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TU-AM-D EMC Assessment and EMI Modelling for Electrical and Electronic Devices in the Low-Frequency Range

Technical Papers (Special Session) **10:30am - 12:00pm**

Room: Gallery Overlook D

Co-Chair: Erjon Ballukja, *University of Nottingham, United Kingdom*

Co-Chair: Karol Niewiadomski, *University of Nottingham, United Kingdom*

10:30am **A Flexible Black-Box Model for Conducted Emission Predictions with Different Switching Frequencies** 1

Lu Wan, Xinglong Wu, Xiaokang Liu, Flavia Grassi, Giordano Spadacini, Sergio A. Pignari

Politecnico di Milano, Italy

Abstract: Black-box modeling technique is an efficient approach to represent the electromagnetic interference behavior of power converters, whose presence may cause malfunctioning in adjacent electronic devices. Although developing a black-box model is simpler and less demanding than extracting an explicit circuit model, model effectiveness is limited to certain operating conditions, such as a fixed modulation strategy. In this work, a flexible black-box model is proposed, which can be effectively used for prediction also in case of different modulation conditions without requiring a new estimation of model parameters if modulation parameter (such as the switching frequency) changes. Flexibility is achieved by modeling time-domain noise waveforms using an analytical curve-fitting model or an autoregressive model, whose accuracy is compared in time and frequency domain. The proposed model is experimentally verified on a boost converter operated with different switching frequencies.

11:00am **A Statistical Approach to Predict the Low Frequency Common Mode Current in Multi-Converter Setups** 7

E. Ballukja[1], K. Niewiadomski[1], D.W.P. Thomas[1], S. Sumsurooah[1], M. Sumner[1], J. Bojarski[2]

[1]University of Nottingham, United Kingdom; [2]Uniwersytet Zielonogórski, Poland

BEST EMC PAPER FINALIST

Abstract: The aim of this paper is to explore a statistical approach to predict the distribution of the harmonics of common mode current in a setup consisting of N converters, knowing the common mode current for a single converter. To this end, we utilize Pearson's random walk approach in comparison with a simulation setup consisting of 4 DC/DC converters with their own DC sources. The two methods, compared with respect to a selected harmonic of the common mode current, show good agreement up to 10MHz – 501st harmonic of the 20kHz switching frequency. The arising mismatch could be due to limitations of our model as well as to computational errors.

11:30am **Design of Proportional-Resonant Control for Current Harmonic Compliance in Electric Railway Power Systems** 13

Iurie Nuca[1], Lu Wan[2], Petre-Marian Nicolae[1], Alexandru Netoiu[3], Augustin Popescu[3], Dusan Kostic[1], Flavia Grassi[2]

[1]University of Craiova, Romania; [2]Politecnico di Milano, Italy; [3]SC Softronic SA, Romania

Abstract: This paper presents the process of designing proportional-resonant controller for a four-quadrant rectifier in electric railway traction system. In the context of ever-stricter power quality and electromagnetic compatibility standards in electric railway power systems, developers of electric locomotives need to adapt with new ways to comply. This paper develops on the process of designing a four-quadrant rectifier proportional-resonant control for mitigation of low frequency current harmonic distortion, a novel method in the field of railway EMC. The control parameters are determined through analytical modeling of the rectifier through transfer functions. For the purpose of studying the harmonic distortion mitigation effects, only the current control loop was modeled and designed. The modeling starts with simplification of the model via large-signal modeling of the power converter. The parameters of the circuit then were used to develop the transfer functions, and select the appropriate parameter values of the current loop plant. The control loop and parameters were evaluated on test locomotive to validate the control, with results confirming the improved impact on the electromagnetic compatibility and conformity to regulation.

TU-ALL-E Computational Electromagnetics, Modeling and Simulation, Multi-Physics Techniques, Tools, and Applications (Sponsored by TC-9)

Technical Papers **10:30am - 5:30pm**

Room: Gallery Overlook E

Co-Chair: Yansheng Wang, *Rivos Inc., Santa Clara, CA, USA*
Co-Chair: Giulio Antonini, *Universita degli Studi dell'Aquila, L'Aquila, Italy*
Co-Chair: Shubhankar Marathe, *Amazon Lab126, Santa Clara, CA, USA*
Co-Chair: Jianmin Zhang, *Google Inc, Mountain View, CA, USA*

10:30am **Finite-Difference Time-Domain Study on the Influence of the Conductor Catenary in the Simulation of Lightning Surges** 18

Erika Stracqualursi, Rodolfo Araneo, Salvatore Celozzi
Universita degli Studi di Roma La Sapienza, Italy

Abstract: When accounting for the catenary shape, overhead power lines are non-uniform structures. Usually, the impact caused by the catenary on the transmission properties of the line is neglected. Hence, the line is simulated as uniform considering a constant equivalent height. In this paper, we investigate the impact of the catenary on induced overvoltages caused by direct and indirect lightning strokes. Employing a recently proposed implicit finite-difference time-domain code, we assess that the catenary may have a severe impact on the correct computation of the overvoltages. Finally, we outline the accuracy limits of the EMTP-RV software in conjunction with the LIOV module through an in-depth comparison.

11:00am **Roughness Losses Computation through the Partial Elements Equivalent Circuit Method** 23

Fabrizio Loreto[1], Daniele Romano[1], Giulio Antonini[1], Albert Ruehli[2], Mauro Lai[3]
[1]Universita degli Studi dell'Aquila, Italy; [2]Missouri University of Science and Technology, USA; [3]Microsoft Azure Perimeter Park, USA

Abstract: Conductor loss caused by conductor surface roughness is a critical aspect in the design of high-speed electronic systems since it significantly affects their performances. Well-established roughness models have been proposed over the years but they have been applied only to the transmission line models of interconnects. Typically the roughness models are used to modify the per-unit-length impedance of the transmission line which is extracted by 2D model methods. The aim of this work is to overcome this limitation thus making it possible to model roughness conductors in the framework of 3D full-wave methods. More precisely, it is presented how to incorporate roughness models in partial element equivalent circuits (PEEC) models. The concept of surface impedance allows a straightforward inclusion of roughness models in 3D full-wave PEEC models. Numerical results are presented for a microstrip line confirming the accuracy of the proposed approach compared to those obtained using standard TL models and a commercial tool.

11:30am **3-D Modeling and Characterization of Ferrite and Nanocrystalline Magnetic Cores for EMI Applications** 28

Rafael Suárez[1,2], María Tijero[1], Roberto Moreno[1], Aitor Arriola[1], Jose Manuel González[2]
[1]Ikerlan Technological Research Centre, Spain; [2]Universidad del Pais Vasco, Spain

BEST EMC PAPER FINALIST

Abstract: Toroidal ferrites and magnetic cores are a key part of electromagnetic compatibility (EMC). They are used in several applications as in power converters, low-power supplies, cables, etc. Therefore, it is crucial to properly characterize them for running 3-D simulations. Typically, complex magnetic permeability (CMP) is taken as the main property of the magnetic cores. In this paper the effect of CMP in simulation up to 100 MHz is investigated. The simulation spectrum has been separated into two regions, split by the resonance frequency, and simulations of several 3-D models with different CMP values are compared with their measurements in each of the regions. Three different magnetic cores are studied: two of them are used for common-mode chokes, while the other is used for interference suppression in wires. With regard to the material, two of them are ferrite cores while the other one is a nanocristalline core. Results show the major importance of CMP in 3-D simulation. However, above the resonance frequency, modeling with only CMP is not valid and other core-related effects as electric permittivity or conductivity must be considered.

1:30pm **Modeling of Imperfectly Shielded Coaxial Cables by Surface Conductivity Boundary Condition** 34

Mazin M. Mustafa[1], James C. West[2], Charles F. Bunting[1], Weitao Dai[2], Paul G. Bremner[2]
[1]Oklahoma State University, USA; [2]RobustPhysics, USA

Abstract: In this paper, we briefly discuss the validity of modeling imperfectly shielded transmission lines such as coaxial cables by a surface conductivity boundary condition. This approach is attractive for numerical simulations since it replaces the complex shielding structures by a homogenized surface boundary condition. We also present and validate a modified Coupled Transmission Lines model in order to introduce the surface conductivity representation, and show the equivalency with the surface transfer impedance. Numerical examples are provided to illustrate the effect of representing the cable's shield by a surface conductivity boundary condition on crosstalk in practical EMC scenarios.

2:00pm **Modelling the IEC 61000-4-4 Capacitive Coupling Clamp** 40

Mohit Gopalraj
Analog Devices Inc., USA

Abstract: This paper talks about modelling the Capacitive Coupling Clamp (CCC) using CST and EMCoS (EM simulation softwares), conforming to the requirements based on IEC 61000-4-4 (industrial). The CCC is used during EMC transient tests to capacitively couple the transient noise onto the harness connected to the Device Under Test (DUT). A good model once achieved, can be used to charctarize different cables and the coupling with respect to these cables could be understood better.

2:30pm **Coupled EMC-Thermal Modeling of Electrical Wiring Interconnection System within Electric Aircraft** ..... N/A

Houssem Chebbi, Michael Ridel, Philippe Reulet
ONERA, France

Abstract: This paper proposes a novel approach for modeling the electromagnetic compatibility (EMC) and thermal coupling effects in cable network installations for future electric aircrafts. In high-voltage cables, where resistance is strongly influenced by temperature rise, it is necessary to simultaneously compute both the R matrix per unit length, as well as other primary electrical parameters, and the temperature distribution of the cable bundle. Our approach is based on a topological description of the electrical network and aims to unify the electromagnetic and thermal models. We exploit the mathematical similarity between the two physics to develop a single model that can determine the LGC matrices of a transmission line and calculate the resistance matrix R that depends on the heat distribution in a cable bundle due to the Joule effect. In this paper, we present an initial analysis of the temperature rise and electromagnetic coupling between conductors.

3:30pm **Metal-Coated Building Blocks as a Tool for Creating Electromagnetic Shielding** 47

Stanislav Kovar, Tomas Kadavy, Iva Kavankova, Jan Valouch, Jan Nemec
Univerzita Tomase Bati ve Zline Fakulta Aplikovane Informatiky, Czechia

Abstract: Electromagnetic compatibility has become an integral part of the development process of any electronic or electrical product; however, maintaining a balance between radiation and susceptibility is not a simple task. When solving problems with EMC, financial and time costs arise, i.e., undesirable phenomena that EMC Risk-based management tries to prevent. This article focuses on a specific type of 3D shielding that can protect and envelop a product. Creating a shielding enclosure can be complex, especially considering atypical user requirements, such as material transparency and roundness. These requirements lead to unique shapes of electromagnetic enclosures, for which no specific procedures exist. Therefore, an idea was born based on simple cubes that could be assembled into arbitrary shapes with the help of metaheuristic algorithms and thereby help developers in their efforts. The principle is based on simply joining cubes of predefined form into the desired structure. To make the process more efficient, the application of artificial intelligence is expected, which will be able to propose a solution for a user-defined design based on experience and habits.

4:00pm **The Random Coupling Model – Introduction and Applications Overview** 53

Steven M. Anlage, Thomas Antonsen
University of Maryland at College Park College, USA

Abstract: The Random Coupling Model (RCM) is a method for making statistical predictions of induced voltages and currents for objects and components contained in complicated (ray-chaotic) over-moded enclosures and subjected to RF fields. It uses minimal information about the enclosures, allowing one to make fast and efficient probabilistic predictions for the relevant EMC-related quantities. It is based on simple universal predictions of wave chaos theory and is quantitatively supported by random matrix theory. The system-specific (non-universal) aspects of the problem are quantified by means of the radiation impedance of the "ports" involved in the problem, as well as prominent short orbits. A dimensionless loss parameter, given by the ratio of a typical mode 3-dB bandwidth to the mean spacing between modes, characterizes the fluctuations of the enclosure impedance. The outcome is a prediction for the statistics of scattering properties, impedance, S-matrix, and induced voltages on ports inside the enclosure. The RCM has been tested in many contexts in one-, two-, and three-dimensional enclosures, in both the frequency and time domains, and for both linear and nonlinear ports. We present an overview of the model and illustrate it use through a series of experimental results that have been used to verify the model and take it into new directions.

4:30pm **Patient-Specific RF-Induced Heating Prediction for Deep Brain Stimulator System under Parallel Transmit at 3T with Machine Learning Method** 54

Ran Guo[1], Jianfeng Zheng[1], Wolfgang Kainz[2], Ji Chen[1]
[1]University of Houston, USA; [2]High Performance Computing for MRI, USA

Abstract: The magnetic resonance imaging (MRI) radiofrequency (RF)-induced heating of the deep brain stimulators (DBSs) is dependent on the patient's characteristics and device implantation. The rule is further varied under parallel transmission. The traditional RF-induced heating evaluation method is comprehensive but time-consuming. Hence, an artificial neural network (ANN) model is developed in this study to predict the RF-induced heating for DBS systems under the parallel transmit condition at 3T. The hyperparameters of the ANN model, including the learning rate and the number of hidden layers and neurons, are optimized to handle the dataset of 66,290,400 samples. The original data is generated with the traditional transfer function method. The performance of the ANN model is validated with four different transfer functions. Using the optimized ANN regression model, the RF heating of the DBS system can be quickly and accurately predicted. The performance of the ANN regression model has a mean absolute error (MAE) of less than 0.84 °C and a coefficient of determination (R2) value of 0.996.

