devices that are certified. It's also easy to miss intermittent disturbance signals with conventional scans since an extended dwell time must occur at each frequency.

With the implementation of a Short Time FFT (STFFT) engine, Keysight's N9048B PXE EMI receiver includes Time Domain Scan (TDS) and Accelerated TDS capabilities that enable independent compliance test laboratories and in- house certification labs to shorten their overall test time.

This presentation will provide an overview of TDS and Accelerated TDS capabilities to meet EMI measurement requirements and comply with EMC standards such as CISPR 16-1-1 and MIL-STD-461 and highlight how you can easily reduce receiver scan and test time from multiple hours to seconds.

On the Application of FFTs for Accelerated Time Domain Scan to Reduce EMI Measurement Time

Bill Koerner
Keysight Technologies Inc., USA

ED19 Patuxent River Lightning and Electrotstatics Team "Precepitation Static Demonstration"

Experiment/Demonstration **10:00am - 12:00pm**
Room: E&D Booth 2

Session Abstract: Demonstration Idea – P-Static has characteristics can be demonstrated in a few different forms. We can set-up 3 different configurations.

UHF/VHF or any sort of aircraft antenna partially screwed on to a grounded aluminum plate. This will demonstrate the sound of the arcing on our Sony radios that can hook up to a speaker.

A grounded windshield/windscreen or piece of plastic that demonstrates how the charge can remain on the surface with a static voltmeter. We then use a static control brush to show the how voltage decreases then increases when the brush moves away.

A simple, aluminum sheet set up, that has one set-up demonstrating the arcing and one set-up that has it grounded and bonded. Painted Bolts could be a backup. This will show us the ideal and non-ideal conditions for proper bonding.

Modify the appearance of the wand to be more presentable.

Create a safety enclosure for the different configurations and HV Power Supply.

Have a professional sign stating who we are and what we do and separate sign that describes P-Static Phenomenon.

Patuxent River Lightning and Electrotstatics Team "Precepitation Static Demonstration"

Christophor Hillyard[1], John Y. Howson[2], Tiffany Morisak[1]
[1]NAWCAD, USA; [2]NAWCAD, USA

ED20 Speed Up Your RC: Accelerated E-Field Measurements in Reverberation Chambers

Experiment/Demonstration **10:00am - 12:00pm**
Room: E&D Booth 3

Session Abstract: The demo session will start with a brief introduction on the basics of reverberation chambers (RCs). Validation and radiated immunity testing are discussed.

We will bring a small, but fully working, stirred RC to the stage. Eight fast, synchronized electric-field probes will showcase real-time E-field strength measurements and closed loop E-field control based on statistics. LUMILOOP's LSProbe E-field Probes enable accelerated measurements according to ISO 11451-5.

Learn on how to improve you EMC measurement. Save time and money while testing!

Speed Up Your RC: Accelerated E-Field Measurements in Reverberation Chambers
Samuel Hildebrandt
LUMILOOP GmbH, Germany

ED21 Troubleshooting EMI Failures on Power Delivery Networks using an Oscilloscope and Near Field Probes

Experiment/Demonstration **10:00am - 12:00pm**
Room: E&D Booth 4

Session Abstract: Power delivery networks (PDNs) including PCB planes, capacitors, inductors and power conversion devices are common sources of both cunducted and radiated EMI. Methods for using near field probes and an oscilloscope to troubleshoot these problems are presented in this demonstration. While oscilloscopes are generally considered for observing and measuring signals in the time domain, most modern digital oscilloscopes are capable of accurate spectrum measurements as well. The benfit of using an oscilloscope with FFT-based spectrum analysis is its ability to measure in both time and frequency domains simultaneousy. Near field EMI measurements on a switched mode power supply under different load conditions and their relationship to the inductor saturation are used to illustrate this benefit.

Troubleshooting EMI Failures on Power Delivery Networks using an Oscilloscope and Neat-Field Probes
Michael Schnecker
Rohde&schwarz, USA

TC2-5 EMC Measurements: Pulsed RFI in Motors, Multi-Tone Susceptibility Impact and Bench to On-Vehicle Emissions Comparisons (Sponsored by TC-2)

Technical Papers **10:30am - 12:00pm**
Room: 125AB
Chair: Ahalya Srikanth, *Ford Motor Company, Lasalle, ON, Canada*
Co-Chair: John Kraemer, *Kraemer EMC, Marion, IA, USA*

10:30am **Influence of Multi-Tone on the Susceptibility of Electronic Devices at the System Level** 479
Alexis Gandon, David Martinez, Islem Yahi, Felix Vega, Chaouki Kasmi
Technology Innovation Institute, United Arab Emirates

Abstract: This work experimentally compares the impact of single-tone (ST) and Multi-tone (MT) immunity tests on an electronic device. The objective is to assess and compare the system's behavior for both conditions. Moreover, the work aims to highlight that MT testing can lead to worsened failure conditions of the equipment with a reduced power ratio.

11:00am **Bench vs On-Vehicle Emissions Correlation?** ..... N/A
Ch. U. Sajjad[1], John F. Dawson[1], Andy Marvin[1], Ayhan Gunsaya[2]
[1]University of York, United Kingdom; [2]Ford Motor Company, United Kingdom

Abstract: This paper explores the radiated emissions from transmission line driven from an equipment enclosure using 1/10th scaled models of a CISPR 25 bench and a commercial van. The differences are presented from the perspective of the radiation pattern of the system in the hemisphere above the ground plane.

SC5-1 Passive Components and Semiconductor Devices (Sponsored by SC-5)

Technical Papers **10:30am - 12:00pm**
Room: 127A
Chair: Shuo Wang, *University of Florida, Gainesville, FL, USA*
Co-Chair: Sebastian Koj, *Jade Hochschule, Wilhelmshaven, Germany*

10:30am **A New Method for Extracting Parasitic Capacitance of MOSFET in a Half-Bridge Configuration** 481
Jaewon Rhee, Sanguk Lee, Hongseok Kim, Jiseong Kim, Seungyoung Ahn
Korea Advanced Institute of Science and Technology, Korea

Abstract: Parasitic capacitance of silicon carbide (SiC) metal–oxide–semiconductor field effect transistor (MOSFET) significantly affects the operation of power circuits and their electromagnetic interference (EMI) performance. The parasitic capacitance of the MOSFET can resonate with PCB traces or cables, generating noise during switching, making it crucial to extract the parasitic capacitance accurately and conveniently. With the increasing use of various electronic devices, such as electric vehicles and household appliances, there is growing interest in inverters for driving motors, where MOSFETs are mainly used in a half-bridge structure. Recently, chip-type MOSFET with a half-bridge type has been developed for miniaturization and weight reduction of the devices. This study proposes a method to simplify the extraction of parasitic capacitance from half-bridge MOSFET, which traditionally requires complex and many procedures. This method allows for the stable and straightforward extraction of parasitic capacitance in a 3-terminal structured MOSFET using a 2-port network without floating errors. The proposed method, compared to the conventional methods, can reduce the required steps, and it has been verified through 3D EM simulation.

11:00am **Comprehensive Surge Analysis: Shielding Cable Response and Power Port Protection Circuit Design** 485
Jianquan Lou[1], David Tang[1], Haiwen Lu[1], Alpesh Bhobe[2], Xuxian Jiang[3]
[1]Cisco Systems (China) R&D Co., Ltd., China; [2]Cisco Systems, Inc., USA; [3]Shanghai University, China

Abstract: This paper introduces two surge generation circuits designed to comply with the IEC61000-4-5 standard. Leveraging these circuits, we conduct a comprehensive investigation into the impact of surges on shielding coaxial cables through simulation. The analysis involves calculating the noise coupled into the inner signal wire across various cable lengths. Additionally, surge noise is applied to the power port, prompting an initial exploration of Coupling/Decoupling Network (CDN) modeling. The study extends to the comparison of three surge protection circuit configurations in the power port through both simulation and measurement. A model incorporating a variable capacitance was established to enhance agreement. The alignment of simulation and measurement results serves as valuable guidance for the early-stage design of surge protection circuits in projects.

11:30am **Accurate Method for Extracting the Multi-Layered Ceramic Capacitor Impedance by Eliminating the Influence of Mounting Pads and Via-Hole** 491
Sanguk Lee, Jaewon Rhee, Seunghun Ryu, Hongseok Kim, Seungyoung Ahn
Korea Advanced Institute of Science and Technology, Korea

Abstract: In this paper, we propose a method for de-embedding the influence of the mounting pads and via-hole in the test fixture for accurate impedance extraction of the multilayered ceramic capacitors (MLCCs). The proposed method can extract the parasitics of the mounting pads and via-hole using the short fixture and de-embed the influence of the mounting pads and via-hole from the measurement results. To accurately extract the parasitics of mounting pads and via-hole, the technique in which the reference plane underneath the mounting pads and short bar is cleared is introduced. The proposed method can reduce the error in self-resonant frequency and equivalent series inductance (ESL) by up to 3.00% and 1.54%.

SS04-1 Stochastic Electromagnetics #1 (Sponsored by TC-4)

Special Session **10:30am - 12:00pm**
Room: 127C
Chair: Paul Bremner, *Robust Physics, Del Mar, CA, USA*
Co-Chair: Evelyn Dohme, *Sandia National Laboratories, Albuquerque, NM, USA*

Session Abstract: Many design challenges in EMC and Signal Integrity involve complexity and uncertainty that can only be quantified statistically. Reverberation chamber testing in EMC; bit error rate (BER) metric for signal integrity (SI) and RMS delay spread in 5G/6G wireless are examples. Stochastic Electromagnetics encompasses both probabilistic simulation methods and supporting statistical testing methods that are rapidly evolving to reliably address these challenges. This special session will highlight new developments in emerging Stochastic Electromagnetics, such as stochastic power balance, random coupling modeling, and stochastic Green's function analysis. The scope of this session encompasses all aspects of stochastic EMC methods, including novel theoretical developments, practical implementation and complexity analysis, and experimental validation.

10:30am **Statistics of Electromagnetic Fields within Wire-Coupled, Nested Reverberant Enclosures** 496
Marshall D. Sowell, Kyle A. Shea, Carl E. Hager IV
Naval Surface Warfare Center, USA
EMC BEST PAPER FINALIST

Abstract: A study has been performed to characterize the statistics within an inner reverberant enclosure when it is electromagnetically illuminated within a larger reverberant enclosure (i.e., nested enclosure). The coupling mechanism used to exchange energy between the two cavities were a series of N = 1, 2, … , 30 wire penetrations. The wires act as the dominate leakage mechanism between the two coupled enclosures and represent each test case. Two well studied distributions were used to fit the measured power – the power form of the double-Rayleigh (termed the double-exponential) distribution and the exponential distribution. The Anderson-Darling and Pearson's chi-squared goodness-of-fit tests were used at the 95% confidence level to evaluate the distributions. The chi-squared goodness-of-fit rejected the null hypothesis at a 5.52% rejection rate when testing against the double-exponential distribution for the N = 1 test case, indicating a good fit. The exponential distribution showed evidence of a good fit only for N ≥ 20 test cases, indicating the two enclosures were statistically acting as a single enclosure. A new hypothesized distribution termed the modified double-exponential distribution was shown to provide a good fit for all N test cases. This distribution indicates that it is a good fit under the conditions of this experiment, and further study into coupled enclosure statistical behavior is ongoing.

11:00am **On the Formulation of Stochastic Green's Function Method for Aperture Coupled Enclosures** 502
Sangrui Luo, Shen Lin, Yang Shao, Zhen Peng
University of Illinois at Urbana-Champaign, USA
EMC BEST STUDENT PAPER SEMI-FINALIST

Abstract: The stochastic Green's function method was recently introduced as a physics-oriented, statistical surrogate model for the vector wave equation in large, complex enclosures. It provides a computationally efficient means of approximating confined EM environments by leveraging a statistical representation of the cavity eigenfunctions and eigenvalues. This paper advances the formulation of the stochastic Green's function method to address the challenges posed by complex targets with hierarchical interactions. The scope of applications spans electromagnetic coupling into multiple interconnected cavities and the prediction of shielding effectiveness for nested enclosures.

11:30am **Experimental Validation of Model for Cavity Field Statistics when Q Factor or Excitation Level are Uncertain** 508
P. Bremner[1], R. Afra[1], J. West[2], C. Bunting[2], M. Mustafa[2], S. Mostafa[2]
[1]RobustPhysics, USA; [2]Oklahoma State University, USA

Abstract: Statistical power balance (SPB) modeling has previously been shown to efficiently predict electric field levels inside enclosures – both shielding effectiveness from exterior sources and radiation from cables inside the enclosure. At high frequencies, the enclosure field is complex, multi-modal (reverberant) and can only be described statistically. However, the maximum expected field level can also be impacted by model uncertainty in the enclosure Q factor and/or uncertainty (variability) in source excitation field strength. This paper documents the theoretical development and the experimental validation of an extension to SPB modeling (Bremner, Proc. EMC Symp. 2023) which incorporates uncertainty in Q factor and/or uncertainty in excitation field strength.

TC12-1 RF Interference and De-Sense (Sponsored by TC-12)

Technical Papers **10:30am - 12:00pm**

Room: 128A

Chair: Francesco de Paulis, *University of L'Aquila, L'Aquila, Italy*

Co-Chair: DongHyun (Bill) Kim, *Missouri University of Science and Technology College of Engineering and Computing, Rolla, MO, USA*

10:30am **Impact of Aging on PIM and DC Resistance of Fabric-over-Foam Metallic Contacts** 514

Kalkidan W. Anjajo[1], Seunghun Ryu[1], Shengxuan Xia[1], Gracie Boyer[3], Yuchu He[2], Haicheng Zhou[2], Hanfeng Wang[2], Jonghyun Park[3], Chulsoon Hwang[1]

[1]Missouri University of Science and Technology, USA; [2]Google Inc., USA

Abstract: In this paper the impact of aging on the level of passive intermodulation (PIM) and DC resistance of fabric-over-foam metallic contacts is presented. These contacts are widely used to maintain metallic connections between modules and chassis in electronic devices. The PIM caused by the loose metallic contact of these materials mainly affects a receiver's RF sensitivity in mobile devices. This aging test under elevated temperature and relative humidity conditions offers an experiment-based approach with respect to various metallic contact cases. Energy dispersive spectroscopy and scanning electron microscopy are used to characterize the change in material composition and the contact surface throughout the aging. The experimental environmental effects showed the aging on the generated PIM level to have little to no impact from weakened adhesive contact and an increase in lowest PIM floor. Also, an increase in DC resistance level of these metallic contact materials was observed due to an oxide growth on the fabric-over-foam surface.