5:00pm **Interval Analysis Method for the Uncertainty and Sensitivity Characterization in Transmission Line Systems** 59

Ping Yuan[1], Lijun Jiang[2]
[1]The University of Hong Kong, China; [2]The Chinese University of Hong Kong, China

Abstract: Uncertainty in electronic fabrication process could cause serious yield issues and stability concerns. Hence, identifying the resultant range caused by the uncertainty in the system is a critical topic in modern EDA design process. Monte Carlo method is considered as a golden standard but with many drawbacks. In the paper, we propose to use the interval analysis (IA) to analyze the signal integrity and power integrity problems in transmission line (TL) systems. Using the interval representing the uncertainty range of parameters in the system, the uncertainty range of the system can be derived by the derived analytical expression. It is very helpful to the early design stages when design margin is being predicted.

TU-ALL-F EMC Wireless Technologies, EMC Planning/Testing/ Specifications, Wireless Coexistence (Sponsored by TC-12)

Technical Papers **10:30am - 5:30pm**

Room: Gallery Overlook F

Chair: Harry Skinner, *Intel Corporation, Hillsboro, OR, USA*

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

Co-Chair: Yihong Qi, *DBJ Technologies (Zhuhai) Co., Ltd., Waterloo, ON, Canada*

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

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

10:30am **RF Desense Risk Prediction Using EM Simulations** 65

Gokul Ramsubbaraj[1], Leo Cheng[2], Krishna Rao[1]
[1]Google LLC, USA; [2]Google LLC, Taiwan

BEST EMC PAPER FINALIST

Abstract: RF desense can significantly affect wireless connectivity performance in consumer electronic devices. In this paper, a workflow is presented to predict RF desense risk before the hardware prototyping stage using a combination of 3D EM simulation and board level RF system test through a consumer electronic prototype application example. First, a noise floor test is performed on the radio receiver modules to quantify the noise power level which could desensitize the radio receiver modules in the application prototype. Next, a full wave 3D EM simulation is utilized to compute the simulated noise power level coupled from a high-speed digital system to the radio receiver modules through the antennas in the application prototype. The noise power levels quantified through the noise floor test are used as a guideline to compare against the simulated noise coupled to the radio receiver system to analytically predict RF desense levels. The predicted RF desense levels are compared with direct desense validation results measured on hardware prototype samples to validate the accuracy of the simulation outcome. This technique can be used to predict RF desense risk during the early hardware prototype phase to help inform hardware design engineers to make better design decisions to mitigate RF desense risk.

11:00am **Decomposition Measurement for Antenna Gain and Radio Sensitivity of Wireless Receiving System** 70

Chaoqiang Zang[1], Lidong Chi[2], Fuhai Li[1], James L. Drewniak[3], Gang Feng[2], Yihong Qi[2]
[1]Hunan University, China; [2]LinkE Technologies Co., Ltd., China;
[3]Missouri University of Science and Technology, USA

Abstract: A general procedure for decomposition measurements for receiver antenna gain and radio sensitivity based on received signal strength indicator (RSSI) reporting is proposed in this paper. This procedure standardizes the measurement steps for eliminating nonlinear error in RSSI reporting. After path loss calibration and RSSI uncertainty calibration, the real performance of the antenna and the radio working in the actual environment of wireless receiving system can be measured. The antenna gain is obtained from the difference between RSSI reporting and transmit power, and the radio sensitivity is obtained from the transmit power. This method helps to improve the development efficiency of radio devices and shorten the development cycle. The general procedure is suitable for single-input single-output (SISO) wireless receiving system having RSSI reporting such as GSM, and Bluetooth systems.

11:30am **Ground Contact of Bendable FPC EMI Film Impact on Desense Noise for Smart Glasses** 74

Chien-Ming Nieh[1], Deepak Pai[1], Jay Park[1], Shiro Yamauchi[2], Nobuyuki Ito[2]
[1]Meta Platforms Inc., USA; [2]Tatsuta Electric Wire & Cable Co., Ltd, Japan

Abstract: AR/VR products face significant challenges in terms of weight and size limitation, particularly as wearable devices. Electrical Magnetic Interference (EMI) shielding film design is becoming increasingly popular due to its cost and weight advantage. The grounding design of EMI film is essential in determining its shielding effectiveness (SE). This work focuses on studying the impact of EMI film grounding design and ground contact performance in DC resistance after bending. The study presents both simulation results and manufacturing capabilities.

1:30pm **Reconfigurable Intelligent Surface (RIS) Design for 5G n260 Frequency Band** 75

Reza Yazdani, Manish Kizhakkeveettil Mathew, Zhekun Peng, DongHyun Kim
Missouri University of Science and Technology, USA

Abstract: In this paper, a new low profile reconfigurable intelligent surface design with high resolution steering reflector and wide frequency band width is proposed at n260 frequency band, used for 5G new radio applications. The dynamic reflection phase and tunability is realized by integrating of varactor diode with each unit cell. This study presents design procedures, reflection simulation verifications, and the effects of important parameters on the performance of the proposed novel resonant unit cell. The proposed unit cell offers a dynamic reflection phase range of more than 270◦ at a wide frequency bandwidth. Simulation results of beam steering capability in horizontal plane at 38 GHz is presented to verify the design performance of the RIS.

2:00pm **Electrically Controlled Smart Surfaces for Reverberation Chambers** 79

Yifan Guo[1], Zibin Weng[1], Yongchang Jiao[1], Lie Liu[2], Yihong Qi[2], Huibin Zhang[2]
[1]Xidian University, China; [2]General Test Systems Inc., China

Abstract: Reverberation chambers (RC) have been utilized for more than half century. Initially, they have been employed in measuring the EM properties of material before using in EMC performance of equipment, like immunity properties or interference. Recently, reverberation chamber has been introduced into the evaluation of over-the-air (OTA) performance of wireless devices, which include TRP, TIS and gain or efficiency of antenna. As compared with anechoic or other methods, RC method can reduce the cost of measurement devices, also increase the test efficiency of TRP. In order to further improve the testing efficiency of the reverberation chamber, this paper proposes an electrically controlled smart surfaces (ESS) which could switch on or off to improve the uniformity of electromagnetic field inside chamber.

2:30pm **Static I-V based PIM Evaluation for Spring and Fabric-over-Foam Contacts** 83

Kalkidan W. Anjajo[1], Yang Xu[1], Shengxuan Xia[1], Yuchu He[2], Haicheng Zhou[2],
Hanfeng Wang[2], Jonghyun Park[1], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]Google LLC, USA

BEST EMC PAPER FINALIST

Abstract: Spring clips and fabric-over-foams (FOFs) are widely used in mobile devices for electrical connection purposes. However, the imperfect metallic connections tend to induce passive intermodulation (PIM), resulting in a receiver sensitivity degradation, known as RF desensitization. Due to the complexity of the PIM characterization, there is not yet a way to evaluate PIM performance using a simple setup for environments like factories. In this paper, a current-voltage (I-V) behavior-based PIM evaluation method is proposed and validated with various metallic contacts and contact forces. The test results demonstrated the feasibility of the PIM performance evaluation based on the measured static I-V curve.

3:00pm **Oxidation Layer Formation on Aluminum Substrates with Surface Defects Using Molecular Dynamics Simulation** 88

Emmanuel Olugbade[1], Hiep Pham[1], Yuchu He[2], Haicheng Zhou[2], Chulsoon Hwang[1], Jonghyun Park[1]
[1]Missouri University of Science and Technology, USA; [2]Google LLC, USA

BEST SIPI STUDENT PAPER FINALIST

Abstract: Aluminum oxide layer affects the integrity of electrical contact and can contribute adversely to passive inter-modulation (PIM) behavior in radio frequency (RF) devices, necessitating a need for understanding its formation mechanism and realistic estimation of its thickness. Using ReaxFF molecular dynamics simulation technique, this study investigated the impact of surface defects on aluminum oxide layer formation. Results reveal that crystallographic orientation did not affect the kinetics of oxidation process of aluminum. However, the reaction kinetics increased significantly with surface inhomogeneities such as cracks, scratches, and grain boundaries. A non-uniform oxide layer with thickness variation in the range of 72-77% was observed due to surface imperfections. Concurrent crack healing and oxidation was observed, where the crack tips acted as sites for oxygen diffusion, thus increasing oxidation kinetics. The observations from this simulation agree with experimental reports and have important implications for optimizing the contact integrity in RF devices and for PIM control.

TU-AM-G Exemplary Paper Session

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

Room: Gallery Overlook G

Chair: Frank Gronwald, *University of Siegen, Siegen, Germany*

Session Abstract: For this newly established symposium session, 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.

Presenting Author: Tom Hartman

Hartman, T., ten Have, B., Dijkstra, J., Grootjans, R., Moonen, N., & Leferink, F. (2022). Susceptibility of Static Energy Meters due to Amplifier Clipping Caused by a Rogowski Coil.

Citation: T. Hartman, B. t. Have, J. Dijkstra, R. Grootjans, N. Moonen and F. Leferink, "Susceptibility of Static Energy Meters due to Amplifier Clipping Caused by a Rogowski Coil," in *IEEE Transactions on Electromagnetic Compatibility*, vol. 64, no. 6, pp. 2024-2032, Dec. 2022, doi: 10.1109/TEMC.2022.3204391.

Presenting Author: Francesco de Paulis

de Paulis, F., & Nisanci, M. H. (2022). Signal Integrity Assessment of Interconnects Routed Within Bandgap Metallic Cavities.

Citation: F. de Paulis and M. H. Nisanci, "Signal Integrity Assessment of Interconnects Routed Within Bandgap Metallic Cavities," in *IEEE Transactions on Signal and Power Integrity*, vol. 1, pp. 83-92, 2022, doi: 10.1109/TSIPI.2022.3199331.

Presenting Author: Javad Meiguni

Meiguni, J. S., Zhou, J., Maghlakelidze, G., Xu, Y., Izadi, O. H., Marathe, S., Shen, L., Bub, S., Beetner, D.G., & Pommerenke, D. (2021). Transient analysis of ESD protection circuits for high-speed ICs.

Citation: J. S. Meiguni et al., "Transient Analysis of ESD Protection Circuits for High-Speed ICs," in *IEEE Transactions on Electromagnetic Compatibility*, vol. 63, no. 5, pp. 1312-1321, Oct. 2021, doi: 10.1109/TEMC.2021.3071644.

Presenting Author: Ling Zhang

Zhang, L., Juang, J., Kiguradze, Z., Pu, B., Jin, S., Wu, S., Yang, Z., Li, E.-P., Fan, J., & Hwang, C. (2022). Efficient dc and ac impedance calculation for arbitrary-shape and multilayer pdn using boundary integration.

Citation: L. Zhang et al., "Efficient DC and AC Impedance Calculation for Arbitrary-Shape and Multilayer PDN Using Boundary Integration," in *IEEE Transactions on Signal and Power Integrity*, vol. 1, pp. 1-11, 2022, doi: 10.1109/TSIPI.2022.3164037.

TU-ALL-H Signal and Power Integrity, Interconnects, Modeling and Characterization, Crosstalk, Jitter, Noise (Sponsored by TC-10)

Technical Papers **10:30am - 5:30pm**

Room: Gallery Overlook H

Chair: Hanfeng Wang, *Google Inc, Mountain View, CA, USA*
Co-Chair: Songping Wu, *Rivos Inc., Mountain View, CA, USA*
Co-Chair: Yansheng Wang, *Rivos Inc., Santa Clara, CA, USA*
Co-Chair: Ling Zhang, *Zhejiang University, Hangzhou, China*
Co-Chair: Kaisheng Hu, *Ciena, Ottawa, ON, Canada*

10:30am **Enhanced Eye Diagram Estimation Method for Nonlinear Systems with Input Jitter** ..... N/A
Hanqing Zhang, Feijun Zheng
Zhejiang University, China

Abstract: An enhanced multiple-edge response (MER) based eye diagram estimation method is proposed to evaluate the performance of nonlinear systems with input jitter. Compared with existing MER-based methods which only took into account the bit effect, the proposed method first determines both orders of bit effect and jitter effect. These decided orders can affirm the necessary MERs. Subsequently, the proposed method figures out the minimal number of sampling points so that the necessary MERs can be recovered quickly based on the Nyquist theory and can be used to create eye diagrams. Lastly, the eye diagrams and their parameters are compared with those generated by traditional transient simulation and an existing MER-based method which introduces input jitter through a convolution process. The result indicates that this enhanced method is more accurate than the existing MER-based method.