11:00am **Design of Experiment Analysis on Multiple PIM Sources in an RF Antenna System** 520

Shengxuan Xia[1], Yuchu He[2], Haicheng Zhou[2], Hanfeng Wang[2], Chulsoon Hwang[1]

[1]Missouri University of Science and Technology, USA; [2]Google Inc., USA

EMC BEST PAPER FINALIST AND BEST STUDENT PAPER SEMI-FINALIST

Abstract: Passive intermodulation (PIM) has been identified as one of the common root causes for receiving sensitivity degradation (desense) on radio-frequency (RF) antennas working in frequency-division duplex mode. The component-level PIM characterization and simulation have been well-established over the years. However, the study has been using an ideal 50 Ω transmission line system while antenna modules are more complicated than a simple transmission line structure. Moreover, the metallic contacts can exist in multiple locations with different connection topologies in real applications. This paper provides a method to simulate the PIM performance caused by the metallic contacts in a practical environment. In addition, the design of experiment (DoE) analysis is conducted to understand the statistical relationship between the component nonlinearity and the total PIM levels. Prioritizing the critical contact locations design insights including what-if scenario studies are found with the DoE.

TC10-9 Power Distribution Networks and Decoupling #3 (Sponsored by TC-10)

Technical Papers **10:30am - 12:00pm**

Room: 128B

Chair: Ying Cao, *Apple Inc, Santa Clara, CA, USA*

Co-Chair: Kaisheng Hu, *Ciena, Ottawa, ON, Canada*

10:30am **Dual-Structure Genetic Algorithm-Based Optimization Method for PDN Design** 525

Suhyoun Song, Ook Chung, Hogeun Yoo, Jaehoon Lee

Korea University, Korea

Abstract: Optimizing the placement of decoupling capacitors (decaps) is crucial in power delivery network (PDN) design, yet it poses challenges due to the large search space. In this paper, we present a dual-structure genetic algorithm (GA)-based optimization method that optimizes both via placement and decap configurations to achieve the target impedance while minimizing the number of capacitors used. The resulting design exhibits a lower cost function compared to previous methods that optimizes decaps at fixed locations, displaying enhanced optimization performance.

11:00am **PDN Noise-Jitter Co-Optimization using Physics-Assisted Genetic Algorithm** 526
Li Jiang, Ling Zhang, Er-Ping Li
Zhejiang University, China

SIPI BEST STUDENT PAPER SEMI-FINALIST

Abstract: Determining the selection of decoupling capacitors (decaps) in power distribution networks (PDNs) is essential to co-designing signal integrity (SI) and power integrity (PI) for high-speed integrated circuits, but it usually requires a long optimization time. This article proposes an efficient decap optimization method for PDN noise-jitter co-optimization with a physics-assisted genetic algorithm (GA). The proposed method can efficiently minimize the number of decaps to simultaneously reduce the power supply induced jitter (PSIJ) and PDN transient noise. Firstly, an initial solution is quickly determined by adding decaps sequentially and evaluating the PSIJ and transient noise through an analytical calculation approach. Secondly, a physics-assisted GA is adopted to continuously improve the solution quality. Instead of using the analytical calculation method, Hspice simulation is adopted to evaluate the PSIJ and transient noise more accurately during the second-stage optimization. The validation result shows that the proposed method can efficiently minimize the decap number and reliably achieve the target PSIJ and transient noise. The proposed method demonstrates a remarkably better performance than the existing GA regarding solution quality and time efficiency.

11:30am **Behavior Model of a Multiphase Voltage Regulator Module with Rapid Voltage Drop Protection** 532
Junho Joo[1], Hanyu Zhang[1], Hanfeng Wang[2], Wei Shen[2], Zhigang Liang[2], Lihui Cao[2], Seungtaek Jeong[2], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]Google Inc., USA

SIPI BEST STUDENT PAPER SEMI-FINALIST ANDBEST PAPER FINALIST

Abstract: In this paper, a modeling method of voltage regulator module (VRM) with rapid voltage drop protection is introduced. The proposed VRM model captures a pulse-width modulation scheme developed to counteract substantial load currents with high di/dt, resulting in a large voltage drop across the power delivery network (PDN). The equations to describe the non-linear behavior associated with the multiphase VRM behavior are proposed and successfully validated for both light and heavy loads, the latter being particularly crucial to trigger the voltage drop protection measures.

ES01-1 Exemplary Paper #1

Technical Papers **10:30am - 12:00pm**
Room: 129A
Chair: Frank Gronwald, *Universitat Siegen Fakultat IV Naturwissenschaftlich-Technische Fakultat, Siegen, Germany*

Session Abstract: Back for the second year at the EMC+SIPI Symposium, authors of already published exemplary papers have been invited to present their work to the IEEE EMC & SPI community. All of the selected exemplary papers are either award-winning, heavily cited, frequently downloaded, or of great practical value. Attendees of this session have the possibility to directly interact with high quality authors and to experience an interesting mix of different EMC & SPI topics. Presenting authors and the audience are encouraged to interact with each other and to initiate discussions and new ideas for future work.

10:30am **Echo TEMPEST: EM Information Leakage Induced by IEMI for Electronic Devices**
Presenting Author: Yuichi Hayashi
Kaji, S., Fujimoto, D., Kinugawa, M., & Hayashi, Y. (2023)

Citation: S. Kaji, D. Fujimoto, M. Kinugawa and Y. Hayashi, "Echo TEMPEST: EM Information Leakage Induced by IEMI for Electronic Devices," in IEEE Transactions on Electromagnetic Compatibility, vol. 65, no. 3, pp. 655 – 666, June 2023, doi: 10.1109/TEMC.2023.3252636.

11:00am **Predicting Statistical Wave Physics in Complex Enclosures: A Stochastic Dyadic Green's Function Approach**
Presenting Author: Zhen Peng
Lin, S., Luo, S., Ma, S., Feng, J., Shao, Y., Drikas, Z.B., Addissie, B.D., Anlage, S.M., Antonsen, T., & Peng, Z. (2023)

Citation: S. Lin, S. Luo, S. Ma, J. Feng, Y. Shao, Z.B. Drikas, B.D. Addissie, S.M. Anlage, T. Antonsen and Zhen Peng, "Predicting Statistical Wave Physics in Complex Enclosures: A Stochastic Dyadic Green's Function Approach," in IEEE Transactions on Electromagnetic Compatibility, vol. 65, no. 2, pp. 436 – 453, April 2023, doi: 10.1109/TEMC.2023.3234912.

11:30am **Mode-Decomposition-Based Equivalent Model of High-Speed vias up to 100 GHz**
Presenting Author: DongHyun Kim
Li, C., Cai, K., Ouyang, M., Gao, Q., Sen B., & Kim, DH. (2023)

Citation: C. Li, K. Cai, M. Ouyang, Q. Gao, B. Sen and DH. Kim, "Mode-Decomposition-Based Equivalent Model of High-Speed Vias up to 100 GHz," in IEEE Transactions on Signal and Power Integrity, vol. 2, pp. 74 – 83, doi: 10.1109/TSIPI.2023.3268255.

SC5-2 Modeling of Wireless Power Transfer Systems (Sponsored by SC-5)

Technical Papers **1:30pm - 3:00pm**
Room: 127A
Chair: Shuo Wang, *University of Florida, Gainesville, FL, USA*
Co-Chair: Chulsoon Hwang, *Missouri University of Science and Technology, Rolla, MO, USA*

1:30pm **Enhancing Efficiency and Robustness in Bi-Directional Wireless Power Transfer via CLLLC Resonant Networks** 537
Babatunde Soyoye, Indranil Bhattacharya, Mary Vinolisha Antony Dhason
Tennessee Technological University, USA

Abstract: Wireless power transfer (WPT) is a rapidly developing field, and strong and efficient systems are essential, especially for bi-directional applications. In this study, the performance of a CLLLC resonant network in a bi-directional WPT system is analyzed and its implementation is explored. We find that the CLLLC network achieves soft-switching capabilities and improves voltage regulation, load adaptability, and provides a considerable improvement in phase shift control and resonant frequency regulation. To build a resonant inverter with a 60kW output, we carefully tune the system parameters using Fundamental Mode Analysis. A noteworthy 90.4% efficiency in power transfers from the grid to the car and from the vehicle to the grid is confirmed by the simulation. The results highlight the advantages of using CLLLC networks and possible drawbacks, demonstrating their superiority in efficiency and system adaptability when compared to traditional LLC converters.

2:00pm **An Equivalent Coil Model of a Wireless Power Transfer System Including Eddy Loss** 544
Hanyu Zhang, Daryl Beetner
Missouri University of Science and Technology, USA

Abstract: A wireless power transfer (WPT) system suffers from eddy loss if a conductive object is placed near the coupling coil. In this paper, a 3-coil equivalent circuit model for the coupling coil in a WPT system is proposed for analyzing the eddy loss due to nearby conductors. This model uses a third coil with inductive coupling to the original transmitting and receiving coils to model the eddy loss. The proposed model was validated by comparing the Z-parameters with a full-wave simulation and showing good correlation over the frequency of interest, where the traditional 2-coil model fails. The 3-coil model is compared with the Steinmetz equivalent circuit model and shows better accuracy in terms of efficiency simulation. This proposed model can be used in efficiency analysis and design optimization of a WPT system.

2:30pm **Radiated Emission Modeling of a Wireless Power Transfer System** 550

Hanyu Zhang[1], Guanghua Li[2], Viswa Pilla[2], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]Apple Inc., USA

EMC BEST PAPER FINALIST

Abstract: A radiated emission (RE) model of a wireless power transfer (WPT) system is proposed in this paper to help designers predict, analyze, and mitigate the RE issues during the design process. The proposed model employs both full-wave simulation and circuit simulation to derive a transfer function. Subsequently, it predicts the emission level by combining the transfer function with the measured transmitter waveform through a straightforward calculation. The predicted emissions match the measured RE peaks well up to 300 MHz, with the error within 3 dB. The impact of functional parameters, such as load and coil gap distance, is analyzed based on the proposed model.

SS04-2 Stochastic Electromagnetics #2 (Sponsored by TC-4)

Special Session **1:30pm - 3:00pm**
Room: 127C
Chair: Paul Bremner, *Robust Physics, Del Mar, CA, USA*
Co-Chair: Evelyn Dohme, *Sandia National Laboratories, Albuquerque, NM, USA*

Session Abstract: Many design challenges in EMC and Signal Integrity involve complexity and uncertainty that can only be quantified statistically. Reverberation chamber testing in EMC; bit error rate (BER) metric for signal integrity (SI) and RMS delay spread in 5G/6G wireless are examples. Stochastic Electromagnetics encompasses both probabilistic simulation methods and supporting statistical testing methods that are rapidly evolving to reliably address these challenges. This special session will highlight new developments in emerging Stochastic Electromagnetics, such as stochastic power balance, random coupling modeling, and stochastic Green's function analysis. The scope of this session encompasses all aspects of stochastic EMC methods, including novel theoretical developments, practical implementation and complexity analysis, and experimental validation.

1:30pm **Statistical Analysis of Electromagnetic Coupling to Printed Circuit Boards** 556

Shengxuan Xia, Victor Khilkevich, Daryl Beetner
Missouri University of Science and Technology, USA

Abstract: Determining electromagnetic (EM) coupling to printed circuit boards (PCBs) is essential to finding potential EM susceptibilities early in the design process. For realistic PCB structures, analysis usually relies heavily on time-consuming full-wave simulations because of the complexity of the geometries and the lack of analytical solutions. In this paper, we adopt a segmentation approach based on far-field reciprocity which allows for rapid estimation of the voltage induced at trace terminations over frequency, and which is then used to estimate statistical characteristic of coupling across trace geometries. Frequency-domain results can then be used to estimate time-domain responses with appropriate transformations. Super-position is then used to separate the coupling contributed by different PCB structures, which provides better insight into the mechanisms responsible for susceptibility.

2:00pm **Three Coupling Models Compared in a Distributed Port** 557

E.A.D. Dhombridge[1], T.W. Hussey[2], Z.V. Peng[3], P. Bremner[4], E. Schamiloglu[2]
[1]Sandia National Laboratories, USA; [2]The University of New Mexico, USA;
[3]University of Illinois at Urbana-Champaign, USA; [4]RobustPhysics, USA

Abstract: It is well known that electromagnetic fields in overmoded high Q cavities are difficult to characterize deterministically because of extreme sensitivity to small variations in boundary conditions. The acoustics community first explored a variant of this problem where, in the highly overmoded limit, the distribution of pressure within a room could be characterized statistically.

2:30pm **Extended Resistance Matrix Formulation for Radiation Coupling of a Multi-Conductor Transmission Line** 558

Weitao Dai, Paul G. Bremner
RobustPhysics, USA

Abstract: This paper proposes a method to extend the resistance matrices of multi-conductor transmission lines (MTL) to model shields. The imperfect shielding effectiveness is modeled with transfer impedance. The radiated emission and susceptibility of quite general MTLs are found to require a full non-diagonal matrix. The full equations with radiation resistance terms, ohmic resistance terms, and shield transfer impedance are derived. The resulting model is validated against published test data.

TC12-2 Wireless Coexistence (Sponsored by TC-12)

Technical Papers **1:30pm - 3:00pm**

Room: 128A

Chair: DongHyun (Bill) Kim, *Missouri University of Science and Technology College of Engineering and Computing, Rolla, MO, USA*

1:30pm **On Comparing Interference Impacts** 559

Aric Sanders[1], Michelle Pirrone[1,2], M. Keith Forsyth[1], Adam Wunderlich[1]
[1]National Institute of Standards and Technology, USA; [2]University of Colorado Boulder, USA

Abstract: Interference between communication systems is a critical issue that can impact performance and operability of devices. A wide range of methods and testbeds have been developed to study susceptibility to interference, and each of these testbeds and their experimental test schedules can have different factors and responses. Although there is a variety in testbed design and measurement, it is common to choose a response that is assumed to vary with signal-to-noise ratio. A fundamental issue in any interference study of this type is the assignment of the power of the interference signal in a way that represents the desired environmental situation. This can be a challenging task for signals with disparate time, frequency and power dynamics. In particular, whether to assign a maximum (peak power) or a time averaged power becomes ambiguous for inter-interference signal comparisons. To address this problem we propose a quantitative scale based on the impact on the receiver of interest. We demonstrate how to form an interference signal agnostic scale and apply that scale for different interference situations. This scale, impact equivalent power ratio, can be transformed into an impact equivalent power with knowledge of the effective noise figure of the system under test.