11:00am **Extraction for Multilayer Ceramic Capacitor Vibration Induced Force** 115
Yifan Ding[1], Jianmin Zhang[2], Mingfeng Xue[2], Xin Hua[2], Benjamin Leung[2],
Eric A. MacIntosh[2], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]Google LLC, USA

Abstract: Due to the piezoelectric characteristic of the MLCC dielectric BaTiO3, the multilayer ceramic capacitor (MLCC) can vibrate when the supply voltage has AC components. The vibration of the MLCC will generate a force on the printed circuit board (PCB) it is connected to, causing the PCB to vibrate as well. The MLCC vibration-generated force is extracted using a measurement-simulation-based methodology in this paper. The force of an MLCC is first extracted at the PCB resonance frequencies. Then, a broadband force profile is obtained by using the interpolating method. The extraction methodology can be used in different boundary conditions, on different PCBs, and for different MLCCs with a good generalization.

11:30am **On Finding an Equivalent Force to Mimic the Multilayer Ceramic Capacitor Vibration** 120
Yifan Ding[1], Jianmin Zhang[2], Mingfeng Xue[2], Shenyin Ding[2], Benjamin Leung[2],
Eric A. MacIntosh[2], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]Google LLC, USA

BEST SIPI STUDENT PAPER FINALIST

Abstract: The multilayer ceramic capacitor (MLCC) can vibrate due to the piezoelectric effect when there is AC noise on the power rail. The vibration of the capacitor will generate a force on the PCB and thus cause the PCB vibration and audible problems may occur. The work in this paper finds an equivalent force with similar behavior to the MLCC-generated force. The force is controllable and knowable and thus can mimic the capacitor vibration on the PCB.

1:30pm **Power Supply Induced Jitter (PSIJ) Modeling, Analysis, and Optimization of High Bandwidth Memory (HBM) I/O Interface** 125

Hyunwook Park[1], Taein Shin[1], Seongguk Kim[1], Keeyoung Son[1], Keunwoo Kim[1], Boogyo Sim[1], Hyungmin Kang[1], Seonguk Choi[1], Jiwon Yoon[1], Hyunwoo Kim[1], Chulsoon Hwang[2], Joungho Kim[1]
[1]*Korea Advanced Institute of Science and Technology, Korea;*
[2]*Missouri University of Science and Technology, USA*

BEST SIPI PAPER FINALIST

Abstract: Power supply induced jitter (PSIJ) in high bandwidth memory (HBM) I/O interface is modeled, analyzed, and optimized for different HBM generations. Precise models for VDDQ power distribution networks (PDNs), simultaneous switching current (SSC), and jitter sensitivities of the clock and I/O buffers are implemented for PSIJ estimation. Compared to the SPICE, the average error rate of the estimated PSIJ is 4.26 %. The critical frequency bands in the jitter spectrum where large jitters occur are derived by comparing the relative impact of the modeled interface factors in the frequency domain. For the optimization, on-chip and on-interposer decoupling capacitor (decap) placement strategies using machine learning (ML) are applied. The decap effects in the critical ranges are analyzed. Finally, based on the integrated analysis of the limitation of the decap solution and all the I/O interface factors, the major challenges of high-frequency PSIJ are characterized.

2:00pm **Signal Integrity Analysis of Notch-Routing to Reduce Near-End Crosstalk for Tightly Coupled and Short Microstrip Channel** 131

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

Abstract: In this paper, the notch-routing is introduced as the novel methodology to reduce the near-end crosstalk (NEXT) in tightly coupled and short microstrip channel. According to the high-integration of diverse components in a package, the space between traces gets arrower, that results in increasing NEXT due to increased capacitive coupling. We propose the modified structure of the transmission line with the uniformly placed notch so as to decrease the capacitive coupling. The proposed structure reduces NEXT by about 15% at 20 Gbps, and secures an additional height of 2.2% on the eye diagram compared to a conventional transmission line without a notch structure.

2:30pm **An Improved Test Method of Additive Jitter Quantification for Clock Buffer** 137

Yang Wu, Rui Mao, Shengzhen Zhang, Lei Wang, Tao Xu
Intel Corporation, China

Abstract: Additive jitter is a critical parameter of the clock buffer in the system clock design. This paper introduced the problem in the additive jitter quantification, discussed causes of the problem, and proposed an improved method for the additive jitter quantification. The proposed method can effectively solve the problem in the additive jitter quantification and is verified by test results.

3:30pm **Signal Integrity Analysis of Wire Bonding Finger Capacitance to Reduce the Reflection of Multi-Drop Topology for Low-Power Double Data Rate (LPDDR)** 141

Hyunwoong Kim[1], Gagyeong Park[1], Seunghun Ryu[1], Jongwook Kim[2], Jaehoon Lee[2], Seungyoung Ahn[1]
[1]*Korea Advanced Institute of Science and Technology, Korea;* [2]*SK hynix Inc., Korea*

BEST SIPI PAPER FINALIST

Abstract: In this paper, in order to minimize the reflection generated in the multi-drop topology, the proposed structure to insert capacitance into the wire bonding finger using a high-K material is presented. The proposed structure can reduce the significant reflected signal due to multi-drop topology at a high-frequency range. Return loss is improved by about 2.26 dB and 0.24 dB, respectively, at 20 GHz for two loadings and four loadings systems, and the insertion loss is also improved due to this effect. Based on the eye diagram, the proposed structure, an additional height, and a width margin is obtained at 3.4 % and 2.0 % at 20 Gbps for four loadings system, respectively.

4:00pm **Design and Analysis of Double-Side Characteristic Impedance Compensation Structure in 2.5D / 3D Package for High-Speed Serial Link** 147

Seonghi Lee[1], Hyunwoong Kim[1], Jiyoung Park[2], Yongho Lee[2], Sungwook Moon[2], Seungyoung Ahn[1]
[1]Korea Advanced Institute of Science and Technology, Korea; [2]Samsung Electronics Co., Ltd., Korea

BEST SIPI PAPER FINALIST

Abstract: A double-side characteristic impedance compensation structure for a 2.5D/3D package is proposed and designed to mitigate the impedance discontinuity caused by the controlled collapse chip connection (C4)-bump. The compensation structures applicable to the interposer and package (PKG) were designed. The insertion loss according to the variables of the structure is analyzed. The insertion loss and eye-height are improved through reflection reduction of the proposed double-side compensation structure compared to the one-side compensation structure. The insertion loss is improved by 5.6 % and 9.8 % at 32 GHz and 64 GHz, respectively. The eye-height is improved by 2.5 % and 12.5 % at 128 Gbps and 256 Gbps, respectively.

4:30pm **Thermally Induced Losses on High Speed Interconnects** 153

Gerardo Romo Luevano, Chris Ferguson, Ennai Ochoa, Harpreet Randhawa
Qualcomm Technologies, Inc., USA

Abstract: This paper presents a systematic approach for broadband characterization of thermally induced losses on high-speed interconnects. The characterization relies on S-parameter measurements of striplines fabricated on a commercial board with 20 GHz bandwidth. The measurements cover a temperature range from 0 to 100 degrees Celsius (°C), taken at 20-degree steps. For each temperature the high-speed interconnects are characterized from two-line measurements, which yields the complex-valued propagation constant at every temperature. As it is well-known, the real part of the propagation constant contains the loss information about the interconnects. By using the losses associated with the propagation constant at T= 0 °C as a reference, the thermally induced losses for all other temperatures are extracted. The thermally induced losses are then analyzed to determine the contribution from both the metal and the dielectric. Our results show that both the metal and the dielectric contribute to the thermally induced losses, but that the main contribution is primarily associated with the dielectric. From that, accurate temperature dependent models for the loss tangent Tanδ(T) and for the metal's resistivity can be defined from the measured data. It follows that the thermally induced losses due to the dielectric and the metal can be easily modelled in commercial EDA software by simply correcting the loss tangent and resistivity values for the desired temperature.

5:00pm **Simulation and Measurement Correlation Study for 112 Gbps PAM4 High-speed Links** 158

Tao Wang, Marvin Yin, Karthik Muniappan, Brian Brecht
Teradyne Inc., USA

Abstract: Base band signal delivery is demanding over 100 Gbps data rate. Hence, simulation and measurement correlation is necessary to ensure the quality of the design. In this work, we focus on 112 Gbps and even higher signal delivery board designs to discuss critical issues affecting simulation accuracy, measurement reliability, and correlation result analysis. Port setups, boundary definitions, probe selections, and result expectations are included in this study. Multiple channels' correlation results in both spectrum and TDR domains will be presented. This paper serves as a ground truth reference to the correlation status for 112 Gbps channel designs.

TU-PM-AtE

Ask the Experts Panels 1:30pm - 3:00pm

Room: Exhibit Hall
Chair: Craig Fanning, *Elite Electronic Engineering, Downers Grove, IL, USA*

Session Abstract: Bring your questions or simply listen and learn!

EMC Challenges of Automotive Electrification

PLANNED PANELISTS INCLUDE:

- Garth D'Abreu, *ETS-Lindgren*
- Cheyne Scoby, *Rivian*
- Robert Mitchell, *TUV*
- Keith Frazier, *Ford*
- Ron Missier, *Ford*
- Rob Kado, *Stellantis*

Abstract: Electrified vehicles (EV, HEV and PHEV) have been successfully used on our roadways for over 20 years. Electric vehicles continue to gain market share with some Countries and vehicle OEMs committing to full electrification. Like all electronic products, new electromagnetic compatibility (EMC) challenges are experienced during the design phases as the technology evolves. Electromagnetic noise sources, such as high-power switching operations and high-speed communication bus architectures, can cause issues for both regulatory compliance and self-compatibility. Understanding these potential issues early in the product design cycle can assist OEMs and their suppliers to make EMC-friendly design choices. Proper power electronics design, cable routing, cable shielding, simulation and modeling, and other disciplines all have a part to play in continuing the success in this area. Join experts in this free-form panel discussion to discuss the regulatory environment, associated standards, the main challenges in both design and testing of EVs, and the best strategies for overall EMC success in the EV space.

TU-PM1-ED2 Shielding Effectiveness Design to 10GHz and Beyond, Using Fast Stochastic Simulation (Sponsored by TC-4)

Experiment/Demonstration 12:30pm - 2:00pm

Room: Exhibit Hall Exp Demo 2
Chair: Jacob Dixon, *International Business Machines Corp, Rochester, MN, USA*
Co-Chair: Gabriel Alcala, *University of California Riverside, San Diego, CA, USA*

Shielding Effectiveness Design to 10GHz and Beyond, Using Fast Stochastic Simulation

Paul Bremner, Weitao Dai, Reza Afra, Arielle Frank
RobustPhysics, USA

Abstract: Designing cables, connectors and enclosures for EMC compliance at system-level and at high frequencies is difficult, due to coupled conduction and radiation paths, shield/joint/seam leakage, connector and cable penetration uncertainties, excitation field complexity, etc. For most EMC engineers, numerically-meshed, full wave models are too large, expensive and slow to be an interactive design tool - particularly at high frequencies 1GHz and above. New, statistically-reduced order models by comparison, are a more natural solution for his class of problem, applicable up to 10 Ghz and beyond.

STOCHASTICA software from RobustPhysics will be used to demonstrate how the new stochastic simulation facilitates fast, interactive EMC environment predictions - both currents on cables and coupled electric fields in reverberant enclosures - in minutes rather than days.

Combined Tutorial and Software demonstrations for three (3) different EMC design applications will be presented.

TU-PM2-ED2 Multiplying Competency: Remote and Autonomous Chamber Validation (Sponsored by TC-2)

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

Room: Exhibit Hall Exp Demo 2

Chair: Jacob Dixon, *International Business Machines Corp, Rochester, MN, USA*

Co-Chair: Gabriel Alcala, *University of California Riverside, San Diego, CA, USA*

Multiplying Competency: Remote and Autonomous Chamber Validation

Nika Amralah[1], Phillip Miller[2]

[1]Raymond EMC Enclosures, Canada;[2]RATLR, USA

Abstract: The proposed activity is a real-time demonstration of remote chamber validation capabilities for at least three labs of diverse geography, industry served, and measurement needs in the United States and Canada. An engineer (one of the presenters) will be shown remotely controlling testing at all sites simultaneously from the Symposium during the presentation. The remote test site participants represent a large segment of the EMC and SIPI community and provide relevance to different market segments of manufacturers and service providers in the Symposium audience. The development and implementation of remote chamber validation with autonomous measurements presents a significant efficiency improvement to the industry, while requiring lower on-site competency. Attendees will learn the advantages of remote testing, watch a live demonstration of its practical application, and have an opportunity to interact with the presenters for a question period.

Several commercial and private lab owners have expressed commitment to the demonstration including automotive labs wishing to demonstrate the CISPR 25 long-wire testing and OEM labs with Near Field Scanning facilities. The presenters will select a group that contains:

- A commercial test lab with 3m SAC in the Southwest United States
- A private Canadian R&D reverberation chamber
- An EMC manufacturer with an internal SAC

TU-PM-ED3 A Novel Cylindrical Mode Filtered SVSWR Method for Above 18 GHz EMC Test Site Evaluation (Sponsored by TC-1)

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

Room: Exhibit Hall Exp Demo 3

Chair: Jacob Dixon, *International Business Machines Corp, Rochester, MN, USA*

Co-Chair: Gabriel Alcala, *University of California Riverside, San Diego, CA, USA*

A Novel Cylindrical Mode Filtered SVSWR Method for Above 18 GHz EMC Test Site Evaluation

Zhong Chen

ETS-Lindgren, USA

Abstract: It has been shown that the conventional SVSWR measurement method does not extrapolate well to above 18 GHz. A novel SVSWR method based Cylindrical Mode Filtering is being actively considered in both ANSI C63.25 and CISPR 16. In the new method, the transmit antenna (typically a low gain omni-directional antenna) is placed at the edge of the turntable, and a single cut vector pattern measurement is acquired. The vector S21 as a function of turntable angle at each frequency is transformed to the cylindrical mode spectrum, where an appropriate filter can be applied to mathematically remove the chamber effects. The SVSWR is derived by comparing the original pattern in the chamber to the "clean" filtered pattern. Compared to the traditional SVSWR method, the mode filtered SVSWR method is easier to perform, faster, more repeatable, and provides a more comprehensive evaluation of the quiet zone. In this demonstration, we will show the measurement process in real time and explain the post processing procedures. Several recent advances will be discussed, including the statistical based robust calculation of SVSWR, and a new post processing algorithm which greatly relaxes turntable positioning accuracy requirements.

TU-PM-ED4 Cabling and Shield Terminations (Sponsored by TC-8)

Experiment/Demonstration **2:00pm - 4:00pm**
Room: Exhibit Hall Exp Demo 4
Chair: Jacob Dixon, *International Business Machines Corp, Rochester, MN, USA*
Co-Chair: Gabriel Alcala, *University of California Riverside, San Diego, CA, USA*

Cabling and Shield Terminations

John C. McCloskey, Jen Dimov
NASA/Goddard Space Flight Center, USA

Abstract: Cabling and shielding are among of the most important aspects of any system for establishing electromagnetic compatibility. Despite this, they are frequently misunderstood and/or overlooked. This demonstration examines cabling and shielding techniques in order to provide a practical understanding of how shielding works and what types of terminations work best for different applications.

TU-PM-B Engineer Soft Skills (Sponsored by TC-1)

Tutorial **1:30pm - 6:00pm**
Room: Gallery Overlook B
Chair: Kimball Williams, *IEEE, Dearborn, MI, USA*

Session Abstract: Description: A common concern among engineers and engineering managers is the effective training of all of our associates in the 'nontechnical' aspects of EMC engineering. These are usually referred to as the 'soft skills' as opposed to the technical tools we all strive to acquire during our time in Colleges or Universities. Some of these may be touched upon briefly in school curricula. However, the effective application is usually left to 'on the job' training, which usually means no training at all, with a 'sink or swim' approach to learning these skills. This Special Session will introduce the tools, with the 'twist' of the EMC engineer's point of view. (Note: Many members acquire the necessary 'practice' through active participation in professional society (IEEE) activities.)

Objective: Our objective is to provide sufficient introductory material and guidance to allow each student to continue to develop the core skills in each area while 'on the job'. Mastery of these subjects is only gained through practice in 'real' situations over sufficient time to allow the student to perceive and understand how to 'adjust' each tool to fit the task at hand. All we can hope to do is introduce and reinforce the fundamentals and encourage each student to continue to explore the nuances within each topic on his or her own time.

Engineering Ethics

Thomas E. Braxton
Elite Electronic Engineering Inc., USA

EMC Leadership – Networking Skills

Daniel D. Hoolihan
Hoolihan EMC Consulting, USA

Effective Presentations

Bruce Archambeault
International Business Machines Corp, USA

Designing a Career Path

Kimball Williams
IEEE, USA

TU-PM1-G Stochastic Simulation for EMC and Signal Integrity (Jointly Sponsored by TC-8 and TC-9)

Technical Papers (Special Session) **1:30pm - 4:30pm**

Room: Gallery Overlook G

Co-Chair: Paul Bremner, *Robust Physics, San Diego, CA, USA*

Co-Chair: Zhen Peng, *University of Illinois at Urbana-Champaign, Champaign, IL, USA*

1:30pm **Recent Developments in Stochastic Power Flow Enable a New Solution for System-Level EMC Modelling** 159

P.G. Bremner

RobustPhysics, USA

BEST EMC PAPER FINALIST

Abstract: Statistical power balance modeling originally applied to reverberation chamber design has the potential to benefit a much wider range of EMC and signal integrity applications. This paper will review the physics and statistical foundations of Hill's model for reverberation chambers, the extension to multiply connected cavities and the coupling to multi-conductor cable currents inside the cavity field. The paper will then introduce a new unconditional probability density function formulation, further expanding the model to handle the statistics of electrically small cavities and the incorporation of uncertainty in the cavity Q factor.

2:00pm **Maximum Expected Electric Field in Multiple Connected Cavities – Experimental Validation of Stochastic Power Flow Model** 165

P.G. Bremner[1], J.C. West[2], R. Afra[1], C.F. Bunting[2], G. Vazquez[3], Dawn Trout[3]

[1]RobustPhysics, USA; [2]Oklahoma State University, USA; [3]NASA Kennedy Space Center, USA

Abstract: In the space community, there is increasing interest in augmentation of launch fairing thermal-acoustic blankets, to also control electromagnetic environment threats. This second paper by the authors reports on the development of simulation methods to predict the maximum expected electric field levels when RF absorbing materials are used to reduce the mean field. To account for frequency variance in a "frequency-stirred" ensemble, the paper reports the experimental validation of a new unconditional probability density function model – an enhancement to Rayleigh statistics -- for the reverberant electric field magnitude at any location and any frequency.

2:30pm **Combined Reactive and Radiation Coupling of Conductors in an Enclosure – Numerical Validation of Stochastic Wavefield Model** 171

W. Dai[1], P.G. Bremner[1], M.M. Mustafa[2], J.C. West[2], C.F. Bunting[2]

[1]RobustPhysics, USA; [2]Oklahoma State University, USA

Abstract: A low-fidelity hybrid transmission line method– stochastic power flow (TLM-SPF) model has been developed to study the coupling of electromagnetic fields to conductors in an enclosure. Model setup time is approximately 10 minutes and computational time less than one minute. The resulting stochastic predictions agree with a high-fidelity full-wave simulation over a broad frequency range that requires days of computation on a high-performance computing system. This low-fidelity hybrid TLM – SPF approach is easily extendable to multi-segment cable harnesses in multi-cavity compartments. It is a computationally compact approach for a full system model of an aircraft, etc.

3:30pm **On Applying the Electromagnetic Probability-of-Effect Assessment Tool to Hazards of Electromagnetic Radiation to Ordnance** 177

Carl E. Hager IV

Naval Surface Warfare Center, USA

Abstract: Traditional hazards of electromagnetic radiation to ordnance testing has leveraged deterministic plane wave illumination of ordnance enclosures to full tactical electromagnetic environments at open air test sites. Previously, an electromagnetic probability-of-effect assessment tool which statistically assesses the magnitude of a system/sub-system's hardness or safety margin to upset/failure under any level of threat was developed. The purpose of this study is to directly compare the results of the electromagnetic probability-of-effect assessment tool to traditional hazards of electromagnetic radiation to ordnance testing on a representative ordnance enclosure. Predicted and measured currents on an electrically initiated device are compared and very good agreement between the methods is demonstrated.

4:00pm **Statistical Characterization of Cavity Quality Factor via the Stochastic Green's Function Approach** 183

Shen Lin[1], Yang Shao[1], Zhen Peng[1], Bisrat D. Addissie[2], Zachary B. Drikas[2]
[1]University of Illinois at Urbana-Champaign, USA; [2]US Naval Research Laboratory, USA

BEST EMC PAPER FINALIST

Abstract: There has been a strong interest in statistically characterizing the cavity quality factor (Q-factor) for large, complex enclosures. While there are existing methods for analyzing the Q-factor statistics due to distributed losses, there is currently little discussion about the statistical cavity Q-factor caused by localized losses, such as aperture leakage and absorptive loading. This paper presents a physics-oriented, hybrid deterministic-stochastic model that calculates the probability distribution of cavity Q-factor. The research work is evaluated and validated through representative experiments.

TU-PM2-G Spectrum Engineering, Characterization and Modeling, Design, Adaptive Interference Mitigation (Sponsored by TC-6)

Technical Papers **4:30pm - 5:00pm**

Room: Gallery Overlook G

Chair: Sarah Seguin, *Resonant Frequency, Maple Grove, MN, USA*

4:30pm **A Versatile Fourier Domain Filtering Library for Diverse Applications** 189

Yibo Wang[1], Zhong Chen[1], Andrew Shyne[2], Dennis Lewis[2]
[1]ETS-Lindgren, USA; [2]The Boeing Company, USA

Abstract: Fourier domain filtering is a commonly applied data post processing technique used in many engineering applications, e.g., time domain gating is often used to remove or isolate responses in a multiple reflective environment. Many commercial vector network analyzers (VNAs) include the gating algorithm as a "black box" function. A user has little recourse to reprocess or further process the data once the data has been downloaded from a VNA. A versatile Fourier domain filtering library has been developed recently, giving users much more flexibility and convenience over the VNA-dependent process. It is well known that the gated results can exhibit significant "band edge effects" due to the band limited measurement data. The new library toolset incorporates the standard edge treatment techniques often found in commercial VNAs. In addition, it includes a newly developed spectrum extension technique which improves the gated data accuracy significantly for many practical applications. The library works equally well for spatial and spectrum applications, such as for image processing and spectrum analyses in antenna measurement applications.

WEDNESDAY – AUGUST 2, 2023

WE-AM-AtE

Ask the Experts Panels 10:00am - 11:30am

Room: Exhibit Hall
Chair: James Drewniak, *Missouri S&T EMC Laboratory, Rolla, MO, USA*

Session Abstract: Bring your questions or simply listen and learn!

Signal Integrity Challenges of SERDES Interfaces

PLANNED PANELISTS INCLUDE:

- John Golding, *Siemens*
- Stephen Scearce, *Cisco*
- Krzysztof Russa, *E3 Compliance*
- Tom Brady, *Analog Devices*
- Hanfeng Wang, *Google*
- Songping Wu, *Rivos*

Abstract: A Serializer/Deserializer (SerDes) is a pair of functional blocks used in high speed communications that convert data between serial and parallel interfaces in each direction. SerDes provides data transmission over a single lane differential pair in order to minimize the number of I/O pins and interconnects. As data rates continue to increase toward 800G, the signal and power integrity challenges associated with SerDes design at the package and PCB levels increase, including cross-talk, inter-symbol interference (ISI), power-net noise and others. High-speed issues are not specific to SerDes design, and insight into high-speed design in general for SI will be an outcome. A brief summary of SerDes design and challenges will be given and then Q&A with the industry experts that each have many years of experience.

WE-AM-ED1 Demonstrating EMI Generation from Battery Packs and a Field Cancellation Method for Mitigation (Sponsored by TC-7)

Experiment/Demonstration 10:00am - 12:00pm

Room: Exhibit Hall Exp Demo 1
Chair: Jacob Dixon, *International Business Machines Corp, Rochester, MN, USA*
Co-Chair: Gabriel Alcala, *University of California Riverside, San Diego, CA, USA*

Demonstrating EMI Generation from Battery Packs and a Fleld Cancellatlon Method for Mitigation

Yongjun (Alan) Zhang, Chenming Zhou
National Institute for Occupational Safety and Health, USA

Abstract: While EMI has been extensively studied for decades, it appears that EMI generation from battery packs is not well known and has not been well investigated. In this demonstration, we will show that a lithium-ion battery pack used for powering a wearable electronic device commonly used in US underground coal mines (i.e., a continuous personal dust monitoring (CPDM)) can generate strong EM emissions that interfere with other mining safety equipment, such as proximity detection systems. We will also show that the EM emissions generated by the battery pack can be effectively mitigated by a novel EMI mitigation method that is based on a field cancelation technique.