2:00pm **Coexistence Testing: Comparing Conducted and Radiated Test Results** 564

Susanna Mosleh[1], Nadia P. Yoza-Mitsuishi[1], Jason B. Coder[1], Carl B. Sunderman[2]
[1]National Institute of Standards and Technology, USA;
[2]National Institute for Occupational Safety and Health, USA

Abstract: In an era of ubiquitous wireless devices, ensuring their coexistence in shared electromagnetic environments has become increasingly critical. This paper explores the dynamics of coexistence testing and compares two coexistence test environments outlined in the ANSI/USEMCSC C63.27 standard: conducted and radiated-anechoic. The objective is to demonstrate how the results from two different test environments can be compared. We conducted a series of tests involving a commercial wireless Emergency Stop (E-Stop) system and IEEE 802.11 WLAN technology - two wireless technologies deployed in machine safety applications in industrial settings, including the mining sector. These tests provide insights into how the different testing environments can influence the outcomes of coexistence tests and how one can compare the results between two different test environments. The paper also presents an overview of general coexistence testing procedures.

TC10-11 High-Speed Interconnects (Sponsored by TC-10)

Technical Papers **1:30pm - 3:00pm**
Room: 128B
Chair: Tao Wang, *Missouri University of Science and Technology, San Diego, CA, USA*
Co-Chair: Thanh Tran, *Rice University, Houston, TX, USA*

1:30pm **Signal Integrity Comparison of Commercially Available Sockets for the 50Gbps Ethernet Channel** 570
Nupur Basak, Oluwafemi Akinwale, Michael E. Ryan
Intel Corporation, USA

Abstract: As the demand for data center networking bandwidth proliferates, improving the test sockets available in the market is imperative. This paper looks at two commercially available sockets, the elastomer and pogo pin sockets, to investigate the feasibility of Ethernet speeds of 50 Gbps and beyond. 3D FEM (Finite Element Modeling) Ansys HFSS software, along with COM (Channel Operating Margin), is used to evaluate the performance delta between socket-less, elastomer, and pogo-pin sockets. The results show that the elastomer socket performs similarly to the socket-less case and is transparent during channel analysis despite additional components in the channel path. The pogo pin socket has only a slight performance degradation due to the resonance interaction between the pin and channel.

2:00pm **Mitigation of Fiber Weave Induced Intra-Pair Skew for Differential Signaling at 64Gbps and Above** 575
Chenghai Yan, Xinjun Zhang, Weizhe Li, Xiaoning Ye, Vijay Kunda, Yi Amy H. Luoh, Luis E. Rosales Galvan, Octavio Miramontes
Intel Corporation, USA

Abstract: Despite the use of multiple mitigation technologies, new challenges arise in the latest server systems to control the intra-pair skew induced by the fiber weave effect when I/O speeds are upgraded to 64Gbps. CuMax and jogged routing are two new mitigation methods proposed in this paper. CuMax can reduce the total intra-pair skew to less than 1ps, while the jogged routing can reduce the largest intra-pair skew by two-thirds. The design guidelines for the impact of the intra-pair skew with mitigation on PCIe 6.0 running at 64Gbps are also discussed.

2:30pm **Identification of Bandwidth Requirements for Channel Optimization at 200 Gbps** 580
Rick Rabinovich[1], Richard Mellitz[2], Mike Resso[1], Francesco de Paulis[3]
[1]Keysight Technologies, USA; [2]Samtec Corporation, USA; [3]University of L'Aquila, Italy

Abstract: With the advent of higher bit rates such as 200 Gb/s PAM4, it is necessary to determine the minimum frequency range required to fully characterize electrical channels and still keep accurate results consistent with the simulation models. This paper dives into the relationship between this range of interest and the receiver equalization input filter. The authors will present the different options available at the standard bodies to agree on a convenient middle ground between “pure science” and “practical world”. The Channel Operating Margin (COM) will be utilized to document the findings.

TC3 Data Analysis in Electromagnetic Environments

Technical Papers **1:30pm - 2:30pm**
Room: 125AB
Chair: Randy Jost, *Utah State University, Hyde Park, UT, USA*

1:30pm **Estimating Radiated Emissions from Device Cabling using Common-Mode Current Measured at a Single Point** 581
Hamidreza Karami[1], Marcos Rubinstein[1], Melina Bouldi[2], Christophe Perrenoud[2], Pascal Kraehenbuehl[2]
[1]University of Applied Sciences Western Switzerland, Switzerland; [2]Federal Office of Communications Electromagnetic Compatibility Section, Switzerland

2:00pm **Visual Space-Time Complexity Analysis of Big Signal Data** 585
Jan Nemec, Stanislav Kovar, Jan Valouch, Milan Adamek
Tomas Bata University in Zlin, Czechia

Abstract: This paper will focus on introducing visual analysis for big signal data suitable for preliminary conclusions and information presented to others. The analysis is to determine uniqueness, focusing on spatial-temporal complexity by the nature of the test data. Alongside introducing the analysis and optimization for programming purposes, the real data will be presented and used to display possible usage of this analysis and to determine the uniqueness of electromagnetic background for the possible use in true random number generators. The data consists of measurements in frequency band increments in many locations using widely available consumer-grade equipment. Visual analyses are especially valuable in situations like search for entropy sources because there is no immediate need for a concrete number or boolean statement of the uniqueness; moreover, presenting work is the daily job of a researcher, and the ability to visualize findings in a simple figure is easier to digest by the wider population.

ES01-2 Exemplary Paper #2

Technical Papers **1:30pm - 2:30pm**
Room: 129A
Chair: Frank Gronwald, *Universitat Siegen Fakultat IV Naturwissenschaftlich-Technische Fakultat, Siegen, Germany*

Session Abstract: Back for the second year at the EMC+SIPI Symposium, authors of already published exemplary papers have been invited to present their work to the IEEE EMC & SPI community. All of the selected exemplary papers are either award-winning, heavily cited, frequently downloaded, or of great practical value. Attendees of this session have the possibility to directly interact with high quality authors and to experience an interesting mix of different EMC & SPI topics. Presenting authors and the audience are encouraged to interact with each other and to initiate discussions and new ideas for future work.

1:30pm **An Approach to Identify Noise-Source Parameters of DC-DC Converter and Predict Conducted Emissions with Different Loads**
Presenting Author: Yoshitaka Toyota
Zhang, S., Iokibe, K., & Toyota Y. (2023)

Citation: S. Zhang, K. Iokibe, and Y. Toyota, "An Approach to Identify Noise-Source Parameters of DC–DC Converter and Predict Conducted Emissions With Different Loads," in Letters on Electromagnetic Compatibility Practice and Applications , vol. 5, pp. 5 – 9, March 2023, doi: 10.1109/LEMCPA.2022.3228199.

2:00pm **Electric Field Probe De-Embedding Calibration based on Through and Line Standards**
Presenting on behalf of the Authors: Yuandong Guo
Xue, S., Yang, S., Shao, W., Tian, X., & Wu, D. (2023)

Citation: S. Xue, S. Yang, W. Shao, X. Tian and D. Wu, "Electric Field Probe De-Embedding Calibration Based on Through and Line Standards," in IEEE Sensors Journal, vol. 23, no. 7, pp. 6999 – 7007, April 2023, doi: 10.1109/JSEN.2023.3248863.

TC11 Nanotechnology and Advanced Materials (Sponsored by TC-11)

Technical Papers **2:30pm - 3:00pm**
Room: 125AB
Chair: Marina Koledintseva, *The Boeing Company, St. Charles, MO, USA*

2:30pm **Design and Manufacture of Periodic Metastructure Materials with Broadband EM Absorption** 591
Dandan Zhang[1], Steven Mamolo[1], Kanat Anurakparaorn[1,2], Eric Michielssen[1], Alan I. Taub[1]
[1]University of Michigan, USA; [2]King Mongkut's Institute of Technology Ladkrabang, Thailand

Abstract: Computational modeling and optimization were utilized to design the metastructure of a polymer nanocomposite system. The goal is to minimize the reflection loss (RL) and broaden the absorption bandwidth. Truncated cones with a perfect electric conductor on the top surface were chosen. With this innovative metastructure, the absorption bandwidth of RL at -20dB has been increased from 0, as observed in non-porous materials, to 1.83 GHz. The samples with optimized metastructures were manufactured using hot pressing and computer numerical control (CNC) machining techniques. This approach provided an efficient way to design and precisely manufacture materials with targeted EM absorption.

TC10&SC3 Applications of AI and Optimization Algorithms (Sponsored by TC-10)

Technical Papers **3:30pm - 5:00pm**
Room: 125AB
Chair: Hanfeng Wang, *Google Inc, Mountain View, CA, USA*

3:30pm **5G Base Station Electromagnetic Field Strength Estimation Method in Complex Hotspot Area using Deep Learning** 592
Dongryul Park[1], Seunghun Ryu[1], Seonghi Lee[1], Namwoo Kang[1], Seongsin Kim[2], Kihwea Kim[3], Donggeun Choi[3], Seungyoung Ahn[1]
[1]Korea Advanced Institute of Science and Technology, Korea; [2]Seongsill University, Korea; [3]National Radio Research Agency, Korea

Abstract: Recently, with the commercialization of 5G, a new electromagnetic field (EMF) evaluation methods is need. However, conventional EMF evaluation methods are only based on measurements that practically impossible to apply to 5G base station (BS). Therefore, in this paper, we propose a 5G BS EMF evaluation method using deep learning (DL) as an alternative to traditional measurement-based evaluation. We selects a U-net that can analyze the entire area based on the technical characteristics of 5G. Furthermore, we design a 2D and numeric converter to inform the physical information of the wireless channel to the U-net. Through network design based on technical features and physical information, the proposed DL model can effectively predicts the EMF radiated from BS. Then, we generate data through simulations that reflect real-world scenarios and use it for training. The results of the training show that the proposed method achieves very high accuracy in various cases, regardless of location and antenna specifications. Furthermore, when quantitatively evaluated, the proposed method only have an 8\% low mean absolute error (MAE), thus demonstrating the superiority of the proposed method. These verification results confirm that the potential of the proposed method can replace EMF evaluations based on measurements with DL-based evaluations in the future.

4:00pm **Reinforcement Learning-Based Power/Ground Ball Map Design Optimization for Multi-Power Domain in 3D-ICs Package** 598

Seunghun Ryu, Dongryul Park, Hyunwoong Kim, Seonghi Lee, Sanguk Lee, Seungyoung Ahn
Korea Advanced Institute of Science and Technology, Korea

SIPI BEST PAPER FINALIST AND BEST STUDENT PAPER SEMI-FINALIST

Abstract: In this paper, the reinforcement learning-based power/ground ball map design optimization methodology is proposed for 3D-ICs package in multi-power domain environments. Multi-power domain forms diverse levels of simultaneous switching noise (SSN) in the complicated form; accordingly, power integrity design becomes more complex than a single power domain. The ball grid array (BGA) is one of the most challenging areas in terms of power integrity design optimization due to a large number of solder balls, multiple domains, and the condition of confined space. Here, the reinforcement learning algorithm is adopted with a deep learning network to optimize the power/ground ball map so that overall SSNs can be minimized. To deal with the sequential action decision problem, Markov decision process (MDP) is designed and the analytical modeling of the power/ground ball map is implemented to establish learning environment. The proposed method successfully optimizes the power/ground ball map, and shows superior optimization performance to conventional optimization algorithms.

TC12-3 Wireless System Measurement/Testing (Sponsored by TC-12)

Technical Papers **3:30pm - 5:00pm**

Room: 128A

Chair: Lie Liu, *Xidian University, Shenzhen, China*

Co-Chair: Gang Feng, *Christie Digital Systems Canada Inc, Waterloo, ON, Canada*

3:30pm **A Method for Eliminating the Phantom Shell Effect using Negative Permittivity Material in Absorbed Power Density Measurement** 604

Changmin Lee[1], Jaewon Rhee[1], Seonghi Lee[1], Hyukchoon Kwon[2], Yongho Park[2], Yujun Shin[3], Seungyoung Ahn[1]
[1]Korea Advanced Institute of Science and Technology, Korea; [2]Samsung Electronics, Korea; [3]Keimyung University, Korea

Abstract: In this paper, we propose a method for eliminating the phantom shell effect using negative permittivity material. The absorbed power density (APD) distribution in the phantom provided by IEC TC 106 is analyzed for the effects of changes in the dielectric characteristics of the phantom shell. The effect of the phantom shell is calculated and analyzed through absorbed power density using the finite-difference time-domain (FDTD) method in the 6-10 GHz. Similar to the existing SAR (Specific Absorption Rate) measurement method, the measurement of the APD requires the presence of the equivalent human tissue model. To measure APD, it is necessary to have not only a phantom but also a phantom shell to contain the phantom liquid. Furthermore, with the increasing communication frequency bands of 5G and 6G, an analysis that reflects the dielectric properties of both the phantom and the phantom shell is required during the actual APD measurement process. A problem arises due to the relative permittivity of the phantom shell, which can lead to the overestimation of APD reaching the phantom. This paper utilizes an impedance model to calculate and analyze the impact of the phantom shell and we propose a method to reduce its effect using negative permittivity material. The APD results are compared with and without the shell and with the proposed method. The proposed method is validated through 3D electromagnetic (EM) simulations.

4:00pm **OTA Measurement of UWB Handhold Devices** 608

X. Wang[1], L. Liu[1,2], D. Shang[1], F. Yu[1]
[1]General Test Systems, China; [2]Xidian University, China

Abstract: The ultra-wide broadband (UWB) handhold devices were measured with compact over-the-air (OTA) test systems. The key technical index like time of flight (TOF) and arrival angle (AOA) were obtained with compact OTA chamber and communication tester with function kits. The measurement uncertainty may be attributed to the reflection of anechoic chamber or the multiple path effect of the environment.