Background: The CPDM is a mandatary device for underground coal miners, according to the Mine Safety and Health Administration (MSHA) regulation (30 CFR § 7S.1732). It protects the health of the miners by monitoring a miner's dust exposure. Unfortunately, not long after the CPDM was placed in the field, it was discovered that the electromagnetic energy emitted by a CPDM interfered with another critical device, called the proximity detection system (PDS), which monitors the distance between miners and mining equipment and protects miners from being accidentally pinned or crushed by mining equipment.

After the incidents of EM interference, an investigation followed, and it was concluded that the battery was the major culprit of the EM emission of the CPDM. Several electromagnetic interference (EMI) mitigation methods were then proposed by vendors and by researchers at the National Institute for Occupational Safety and Health (NIOSH). These include, but are not limited to, a copper-mesh pouch made by Strata (the PDS vendor), shielding on the battery pack, administrative control on the miners (maintaining six-inch distance between CPDM and PDS device), and others. Each method has its pros and cons; yet none of them has addressed the issue satisfactorily.

In this demonstration, we will present a new method that we discovered during our research. It can effectively address the problem. The new method is based on the concept of magnetic field cancellation. The idea is to utilize the coherent nature of the currents in battery cells and rearrange the cells in such a way that the magnetic fields produced from the cells are cancelling each other.

First, we will show that the difference of the EM emission between the stock battery and the newly designed battery when each of them is powering the circuit board of a CPDM. To isolate the EM emission of the battery from that of the circuit board, a half-meter-long shielded cable will connect the battery to the circuit board. The circuit board is then housed in a shielded enclosure. The new battery has the same serial and parallel configuration of battery cells as the stock battery, which is 2S/SP. The new battery also has the same shape and size so that it can replace the stock battery in existing CPDM devices. The experiment uses an RE101 passive loop antenna and a spectrum analyzer to measure EM emission. The result will show that the EM emission is reduced on every side of the battery.

Then, we will install the battery pack into the CPDM device and measure EM emission from the CPDM device. It will once again reveal that the CPDM with a new battery, compared to the one with a stock battery, has less EM emission on most of the sides, especially in the area close to the battery. The new battery design has been reviewed by the CPDM manufacturer and is being considered for implementation in their future product.

WE-AM-ED2 Direct Radar Pulse Measurement and Other Applications of Fast E-Field Probes (Sponsored by TC-2)

Experiment/Demonstration **10:00am - 12:00pm**

Room: Exhibit Hall Exp Demo 2

Chair: Jacob Dixon, *International Business Machines Corp, Rochester, MN, USA*

Co-Chair: Gabriel Alcala, *University of California Riverside, San Diego, CA, USA*

Direct Radar Pulse Measurement and Other Applications of Fast E-Field Probes

Samuel Hildebrandt

LUMILOOP GmbH, Germany

Abstract: Radar pulse measurements are usually performed in the signal chain between generator and transmitting antenna.

LUMILOOP will demonstrate direct measurement of radar pulses in the electric field, exactly at the location of a DUT. A LSProbe high-speed E·Field Probe and a LSPM RF power meter are combined to evaluate the typical 3 Qs pulses used in automotive component testing.

The demo will also feature high-speed E-Field mapping. A LSProbe E-field probe, a LSPM Powermeter and a RF signal generator are orchestrated by our PixEdust® software. PixEdust utilizes the frequency sweep capability of all these devices to iterate quickly through a frequency list. This method reduces measurement time per spatial point down to single-digit seconds. A complete IEC 61000- 4-3 17 point field uniformity evaluation can easily be performed in under one hour. We will demonstrate this live in a sma ll-scale setup.

WE-AM-ED3 Efficient Analysis of Electrically Large EMC Problems using Parametrized Spherical Wave Based Macro Models (Sponsored by TC-9)

Experiment/Demonstration **10:00am - 12:00pm**

Room: Exhibit Hall Exp Demo 3

Chair: Jacob Dixon, *International Business Machines Corp, Rochester, MN, USA*

Co-Chair: Gabriel Alcala, *University of California Riverside, San Diego, CA, USA*

Efficient Analysis of Electrically Large EMC Problems using Parametrized Spherical Wave Based Macro Models

Moein Nazari

Cadence Design Systems Inc., USA

Abstract: Traditional full-wave electromagnetic (EM) simulation tools offer a high degree of flexibility to efficiently model EM emission, immunity, and radiated coupling for a wide range of 3D geometries in complex electromagnetic environments. However, for practical EMC problems, these full-wave solvers can be computationally intensive, particularly when analyzing complex structures in an electrically large environment, where the broadband and unintentional radiation characteristics of DUTs interactions need to be considered. To address this issue, we proposed an efficient framework that utilizes the Spherical Wave Expansion (SWE) theory. This framework decomposes the computational domain into pre-computed parameterized macro models and subsequently combines the individual results using appropriate system level simulation engines. The proposed theory offers a suitable SWE higher order mode truncation scheme that allows for the coupling of spherical modes between DUTs with high precision in both the nearfield and farfield regions, without the requirement of running a combined model. Decoupling the macro model simulations leads to significant reductions in memory/ disk requirements and overall simulations times by an order of magnitude or more in typical situations. A subset of the parametric/what-if EMC investigations especially those involving changes in orientation and separation between DUTs are extremely faster comparing to traditional methods. The performance and accuracy of the proposed method is evaulated using several examples including complex PCBs and standard antenna types commonly used in anechoic chambers.

WE-AM-ED4 Impact of a Decoupling Capacitor and Trace Length on Signal Integrity in a CMOS Inverter Circuit (Sponsored by TC-4)

Experiment/Demonstration **10:00am - 12:00pm**

Room: Exhibit Hall Exp Demo 4

Chair: Jacob Dixon, *International Business Machines Corp, Rochester, MN, USA*

Co-Chair: Gabriel Alcala, *University of California Riverside, San Diego, CA, USA*

Impact of a Decoupllng Capacitor and Trace Length on Slgnal Integrity in a CMOS Inverter Circuit

Mathew Yerian-French[1], Bogdan Adamczyk[2]

[1]E3 Compliance, USA; [2]Grand Valley State University, USA

Abstract: This demonstration shows the impact of the decoupling capacitors on the signal integrity at the VCC and GND pins in a CMOS inverter circuit. The length of the traces from the power source to the load is varied to change the loop inductance of the circuit. Waveforms at the VCC and GND pins, with respect to the source ground, with and without the decoupling capacitors are measured. The impact of the trace length and the capacitors on the power rail collapse and ground bounce is explained.

WE-PM-ED3 Signal Comparison in Time Domain and Frequency Domain (Sponsored by TC-2)

Experiment/Demonstration **12:00pm - 2:00pm**

Room: Exhibit Hall Exp Demo 3

Chair: Jacob Dixon, *International Business Machines Corp, Rochester, MN, USA*

Co-Chair: Gabriel Alcala, *University of California Riverside, San Diego, CA, USA*

Signal Comparison in Time Domain and Frequency Domain

Reza Yazdani

Missouri University of Science and Technology, USA

Abstract: In this experiment, the presenter will compare the signal waveform in the time domain and frequency domain. The measurements will show the results from the Oscilloscope and Spectrum Analyzer. From the Oscilloscope, the presenter will use the time domain and FFT results and from the Spectrum analyzer, and show the frequency domain and zero span results. The Zero span feature of the spectrum analyzer enables the time domain measurements. Lastly, the presenter will compare different waveforms and the results from both Oscilloscope and Spectrum analyzer and compare the results, and in conclusion, show the advantages and disadvantages of each method and measurement facility.

WE-ALL-D EM Interference Control, Shielding, Gaskets, Cables, Connectors, Grounding and PCB Layout (Sponsored by TC-4)

Technical Papers **8:00am - 4:30pm**

Room: Gallery Overlook D

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

Co-Chair: Davy Pissoort, *Katholieke Universiteit Leuven, Bruges, Belgium*

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

Co-Chair: Srinath Penugonda, *Missouri University of Science and Technology, Milpitas, CA, USA*

8:30am **Analysis of Methodology of Breakpoint Detection Method for 22.9kV Submarine Power Cable Based on the Time Domain Reflectometer (TDR)** 191

Hyunwoong Kim[1], Sanguk Lee[1], Jong-Man Joung[2], Bumjin Park[3], Seungyoung Ahn[1]

[1]Korea Advanced Institute of Science and Technology, Korea; [3]Korea Electric Power Corp, Korea; [3]Samsung Electronics, Korea

Abstract: This paper proposes and analyzes the breakpoint detection method for a long 22.9 kV submarine power cable based on a time domain reflectometer (TDR) depending on the various fault situations. Appropriate conditions are required in the fault situations to apply the detection method based on TDR impedance. The detection method requires that the rising time of the input source should be short enough to detect the length of the breakpoint. The shorter the rising time is, the more advantageous it is to detect the breakpoint, but a long power cable can significantly attenuate the high-frequency signal. Therefore, it is derived through analysis that the performance of the breakpoint can be determined depending on the input source and rising time.

9:00am **Comparison of Suppression Effect by CMF for UTP and STP Lines Using Chain Parameter Matrix** 196

Nobuo Kuwabara, Tohlu Matsushima, Yuki Fukumoto

Kyushu Institute of Technology, Japan

Abstract: Common-mode filter (CMF) is a vital device to improve electromagnetic compatibility (EMC), and the analysis of the CMF effect is essential to improve the design quality of EMC. This paper analyzes the suppression effect of CMF used for telecommunication lines using a chain parameter matrix. The chain parameter matrix represented the CMF and the interface cable, and the S21 at the far end of the cable was calculated. The analytical method was validated by comparing measurements using unshielded twisted pair (UTP) and shielded twisted pair (STP) cables. The results showed that the analysis method was appropriate for analyzing the suppression effect. Using the analysis method, the suppression effect was evaluated by the common mode (CM) current at the cable input and the radiated electric field. The result showed that the characteristic impedance and the transmission loss of the CM transmission line affect the suppression effect. The result also showed that the suppression effect by the radiated electric field could be estimated from the suppression effect by the CM current at the cable input.

9:30am **Near Field Scanning-Based EMI Radiation Root Cause Analysis in an SSD** 202

Xiangrui Su[1], Wenchang Huang[1], Junghee Cho[2], Joonki Paek[2], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]SK hynix Inc., Korea

BEST EMC STUDENT PAPER FINALIST

Abstract: In modern portable electronic devices, solid-state drives (SSDs) are commonly used and have been identified as one of the dominant electromagnetic interference (EMI) noise sources that can cause RF desensitization issues. In this paper, the EM emission source from an SSD module is identified and analyzed using near field scanning and dipole moment source reconstruction. The identified noise current path including the power management integrated circuit and the decoupling capacitor is validated with the assistance of full-wave simulation. The measured noise voltage is used as an excitation in the simulation and the simulated near fields showed a good correlation with measured near fields in both pattern and magnitude. Based on the validated radiation mechanism, an optimized layout is proposed and validated in simulation reducing the far field radiation by 10 dB.

10:30am **Two Advanced Types of Air Vent for Improved EMI Shielding and Air Flow** 207

Jianquan Lou[1], Alpesh Bhobe[2], Jerry Pianin[2], Joel Goergen[2]
[1]Cisco Systems (China) R&D Co., Ltd., China; [2]Cisco Systems, Inc., USA

BEST EMC PAPER FINALIST

Abstract: Air-vents on a system chassis are designed to allow efficient air flow to cool the system, while at the same time shield unwanted electromagnetic energy. With the speed and power consumption of systems increasing with new product generation, striking a balance between reducing EMI and meeting thermal requirements has become more challenging. This paper investigated two novel types of air vent for better shielding effectiveness (SE) and air flow performance. First one is air vent with openings of random size and location, dozens of cases were simulated and demonstrate that there exist some random cases which have better SE in certain frequency range without impacting on air flow performance. The other one is called air vent with non-uniform cross section, based on the Bernoulli's principle, several cases of air vent with different non-uniform cross section types were modeled, and both simulation data and measurement results show the improvement in EMI shielding effectiveness and pressure drop of air flow.

11:00am **EMI Performance of Multilayered Al-CoTaZr Films in Shielded Power Inductors** ..... N/A

Ghaleb AL Duhni[1], Mohammad Mohtasim Hamid Pial[1], Mudit Khasgiwala[2],
John L. Volakis[1], Pulugurtha Narkondeya Raj[2]
[1]Florida International University, USA; [2]Applied Materials, USA

Abstract: This paper examines the performance of multilayered Al-CoTaZr films as electromagnetic interference (EMI) shields. The first part of the paper simulates the shielding effectiveness (SE) of several combinations of multilayered stacks of Al and CoTaZr of 10 µm thickness. Using the NSA 65-6 standard in the frequency range of 1-100 MHz, four and five layers of [Al (2 layers)-CoTaZr (2 layers) and Al (2 layers)-CoTaZr (3 layers)] are shown to provide SE of 10-62 dB. By comparison, commercial EMI shielding, such as Cu, shows only 6-41 dB in the same frequency range. Alternatively, using the IEEE 299 standard, the same thickness of AL and CoTaZr samples give 40-70 dB SE as compared to that of Cu which ranges from 12-46 dB. The second part of the paper studies the impact of various multilayers of Al CoTaZr to mitigate undesired magnetic radiation of power inductors. The last part of the paper compares the SE of thin multilayered samples (5µm) versus thick films of Copper and Al (10 µm). It is demonstrated that four and five-layer stacks of Al and CoTaZr (5 µm thick) based on the NSA 65-6 standard, exhibit similar shielding performance as commercial materials of 10 µm of Cu and Al.

11:30am **Design and Optimization of the Porous Metamaterial EM Absorbers in X-band** 218

Kanat Anurakparadorn, Alan Taub, Eric Michielssen
University of Michigan, USA

Abstract: A strategy that combines experiment and simulation to design and optimize electromagnetic (EM) metamaterial absorbers containing a periodic porous structure is described. The approach provides the ability to produce absorbers that meet multiple user-specified objectives. Using the measured intrinsic properties of the baseline materials as an input to EM-field based computational modelling and optimization, absorption by the studied metamaterials measured by their reflection loss (RL) increases significantly. The resulting metamaterials have the potential for lower cost and lighter weight while providing greater protection than traditional metal gaskets and foams.

1:30pm **Determining the Coaxial Cable Transfer Impedance with the 3-Port Equations of the Transmission Line** ..... N/A

Valentin Buzduga

Scantek, Inc., Switzerland

Abstract: This paper proposes a method for calculating the transfer impedance of the coaxial cables by using the three-port characteristic equations of the transmission line. The author presents these three-port equations, discusses the characteristic parameter named the asymmetry coefficient of the line, and then calculates the transfer impedance of the coaxial cables.

2:00pm **Interference in RF Shielded Rooms Due to Potentials between Grounded Surfaces** 220

Marc Gaidosh

Fujifilm Healthcare Americas, USA

Abstract: Potentials between 'grounded' surfaces in a RF shielded room can cause interference in sensitive equipment. RF shielded rooms such as those used for Magnetic Resonance Imaging (MRI) scanners are examples of equipment susceptible to interference as a result of imperceptible arcs. These tiny arcs are usually intermittent making them problematic for troubleshooting.

WE-AM-E Computational Electromagnetics, Modeling and Simulation, Multi-Physics Techniques, Tools, and Applications (Sponsored by TC-9)

Technical Papers **8:00am - 12:00pm**

Room: Gallery Overlook E

Co-Chair: Scott Piper, *General Motors Corp, Canton, MI, USA*

Co-Chair: Shaowu Huang, *Marvell Semiconductor Inc, Cupertino, CA, USA*

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

8:00am **Understanding the Time Reversal Symmetry in Classical Electrodynamics** ..... N/A

Bohao Zhang, Shaoyin He, Yanzhao Xie

Xi'an Jiaotong University, China

Abstract: In this paper, the time reversal operation of physical laws with covariant forms is analogous to a generalized Lorentz boost. Based on this ideation, a time reversal form of the classical Maxwell's equations is proposed, which is intended to provide theoretical support for relevant research in the field of EMC/EMI based on electromagnetic time reversal technique.

8:30am **Isogeomtric Analysis Using C^2 Interpolating Splines for Curved Objects in EMC Problems** 226

Tadatoshi Sekine, Nobuhisa Tanaka, Shin Usuki, Kenjiro T. Miura

Shizuoka University, Japan

Abstract: This paper describes an electromagnetic simulation technique based on isogeometric analysis (IGA) using C^2 interpolating splines. Since the C^2 interpolating splines pass through control points of curves and surfaces, boundary conditions can be directly applied on the control points in the proposed IGA formulation.

9:00am **A Data-Driven Approach to Multiresolution Analysis of Near-Field Scanning** 227
Yanming Zhang, Lijun Jiang
The Chinese University of Hong Kong, China

Abstract: Near-field scanning has been widely adopted as a valuable tool in diagnosing electromagnetic compatibility (EMC) and electromagnetic interference (EMI) problems. This paper proposes a multiresolution dynamic mode decomposition (MRDMD)-based method for analyzing time-varying near-field radiation. MRDMD executes the traditional DMD method recursively and hierarchically. The distribution of DMD eigenvalues determines the slow and fast modes in a level's decomposition, in which the slow modes are reserved, and the fast modes are utilized to generate the input data for the next level. Finally, the multiresolution time-frequency representation of the near-field radiation field is obtained. And the spatial distributions corresponding to each frequency component are also extracted. A numerical example of turning three loop antennas on and off is conducted to validate the proposed MRDMD method. The multiresolution time-frequency representation of the near-field radiation shows a good agreement with the actual ones regarding the excitation duration and frequency components. Besides, the spatial distributions in the scanning plane radiated by each loop antenna are derived correctly. Hence, our work offers a multiresolution analysis tool for near-field scanning, especially when the spatial-temporal information of each frequency component is needed.

9:30am **Data Assessment Method Based on the Statistical Analysis** 232
Beatrice Jiang[1], Lisa Ryder[1], Ping Li[2]
[1]Westlake High School, USA; [2]Shanghai Jiao Tong University, China

Abstract: Data quality assessment for results from computational electromagnetics (CEM) tools and experimental data is an important and necessary part of electromagnetic compatibility (EMC), signal integrity (SI) and power integrity (PI) studies. This problem was addressed by the popular feature selection validation (FSV) method that has been taken into IEEE P1597 standard for CEM. In this paper, we propose a new idea by using a statistical method and the Data Science tool R to quantitatively analyze the differences between two data sets. The Pearson correlation coefficient r and the coefficient of determination R2 are both employed as quantified indicators to analyze the pattern of data sets and their mutual agreement respectively. It further calculates the shift between datasets. By removing the shift, it can disclose their hidden relationship. Benchmarks for transient and spectrum cases are used to demonstrate its effectiveness. The proposed method will serve as a convenient addition to existing methods in IEEE P1597.1 and P1597.2 adopted by the IEEE EMC community. It will be released as a web tool coded for the EMC society by the time of conference.

10:30am **Magnetic Noise Calculations in the Presence of Three Torque Rods for Spacecraft Applications** 237
David Norte
Ball Aerospace, USA

Abstract: This paper addresses magnetic noise calculations in the presence of X, Y, and Z directed torque rods for spacecraft, and where it is desired to obtain the magnetic noise, in units of nT/√***Hz***, at the location of a magnetically sensitive instrument that is characterized with an extremely low bandwidth (0.5 – 20.0) Hz. The instrument, characterized with a maximum ambient magnetic noise level of 1.0 nT/√***Hz*** that cannot be exceeded, is either 0.5m, 1.0m, or 1.5m from the set of torque rods, and where the torque rods are controlled through PWM signals. Exceeding this level (1.0 nT/√***Hz***) can interfere with the intended operation of the instrument.

11:00am **The Impacts of On-Board ESD and Time-Division Multiplexed Switching Events on the Magnetic Noise from Solar Panels for Space Applications** 238
Rachel Lumnitzer, David Norte
Ball Aerospace, USA

Abstract: Regarding the management of power derived from solar panels for space missions, it is of interest to understand how switching events can cause magnetic noise from the panels, which might then interfere with the success of the mission. In this paper, the magnetic noise resulting from the time-division-multiplexed switching of groups of strings of solar cells to regulate the current that is available from the panel is addressed. In addition to these switching events, it is also of interest to understand how ESD events, originating from the spacecraft itself, can cause high-frequency secondary magnetic noise from the panel. By characterizing these noise sources, it can be determined, for example, if the strengths of these interferences cause degradations in the intended operation of the mission. In this paper, these determinations are based upon the use of the magnetic transfer function from the panel to a given location of interest on the spacecraft. Once the frequency spectrum of the interfering event is characterized, then the product of this spectrum with the magnetic transfer function produces the expected interference at the location of interest, after which it can be determined if any mitigation is required.

11:30am **Magnetic Fields and Minimum Safe Distances for UAS during Transformers Inspection** 244
Dulana Rupanetti, Issam Boukabou, Landon Foust, Selma Benouadah, Naima Kaabouch
University of North Dakota, USA

Abstract: Nowadays, Unmanned Aerial Systems (UAS) play a crucial role in inspecting and maintaining powerline systems, such as transmission towers, power lines, transformers, etc. UAS operating in the vicinity of these high-voltage components are constantly affected by the emitted magnetic fields, such as large power transformers, which can impact the electronic components of the UAS, resulting in collisions, casualties, and injuries. Minimal work has been done to estimate these fields and the safe distances from transformers for UAS to operate. This paper uses three-dimensional (3D) finite element analysis to analyze the minimum safe operating distances for UAS around power transformers emitting low-frequency magnetic Fields. We Examine a three-phase 2500 kVA pole-mounted transformer and a bank of single-phase pole-mounted 20 kVA transformers using finite element analysis and provide analyzed data on the safe operational distances for UAS.

WE-AM-F Lessons Learned from NASA EMC: Looking Back and Forward (Sponsored by TC-8)

Tutorial **8:00am - 12:30pm**
Room: Gallery Overlook F
Chair: Jen Dimov, *NASA, Greenbelt, MD, USA*
Co-Chair: Manuel Soriano, *NASA-Jet Propulsion Laboratory, Los Angeles, CA, USA*

Session Abstract: With several big flagship programs getting launched, this is an opportune year to take some time for a retrospective on the lessons learned applicable to large aerospace programs – what went well and can offer an example of good practices? What went poorly and serves as an example of what not to do? – from both long and short programs.

Twenty Years with the James Webb Space Telescope
John McCloskey
NASA Goddard Space Flight Center, USA

JWST Deep Dive – The NIRCam Instrument-Level Test
Jim Lukash
Lockheed Martin Space Systems, USA

Preventable Disasters: What Not To Do
Annabelle Epplin, Robert Houle
NASA Goddard Space Flight Center, USA

Roman Space Telescope EMC Testing
Nick Davis
NASA Goddard Space Flight Center, USA

Heavy Metal: EMC and Magnetics for the Psyche Mission
Manuel Martin Soriano
NASA - Jet Propulsion Laboratory, USA

PACE – Adventures in Magnetics
Jen Dimov
NASA Goddard Space Flight Center, USA

WE-AM-G Cutting through the Copper Tape: Getting to Root Cause when Troubleshooting (Sponsored by TC-4)

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

Room: Gallery Overlook G

Chair: Kajsa Johnson, *Microsoft Corp, Redmond, WA, USA*

Co-Chair: Karen Burnham, *Electro Magnetic Applications, Inc., Lakewood, CO, USA*

Session Abstract: The lab called, your product is failing. Now what? What does it take to fully understand the problem, and fix it at its root cause? Join us as we explore some common areas for bugs (emissions, ESD, and transients), how to quickly get to root cause, and arrive at more effective solutions.

Radiated Emissions Troubleshooting 102: Understanding and Fixing the Problem (at the Root-cause!)

Kajsa Johnson

Microsoft Corporation, USA

Debug Conducted Issues

Patrick André

André Consulting, Inc., USA

Benchtop Troubleshooting Top Two Immunity Issues

Kenneth Wyatt

Wyatt Technical Services LLC, USA

WE-ALL-H Signal and Power Integrity, Interconnects, Modeling and Characterization, Crosstalk, Jitter, Noise (Sponsored by TC-10)

Technical Papers **8:00am - 5:30pm**

Room: Gallery Overlook H

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

Co-Chair: Yuandong Guo, *Missouri S&T EMC Laboratory, Missouri University of Science and Technology, Rolla, MO, Foster City, CA, USA*

Co-Chair: Yin Sun, *Missouri University of Science and Technology, Rolla, MO, USA*

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

Co-Chair: Tao Wang, *Teradyne Inc, Agoura Hills, CA, USA*

Co-Chair: Hanqiao Zhang, *Meta Platforms Inc, Redmond, WA, USA*

8:00am **System Level PDN Impedance Optimization Utilizing the Zeros of the Decoupling Capacitors** 249

Yifan Ding[1], Shuang Liang[1], Francesco de Paulis[2], Matteo Cocchini[3], Samuel Connor[3], Matthew S. Doyle[3], Albert Ruehli[1], Chulsoon Hwang[1], James Drewniak[1]

[1]Missouri University of Science and Technology, USA; [2]University of L'Aquila, Italy; [3]IBM, USA

Abstract: System-level power distribution network (PDN) impedance optimization utilizing the zeros of the decoupling capacitors (decaps) is discussed in this paper. An example of a practical PDN application is proposed to validate the poles and zeros algorithm (P&Z) presented. The system-level PDN is with the printed circuit board (PCB), package (PKG), and chip, as well as the low-frequency decaps on the PCB and the on-PKG decoupling capacitors. The PDN optimization results are compared with those from the genetic algorithm (GA) to show the reasonableness and validity of the P&Z algorithm.