4:30pm **Low Noise Wireless Sensing in Termite Detection** 609

Wei Zhang[1], Xiangshu Qi[1], Yunlong Luo[2], Alex Qi[3], Yihong Qi[2,3,4], Gang Feng[5]
[1]Changsha University, China; [2]Southwest Jiaotong University, China; [3]Pontosense Inc., Canada; [4]Missouri University of Science and Technology, USA; [5]Christie Digital Systems Canada Inc., Canada

Abstract: Termites cause enormous financial damages all around the world every year. The majority of research on wireless sensing is always concerned with the various human-centric applications, however, the vast potential of wireless sensing for termite detection is often disregarded. In this article, a Wireless Intelligent Sensing (WISe) millimeter-wave (mmWave) radar system for termite detection is proposed. Here, we design a three-layer architecture with some intelligent resources to monitor the movement signs of the termites. In addition, we present a low noise sensing architecture that minimizes the noise in hardware and digital signal processing, which can reduce the impact of environment factors on termite detection. Experimental results demonstrate that, the proposed system is capable of detecting termites and differentiating them from other insects.

TC10-10 Crosstalk, Jitter, Noise Coupling, BER Analysis #2 (Sponsored by TC-10)

Technical Papers **3:30pm - 5:00pm**

Room: 128B

Chair: Songping Wu, *Rivos Inc., Mountain View, CA, USA*

Co-Chair: DongHyun (Bill) Kim, *Missouri University of Science and Technology, College of Engineering and Computing, Rolla, MO, USA*

3:30pm **DB-KBNN based Approach for PSIJ Analysis with a Comparative Study of Energy Models** 613

Ahsan Javaid[1], Ramachandra Achar[1], Jai Narayan Tripathi[2]
[1]Carleton University, Canada; [2]Indian Institute of Technology Jodhpur, India

SIPI BEST PAPER FINALIST

Abstract: An efficient hybrid neural network method for handling multiple noise sources, including the power supply noise, input data noise, and the ground bounce noise in a power integrity analysis is presented. The proposed hybrid model, combination of deep belief and knowledge-based neural networks, provides reasonable accuracy for PSIJ response using training data from semi-analytical models as well as a circuit simulator. Also, a comparative study of different energy models in generating an optimal training data set is presented.

4:00pm **Nonparametric Crosstalk Evaluation Method using the Kolmogorov-Smirnov Test** 617

Beatrice Jiang[1], Ping Li[2]
[1]Westlake High School, USA; [2]Shanghai Jiao Tong University, China

Abstract: Evaluating the crosstalk level in a system is essential for signal integrity in high-speed systems. A rarely discussed question is whether it is possible to determine if a contaminated signal's crosstalk level is acceptable or not without knowing the system's network parameters. This paper introduces a novel approach using the goodness-of-fit method, specifically the two-sample Kolmogorov-Smirnov Test (K-S Test). The K-S Test is a nonparametric method used to test the null hypothesis between two samples. For crosstalk analysis, the K-S Test is applied to a reference signal and another signal that may contain crosstalk. The resulting K-S statistic indicates the maximum discrepancies in the empirical cumulative distribution functions (CDF) of two tested signals. This statistic is then compared to a threshold based on the statistical significance level α to determine whether to reject the null hypothesis. Accepting the null hypothesis implies that the crosstalk noise in the contaminated signal is within acceptable limits, and so the original signal and the contaminated signal are not significantly different. The comparison threshold can be further calibrated to meet the specific crosstalk requirements of practical applications. The results demonstrate that the proposed method is effective and reliable in determining the crosstalk level for both ideal sinusoidal and practical PRBS signals.

Abstract: The far-end crosstalk (FEXT) from socket pins and motherboard Plated-through-hole (PTH) vias is a major signal integrity performance limiter, especially for crosstalk sensitive single-ended memory signals. A novel passive crosstalk reduction feature called coupled via is proposed to effectively mitigate the risk. This paper demonstrates an on-package implementation of the coupled via concept within existing substrate design rule and cost boundary conditions. The benefits of coupled via was verified through modeling and validation data and it has been adopted for multiple generations of Intel's CPU products.

SC5-3 EMI Mitigation in Wearable Devices and EV Drives (Sponsored by SC-5)

Technical Papers **3:30pm - 4:30pm**

Room: 127A

Chair: Chulsoon Hwang, *Missouri University of Science and Technology, Rolla, MO, USA*

Co-Chair: Sebastian Koj, *Jade Hochschule, Wilhelmshaven, Germany*

Abstract: In the rapidly growing market of wearable wireless audio devices, consumer expectations for comfort, functionality, and sound quality are rising. These demands introduce complex challenges in electromagnetic compatibility (EMC) design, primarily due to increased multifunctionality leading to more sensitive components and interference sources, diversified industrial designs complicating internal layouts, and the necessity for miniaturization which intensifies component interference. This paper presents a focused study on True Wireless Stereo (TWS) earbuds, offering a novel methodology for EMC design to mitigate current noise issues caused by electromagnetic interference, particularly from power inductors. By proposing a new symmetric magnetic field lines guidance method validated through comprehensive analysis and simulations, this study contributes an effective solution for enhancing EMC in wearable audio devices.

SS04-3 Stochastic Electromagnetics #3 (Sponsored by TC-4)

Special Session **3:30pm - 4:30pm**

Room: 127C

Chair: Paul Bremner, *Robust Physics, Del Mar, CA, USA*

Co-Chair: Evelyn Dohme, *Sandia National Laboratories, Albuquerque, NM, USA*

Session Abstract: Many design challenges in EMC and Signal Integrity involve complexity and uncertainty that can only be quantified statistically. Reverberation chamber testing in EMC; bit error rate (BER) metric for signal integrity (SI) and RMS delay spread in 5G/6G wireless are examples. Stochastic Electromagnetics encompasses both probabilistic simulation methods and supporting statistical testing methods that are rapidly evolving to reliably address these challenges. This special session will highlight new developments in emerging Stochastic Electromagnetics, such as stochastic power balance, random coupling modeling, and stochastic Green's function analysis. The scope of this session encompasses all aspects of stochastic EMC methods, including novel theoretical developments, practical implementation and complexity analysis, and experimental validation.

3:30pm **Chassis-Integrated Mode Stirring for Statistical Shielding Effectiveness Characterization** 630

Jon W. Wallace

Sandia National Laboratories, USA

Abstract: Characterizing shielding effectiveness (SE) of enclosures is important in aerospace, military, and consumer applications. Direct SE measurement of an enclosure or chassis may be considered an exact characterization, but there are several sources of possible variability in such measurements, e.g., mechanical tolerances, the absence of components during test that exist in a final assembly, movement of components and cables, and perturbations due to probes and associated cabling. We explore internal stirrers as a way to quantify variability and sensitivity of an SE measurement, not only indicating the uncertainty of the SE measurement, but also delineating frequency ranges where either deterministic or statistical simulations should be applied.