8:30am **Augmented Genetic Algorithm v2 with Reinforcement Learning for PDN Decap Optimization** 255

Haran Manoharan[1], Jack Juang[1], 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

Abstract: Genetic algorithms (GAs) use many hyperparameters, and tuning these parameters can determine the optimization performance. A GA with an augmented initial population was proposed for decap optimization but it had convergence issues by getting stuck in the local minimum. This work uses a reinforcement learning (RL) approach to adaptively tune the hyperparameters of GA during its operation. With this approach, the agent tries to change the parameters so that the GA does not get stuck in the local minimum. The proposed method combining the RL agent and Augmented GA showed better performance in terms of solution quality and time cost. Overall, in all the cases tested, the proposed method showed better performance than the Augmented GA without RL.

9:00am **Die Capacitance and Power Distribution Network Modeling Method through Measurement of Resonant Frequency** 259

Marie Peyrard[1,2], Gilles Jacquemod[1], Nicolas Froidevaux[2], Mélanie Moign[2]

[1]Universite Cote d'Azur Institut Universitaire de Technologie, France; [2]STMicroelectronics, France

BEST SIPI STUDENT PAPER FINALIST

Abstract: This paper presents a modeling method of the die capacitance and Power Distribution Network (PDN) of a microcontroller (MCU), using the measurement of its main resonant frequency. Occurring between the die capacitance and the microcontroller's interconnect inductance, this resonance is an important concern for the power integrity of an MCU power supply. Therefore, modeling the PDN and simulating this frequency is crucial during the design phase. The die model is usually established for a defined worst-case activity, hard to correlate with measurements. In this paper, we present a method to model the die capacitance independently of any specific MCU operation. The model is built and validated using a previously developed measurement method for several decoupling configurations [1]. The resonant frequency measurement and simulation results showed good correlation.

9:30am **An Analysis on the Effectiveness of 2 and 3 Terminal Capacitors in PDN Design** 264

Jack Juang[1], Jiahuan Huang[1], Anfeng Huang[1], Kelvin Qiu[2], Hanfeng Wang[2], Yansheng Wang[3], Zhiping Yang[4], Chulsoon Hwang[1]

[1]Missouri University of Science and Technology, USA; [2]Google LLC, USA; [3]Rivos Inc., USA; [4]Waymo LLC, USA

Abstract: The parasitic inductance of a capacitor depends on its physical structure. Due to the geometry of 3-terminal capacitors, they boast a lower parasitic inductance compared to 2-terminal capacitors of the same and possibly smaller package sizes. While the parasitic inductance of a single 3-terminal capacitor may be lower, using multiple 2-terminal capacitors may result in similar performance. In this work, the inductance of 2-terminal (0201, nominal 2.2 uF) and 3-terminal (0402, nominal 4.3 uF) capacitors is extracted and compared through measurements. From our de-embedding method and characterized capacitors, the inductance of 2-terminal capacitors is only about ~20 pH higher than the characterized 3-terminal capacitor. On a power net of a real product, 3-terminal capacitors of the same type as characterized were replaced with 2-terminal capacitors of the same type as characterized. From measurement results, the measured inductance at 100 MHz is lower by only

10:30am **Signal Integrity Comparison of Commercially Available Sockets for the 50Gbps Ethernet Channel** ..... N/A

Nupur Basak, Oluwafemi Akinwale

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.

11:00am **Noise Performance Comparison: ENRZ, NRZ, PAM3, and PAM4** 275

Sherman S. Chen[1], Armin Tajalli[2], Brian Holden[1], Francesco de Paulis[3], Bob (Pushui) Xu[4]
[1]Kandou Bus, United Kingdom; [2]The University of Utah, USA; [3]University of L'Aquila, Italy; [4]Analogix Semiconductor Inc., USA

Abstract: The noise performances of four line codes, i.e., Ensemble Non-Return-to-Zero (ENRZ), Non-Return-to-Zero (NRZ), Pulse Amplitude Modulation of 3-level (PAM3), and Pulse Amplitude Modulation of 4-level (PAM4) are investigated. The closedform signal-to-noise ratio (SNR) formulas of the four codes are deduced. The method of injecting noise onto high-speed channels is described. Channel simulation running at 128 Gbps (for NRZ, PAM3, and PAM4) and 256 Gbps (for ENRZ) is performed and the resulting eye diagrams are compared. In addition, a brief categorization of external and internal noise types is also presented. The study shows that ENRZ and NRZ demonstrate less degradation than PAM3 and PAM4 under the influence of Gaussian thermal noise.

11:30am **High-Speed Differential Via Optimization using a High-Accuracy and High-Bandwidth Via Model** 280

Chaofeng Li[1], Kevin Cai[2], Manish Kizhakkeveettil Mathew[1], Seyedmehdi Mousavi[1], Muqi Ouyang[1], Bidyut Sen[2], DongHyun Kim[1]
[1]Missouri University of Science and Technology, USA; [2]Cisco Systems, Inc., USA

Abstract: A physics-based equivalent model of the high-speed differential via pair with high accuracy and high bandwidth is proposed for the first time. The proposed physics-based equivalent circuit model of the differential via pair includes the effect of adjacent ground (GND) vias. The proposed model is verified using 3D full-wave numerical simulation results. In addition, the change in electrical performance due to change in anti-pad radius, the via pitch and the GND-via- -to-differential-via distance is analyzed. Based on the analysis, electrical performance of differential via pair can be accurately and rapidly optimized with respect to design parameters, such as the via pitch, the anti-pad radius and the GND-via-to-differential-via distance using the proposed model, to provide pre-layout design guide for high-speed channel designers. By using the proposed high-accuracy and high-bandwidth physics-based via model, the via optimization time can be drastically reduced with high accuracy.

1:30pm **Analysis of Mesh Ground Impact on Microstrip Lines in Flexible Printed Circuits** 286

Yuchu He, Hanfeng Wang
Google LLC, USA

Abstract: Meshed ground (GND) planes are widely used in flexible printed circuit boards to reduce weight and increase flexibility. However, analyzing the impact from the meshed GND in a transmission line structure can be challenging. In this paper, an extraction method is proposed to obtain the characteristic impedance of a transmission line over the meshed GND planes. With the proposed method, a systematic study was carried out to investigate the relationship between the meshed GND plane geometric parameters and the trace characteristics.

2:00pm **Modeling of a Microstrip Line Referenced to a Meshed Return Plane** 291

Ze Sun[1], Jian Liu[2], Xiaoyan Xiong[2], Yuan Liu[2], Victor Khilkevich[1], DongHyun Kim[1], Daryl Beetner[1]
[1]Missouri University of Science and Technology, USA; [2]Cadence Design Systems Inc., USA

Abstract: Transmission lines referenced to meshed return planes are widely used because of the physical flexibility imparted by the meshed plane. Poor accounting for the meshed ground, however, can lead to severe signal integrity and radio frequency interference issues. Full-wave simulation can characterize the electrical performance at an early design stage, but it is both time and computational resource consuming. To make the simulation more efficient, a method is proposed in this study to model transmission lines with a meshed reference ground using 2D analysis. The 2D analysis is performed at several locations along the length of the trace above the meshed return to determine per-unit-length RLGC parameters and partial self- and mutual-inductances of the trace and meshed return. The partial self-inductance of the return is then corrected to account for the current direction along the mesh. Cascading the corrected S-parameters for each segment is then used to estimate the overall characteristics of the transmission line. Results found using this approach closely match those found with 3D full-wave simulation.

2:30pm **Target Signal Reconstruction by Reflection Cancellation Method to Distortion Signal from Measurement** ..... N/A

ChunJu Lin, Scott Lee
Ring, Taiwan

Withdrawn

Abstract: It is essential to measure signals to verify and validate the functionality of the circuit. However, due to physical limitations, sometimes we can't measure the signal at an arbitrary point. This may cause the inaccurate measurement. We developed an algorithm to recover the signal we want at the receiver end. Since the main sources of the difference between measure signal and real input are the reflections from the receiver, we first utilized autocorrelation to find the delay of the reflection. Then we calculated the reflection coefficient based on the waveform we obtained. After developed the algorithm, we listed some limitations of our method and the reasons of these limitations.

3:30pm **Simplifed Equivalent Golden Finger Port Setup for Fast and Accurate High-Speed Channel Simulation** 301

Chaofeng Li[1], Kevin Cai[2], Mehdi Mousavi[1], Manish Kizhakkeveettil Mathew[1], Bidyut Sen[2], DongHyun Kim[1]
[1]*Missouri University of Science and Technology, USA;* [2]*Cisco Systems, Inc., USA*

Abstract: A simplified equivalent golden finger port setup is proposed for efficient, accurate 3D full-wave simulation for high-speed channels. The bent connector pins, which mate with the golden finger, are simplified as equivalent cylindrical pins to meet the wave port setting requirements for 3D full-wave simulation. The effects of the equivalent cylindrical pin location and diameter are analyzed through 3D full-wave simulation. A closed-form expression is newly proposed to correlate the location and diameter of the equivalent cylindrical pin with respect to the widely used bent connector pin. On the basis of the closed-form expression, the bent connector pin can be accurately replaced by the simplified equivalent cylindrical pin structure in 3D full-wave simulation. Practical examples using commercial high-speed connector pin models with gold fingers verify that the proposed modeling method is accurate and efficient up to 40 GHz.

4:00pm **A Comparative Study of Performance of Eigenvalue Solvers for Parallel Vector Fitting in Multiport Tabulated Data Modeling** 306

Vinay Kukutla, Ramachandra Achar
Carleton University, Canada

Abstract: Modelling of high-speed modules such as electronic packages and non-uniform transmission lines based on multi-port tabulated measured or EM simulated data is becoming increasingly important in modern designs. Vector Fitting (VF) was first introduced as an algorithm for system identification via rational function approximation from tabulated data. Since the algorithm is iterative in nature, minimizing its computational cost and parallel efficiency on mixed CPU and GPU environments is critical in reducing the overall time needed for convergence. One of the expensive steps in these parallel VF approaches is computing the complex eigenvalues of thousands of small, square matrices that result from the All-Splitting method of the parallel VF algorithm. The computational expense of this step tends to vary vastly based on the solver as well as the multi-core CPU architecture used, hence it is useful to the designer to know which solver and platform to use for efficient use of the algorithm. For this purpose, a comparative performance study of the state-of-the-art eigenvalue solvers when using prominent multi-core platforms of AMD and Intel is presented in the context of parallel VF. Results demonstrate that the architecture as well as the type of solver used can significantly impact the efficiency.

4:30pm **Near-Field EMI Analysis of LPDDR5 DRAM at Idle Mode** 311

Jun-Bae Kim[1], Chang Ki Kwon[1], Taeho Kim[1], Sangwook Park[1], Yoo-Chang Sung[1], Jeong Don Ihm[1], Seung-Jun Bae[1], Jingook Kim[2]
[1]*Samsung Electronics, Korea;* [2]*Ulsan National Institute of Science and Technology, Korea*

Abstract: We conducted an analysis to reduce Electro- Magnetic Interference (EMI) from mobile Dynamic Random Access Memories (DRAMs) by measuring baseline EMI radiation, specifically during idle modes of LPDDR5 DRAMs. We measured the peak H-field over LPDDR5 dies and compared it against our High Frequency Structure Simulation (HFSS). Our observation showed that the peak H-field's frequency components are well correlated with the harmonic frequency spectrum of the internal LPDDR5 Command and Address (CA) path's Common Mode (CM) currents that pass through chip power or ground Re- Distribution Lines (RDL), package power or ground layers, and Printed Circuit Board (PCB) substrate layers. Both near H-field maps of our measurement and simulation showed reasonable agreement on the peak H-field radiation mostly through the CM current's power or ground paths. This finding suggests that the other radiation through external CA signal paths can be neglected, particularly during the idle modes.

WE-PM-AtE

Ask the Experts Panels 2:00pm - 3:30pm

Room: Exhibit Hall
Chair: Larry Banasky, *Stryker Medical, Atlanta, GA, USA*

Session Abstract: Bring your questions or simply listen and learn!

Challenges in Medical EMC

PLANNED PANELISTS INCLUDE:

- Matt Owen, *Stryker Instruments*
- Jeff Silberberg, *FDA*
- David Schaefer, *Element Materials Technology*
- Curt Sponberg, *Medtronicy*

Abstract: The safety of patients and caregivers is vitally important when considering the design of medical devices. Safety considerations, along with the increased use of electronics in environments of use, make medical device EMC a difficult process. This discussion will focus on the challenges in medical EMC and will include panelists with experience from different facets of the medical device world.