4:00pm **Statistical Comparison of Time- and Frequency-Domain Measurements for Cylindrical Cavities** 631

Saif Mostafa[1], Charles F. Bunting[1], Mazin M. Mustafa[1], Mostafa Ibrahim[3], Paul Bremner[2], Reza Afra[2], James C. West[1]

[1]Oklahoma State University, USA; [2]RobustPhysics, USA; [3]Texas A&M University, USA

Abstract: The efficacy of direct time-domain measurements is compared to frequency-domain measurements in the characterization of a cylindrical, reverberant cavity within frequencies ranging from 1 GHz to 3.69 GHz. Considered is the agreement and challenges posed by both methods rather than exclusively focusing on the advantages relative to their alternatives. Moreover, the inquiry undertaken is expected to result in a robust alignment between the investigated experimental methods, demonstrating that the frequency domain is not necessarily more accurate than the time domain, but is nonetheless reliable and satisfactory.

ES01-3 Exemplary Paper #3

Technical Papers **3:30pm - 4:30pm**

Room: 129A

Chair: Frank Gronwald, *Universitat Siegen Fakultat IV Naturwissenschaftlich-Technische Fakultat, Siegen, Germany*

Session Abstract: Back for the second year at the EMC+SIPI Symposium, authors of already published exemplary papers have been invited to present their work to the IEEE EMC & SPI community. All of the selected exemplary papers are either award-winning, heavily cited, frequently downloaded, or of great practical value. Attendees of this session have the possibility to directly interact with high quality authors and to experience an interesting mix of different EMC & SPI topics. Presenting authors and the audience are encouraged to interact with each other and to initiate discussions and new ideas for future work.

3:30pm **Impact of Parasitic PCB and EMI Filter Inductances on System-Level ESD Protection**
Presenting Author: Andreas Hardock
Mergens, M., Bub, S., Seider, S., Holland, S., Hardock, A., & Schütt, J. (2022)

Citation: M. Mergens, S. Bub, S. Seider, S. Holland, A. Hardock and J. Schütt, „Impact of Parasitic PCB and EMI Filter Inductances on System-level ESD Protection," in Proceedings of the 17th ESD Forum 2022, Dresden, Germany.

4:00pm **Practical SI EM Simulator using Neural Language Models**
Presenting Author: Chulsoon Hwang
Park, H., Ding, Y., Zhang, L., Bondarenko, N., Ye, H., Achkir, B., & Hwang, C. (2024)

Citation: H. Park, Y. Ding, L. Zhang, N. Bondarenko, H. Ye, B. Achkir and C. Hwang, "Practical SI EM Simulator using Neural Language Models," in Proceedings of DesignCon 2024, Santa Clara, CA, USA

TC5-2 Immunity and EM Info Leakage (Sponsored by TC-5)

Technical Papers **4:30pm - 5:30pm**

Room: 127A

Chair: Yuichi Hayashi, *Nara Sentan Kagaku Gijutsu Daigakuin Daigaku Joho Kagaku Kenkyuka, Ikoma, Japan*

Co-Chair: William Radasky, *Metatech Corporation, Goleta, CA, USA*

4:30pm **Experimental Study of Radiated Immunity Impact Analysis due to Conventional and Broadband Signal Sources** 637
GyeongRyun Choi[1], Younggi Hong[1], Taewook Kwon[1], Hongsik Keum[2], Se-eun Park[3], Wansoo Nah[1]
[1]Sungkyunkwan University, Korea; [2]E&R, Korea; [3]National Radio Research Agency, Korea

Abstract: The radiated immunity standard IEC 61000-4-41, which utilizes orthogonal frequency division multiplexing (OFDM) signal sources to address the drawbacks of existing immunity test signal sources such as IEC 61000-4-3, 61000-4-39 and ISO 11452-1, is currently being developed. This study was conducted to compare and analyze the impact of existing test signal sources and OFDM signal sources on the EUT. Various signals, including continuous wave(CW), amplitude modulation(AM), pulse modulation(PM), and an OFDM signal within the 20 MHz bandwidth, were used for RI tests at a 1 meter distance from the antenna to the EUT. Comparing the impact of each signal based on the immunity level as a reference parameter, it is revealed that the OFDM signal had the lowest immunity level across most of the frequency ranges. During the immunity test, CE in the low-frequency range (9 kHz to 30 MHz, CISPR standard) were also measured using a LISN. When malfunctions occurred in the EUT, it was observed that the CE spectrum remained almost unchanged up to 20 MHz, but the CE spectrum changed quite a lot with malfunctions, especially in the frequency range from 20 MHz to 30 MHz.

5:00pm **Information Leakage of a Quantum Receiver based on Polarization of EM Radiated Emissions** 642

John J. Pantoja, Dimitris Anagnostou, Ross Donaldson
Heriot-Watt University, United Kingdom

Abstract: In this contribution, a side-channel attack based on the polarization of radiated emissions is presented. Results show that the particular orientation of electronic components lead to radiated emissions with different polarizations that can be used for side-channel attacks.

FRIDAY – AUGUST 9, 2024

WT20 EMC in Power Electronics: Electrical Systems and Electrical Transport (Sponsored by TC-7)

Tutorial **8:30am - 12:00pm**

Room: 125AB

Co-Chair: Niek Moonen, *Universiteit Twente, Enschede, Netherlands*

Co-Chair: Sebastian Koj, *Jade Hochschule, Wilhelmshaven, Germany*

Session Abstract: Before electrical energy can be made available at the point of use, it must be distributed, converted, and regulated. This is the task of power electronics. Their importance will continue to increase because the share of electrical energy in primary energy consumption will increase massively due to the energy transition and growing digitalization. Regardless of the area of application - automotive, aerospace, electrical energy supply - power electronics always brings challenges with regard to electromagnetic compatibility. In this tutorial, the different areas of application of power electronics and the resulting requirements for electromagnetic compatibility as well as methods for controlling them are presented, explained and discussed.

Introduction to EMC in Power Electronics and Systems

Niek Moonen
Universiteit Twente, Netherlands

Abstract: Before electrical energy can be made available at the point of use, it must be distributed, converted and regulated. This is the task of power electronics. Their importance will continue to increase because the share of electrical energy in primary energy consumption will increase massively due to the energy transition and growing digitalization. Regardless of the area of application - automotive, aerospace, electrical energy supply - power electronics always brings challenges with regard to electromagnetic compatibility. In this tutorial, the different areas of application of power electronics and the resulting requirements for electromagnetic compatibility as well as methods for controlling them are presented, explained and discussed.

DC-DC Converter as Educational and Research Platform

Sebastian Koj, Alexandra Burger, Jens Werner, Karsten Schubert
Jade University of Applied Sciences, Germany

Abstract: A challenge in higher education for engineers today is to provide students with practical experience in implementing and designing controls. This requires concrete practical applications. One of these applications is the design of EMC-compliant control strategies for step-down converters (DC-DC converters). The advantage of this application is that different specialist areas overlap and, in addition to the practical aspect, interdisciplinarity is also brought to the fore. This talk presents an open teaching and research platform based on FPGA, which enables the application of various control strategies and an assessment of their influence on the EMC properties. In addition, this newly developed platform enables the analysis and comparison of different strategies for achieving EMC requirements in the development process as well as their effects on the performance of the controller. The novelty of this work lies in the fact that the circuit presented creates a flexible teaching and research platform with which students can excellently experience and deepen the interconnection of control technology, EMC, computer science, system theory and power electronics in practice.