WE-PM1-ED1 Shielding Effectiveness Design to 10GHz and Beyond, Using Fast Stochastic Simulation (Sponsored by TC-4)

Experiment/Demonstration 12:00pm - 2:00pm

Room: Exhibit Hall Exp Demo 1
Chair: Jacob Dixon, *International Business Machines Corp, Rochester, MN, USA*
Co-Chair: Gabriel Alcala, *University of California Riverside, San Diego, CA, USA*

Conducted and Radiated Crosstalk between Shielded Cables, using Fast Stochastic Simulation

Paul Bremner, Weitao Dai, Reza Afra, Arielle Frank
RobustPhysics, USA

Abstract: Designing cables, connectors and enclosures for EMC compliance at system-level and at high frequencies is difficult, due to coupled conduction and radiation paths, shield/joint/seam leakage, connector and cable penetration uncertainties, excitation field complexity, etc. For most EMC engineers, numerically-meshed, full wave models are too large, expensive and slow to be an interactive design tool - particularly at high frequencies 1GHz and above. New, statistically-reduced order models by comparison, are a more natural solution for his class of problem, applicable up to 10 Ghz and beyond.

STOCHASTICA software from RobustPhysics will be used to demonstrate how the new stochastic simulation facilitates fast, interactive EMC environment predictions - both currents on cables and coupled electric fields in reverberant enclosures - in minutes rather than days.

Combined Tutorial and Software demonstrations for three (3) different EMC design applications will be presented.

WE-PM2-ED1 Common Mode Currents, Loop Impedance, and the Use of Ferrites (Sponsored by TC-4)

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

Room: Exhibit Hall Exp Demo 1

Chair: Jacob Dixon, *International Business Machines Corp, Rochester, MN, USA*

Co-Chair: Gabriel Alcala, *University of California Riverside, San Diego, CA, USA*

Common Mode Currents, Loop Impedance, and the Use of Ferrites

Patrick G. André

Andre Consulting, Inc., USA

Abstract: Understanding Common Mode Current and how it is generated is important for the control of radiated emissions. This demonstration will discuss and show how the loop impedance affects the return path of the current over frequency. There will be an explanation of the physics behind the signal path taken for the return signal. Finally, a discussion on how the use of ferrites can influence the return path of the signal, and limitations on the use of ferrites at high frequency.

WE-PM-ED2 Impact of Decoupling Capacitors and Embedded Capacitance on Impedance of Power and Ground Planes (Sponsored by TC-4)

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

Room: Exhibit Hall Exp Demo 2

Chair: Jacob Dixon, *International Business Machines Corp, Rochester, MN, USA*

Co-Chair: Gabriel Alcala, *University of California Riverside, San Diego, CA, USA*

Impact of Decoupllng Capacitors and Embedded Capacitance on Impedance of Power and Ground Planes

James E. Teune[1], Bogdan Adamczyk[2]

[1]E3 Compliance , USA;[2]Grand Valley State University, USA

Abstract: In Part I we investigate two four-layer PCBs with the power- and ground-plane pairs spaced 3 mils and 30 mils apart, respectively. The boards are populated with decoupling capacitors of the same value (lnF), placed at three different distances from the measurement point.

In Part II we use the 30-mil boards and populate them with multiple capacitors of the same value, as well as with the capacitors of different values, decades apart. The location of the capacitors for all cases in this study is 1 inch away from the measurement point.

WE-PM-ED4 Shielding Effectiveness Design to 10GHz and Beyond, Using Fast Stochastic Simulation (Sponsored by TC-4)

Experiment/Demonstration **2:00pm - 4:00pm**
Room: Exhibit Hall Exp Demo 4
Chair: Jacob Dixon, *International Business Machines Corp, Rochester, MN, USA*
Co-Chair: Gabriel Alcala, *University of California Riverside, San Diego, CA, USA*

Predicting Integrated System EMC Levels for Test Level Tailoring , using Fast Stochastic Simulation

Paul Bremner, Weitao Dai, Reza Afra, Arielle Frank
RobustPhysics, USA

Abstract: Designing cables, connectors and enclosures for EMC compliance at system-level and at high frequencies is difficult, due to coupled conduction and radiation paths, shield/joint/seam leakage, connector and cable penetration uncertainties, excitation field complexity, etc. For most EMC engineers, numerically-meshed, full wave models are too large, expensive and slow to be an interactive design tool - particularly at high frequencies 1GHz and above. New, statistically-reduced order models by comparison, are a more natural solution for his class of problem, applicable up to 10 Ghz and beyond.

STOCHASTICA software from RobustPhysics will be used to demonstrate how the new stochastic simulation facilitates fast, interactive EMC environment predictions - both currents on cables and coupled electric fields in reverberant enclosures - in minutes rather than days.

Combined Tutorial and Software demonstrations for three (3) different EMC design applications will be presented.

WE-PM-PS Poster Session

Poster Session **1:30pm - 3:30pm**
Room: Exhibit Hall Posters
Chair: Eugene Saltzberg, *University of Detroit Mercy, Detroit, MI, USA*

The Application of a High-Precision Spherical Calibrator to Millimeter-Wave Radar Product Production Test ..... N/A

Yu Tian[1], YongChang Jiao[1], Zibin Weng[1], Yunlong Luo[2], Jun Li[3], Yihong Qi[4]
[1]Xidian University, China; [2]Southwest Jiaotong University, China; [3]Dalian Maritime University, China; [4]General Test Systems Inc., China

Abstract: Millimeter wave (mmWave) radar has demonstrated good target monitoring capabilities in total multiple domains for its low cost and good environmental adaptability, such as smart home, health monitoring, autonomous driving, and in-vehicle applications. For these mission-critical applications, the performance of radar has become the key to the safe application of products. A widely used method for evaluating the performance of radar systems is to calibrate the antenna link pattern of radar transceivers by using calibrators. For mass production applications of mmWave wave sensors with critical performance, the use of trihedral corner reflectors as calibration objects may require a lengthy calibration process. In this paper, the spherical ball is proposed as a calibration target for radar system performance evaluation, and its scattering characteristics are analyzed. The simulation analysis and experimental test of the radar cross section (RCS) stability of different calibration objects are carried out, which proves that the scattering performance of the spherical ball reflector is more stable than that of trihedral corner reflectors stable and ensures higher calibration accuracy. In addition, using the spherical ball reflector as a calibration object can also reduce the overall size of the test system.

Abstract: Recently, the exposure of automotive electronic components to electromagnetic waves in the near-field has become a serious concern due to the rapid increase in the application of wireless communication technology in vehicles. Hence, having a good performance for near-field electromagnetic immunity becomes highly required. However, many automotive electronic components face challenges in meeting the requirements of near-field immunity tests. One of the primary reasons for this problem is the lack of robust design for electromagnetic immunity during the design phase, as the level of radiated field strength at the DUT (Device Under Test) is not known. Despite this necessity, studies on near-field strength prediction methods lack. In this paper, the test environment of near-field immunity test that the requirement highly increased recently was studied and the prediction method of field strength using simulation is proposed. The use of two designed antennas was proposed to increase the coincidence rate of the pre-prediction, and the validity was performed under various conditions that considered the real test conditions. As a result, the proposed prediction method satisfies the error rate +/-10% compared to the measurement result. Since it is possible to consider the electromagnetic field strength in the design stage, we expect that it will be possible to reduce development costs and increasing design work efficiency by strengthening the design and reducing failure cases.

Abstract: In order to research relaxation in long cables and record the trailing signal under rectangular pulse, TVS diode is deployed to limit the magnitude of the measured signal. However, the large junction capacitance values of conventional transient voltage suppressor (TVS) diode can cause some serious problems like high insertion loss and waveform distortion of the trailing signal. A TVS diode based voltage limiter that features low capacitance values is proposed. Its circuit is essentially a series and parallel circuit of diodes and TVS diode. The TVS diode based protection circuits were measured under rectangular pulse with their protection effects recorded. The results show that the voltage limiter makes an effective protection of the oscilloscope and limits the degradation of signal integrity, improving the wave quality of the recording trailing signal.

Abstract: Today, the application range of electromagnetic compatibility technology in communication network continues to expand, making the interference problems among antenna devices in the network obviously reduced, which are also the basis for these devices to achieve normal network coverage. In this paper, the antenna optimization technology and the common coverage problem in the network would be studied as the analysis object. In order to respond to the coverage invalidation problems caused by equipment shutdown or configuration errors of existing network base stations, the rapid optimization design scheme of coverage compensation based on the soft adjustment method of antenna weight parameters is proposed. The coverage compensation mechanism is mainly triggered by the base station alarm information. Based on network data and intelligence simulation technology, the coverage ranges to be compensated for the invalid base stations are identified. By calculating and determining the adjacent base stations that meet the optimization conditions and analyze the weight optimization schemes one by one, judging the coverage effect simultaneously, and then outputting the current optimal weight scheme to complete the dynamic compensation of the coverage. The actual verification shows that the optimization schemes achieved coverage compensation optimization goal of the expired base station better on the basis of keeping the original coverage indicators of the compensated base station stable. The research scheme has obvious optimization effect on the coverage invalidation problems and has the positive effect on ensuring stability of network quality.

Abstract: The requirements of advanced elastomeric materials for automotive, communications and consumer electronics become more demanding as devices continue to miniaturize and receive data at wider ranges of frequencies. Electrically conductive and EMI shielding silicone composites are advanced elastomeric solutions for shielding, grounding, and bonding and offer broad application temperatures, high purity, low flammability and toxicity, fast processing speed, and thermal aging stability. Tunable electric and mechanical performance of these silicones is discussed and compared to other organic resin solutions such as epoxy and polyurethanes.

Abstract: The paper explores an inductive matching network to compensate for impedance discontinuities on high-speed MIPI CPHY links on XR development, prototyping and production platforms, such as the intrinsic low characteristic impedance of a Multiplexers (MUX). A 5.5 PI spiral matching network improved impedance and return loss from 30 to 45ohms and at least 5 dB, respectively. The eye width and eye height also improved across different data rates. The matching network was designed with PCB area in consideration to accommodate the ultra-compact nature of XR devices. It also should not add extra cost to PCB manufacturing.

WE-PM1-E Nanotechnology and Advanced Materials (Sponsored by TC-11)

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

Room: Gallery Overlook E

Chair: Emmanuel Decrossas, *NASA Jet Propulsion Laboratory, Pasadena, CA, USA*

Abstract: In this work, the permittivity of a 3D-printed carbon fiber-loaded anisotropic material, XT-CF20, is examined further. The microstructure of XT-CF20 is first examined via optical imaging and is shown to be composed of inclusions that are aligned with the print direction of the sample. The permittivity tensor for the aligned microstructure is then measured using a capacitive measurement technique and simulations are provided to demonstrate the validity of this measurement method. The simulated permittivity values for XT-CF20 samples with varying infill structures are then presented and compared to the measured permittivity values of said samples. An error of less than 12% between the simulated and measured permittivity values was observed validating the measured permittivity tensor and claims about the cause of the anisotropy presented in this work. The pronounced effect of a sample's infill on the permittivity tensor of the sample is then discussed along with the conclusions of this work and possible future topics of work for the authors.

Abstract: A new method to design graphene based absorbing textiles is proposed. These textiles consist of graphene based coatings acting as lossy layers, of textiles acting as spacers and supported by metallic layers functioning as perfect electric conductors. Polyester fabrics are selected as textiles and coatings are made of polyvinylidene fluoride (PVDF) matrices filled with different amounts of graphene nanoplatelets (GNPs). The developed method is used to evaluate the ideal thicknesses of the graphene based coatings and of the textiles. The optimal thicknesses are calculated for frequencies of 25.8 GHz and 27.9 GHz to achieve a -10 dB bandwidth that covers the 5G frequency bands between 23.8 and 40 GHz. The absorption performances of the resulting absorbing structures will be evaluated in the 5G high frequency range.

2:30pm **Solventless Electrically Conductive Silicones for EMC Applications** 400
Dan Zhao, Shuangbing Han, Kyle McDonald, Joe Sootsman, Brandon Crosby, Scott Fleming, Dan Marple, Yanhu Wei, Tom Bekemeier, Julia Sunderland
The Dow Chemical Company, USA

Abstract: Electrically conductive silicones have been used in applications including automotives, communications, and consumer electronics. These applications are expected to significantly grow with the evolving technologies in autonomous driving, electrical vehicle, and 5G ecosystem. Here we present two novel solventless electrically conductive silicones (one silver based, one nickel-coated graphite based) with excellent conductive, shielding, and adhesive performance designed for electromagnetic compatibility (EMC) as an adhesive, a form-in-place gasket (FIPG), or a cure-in-place gasket (CIPG).

WE-PM2-E EM Environment (Sponsored by TC-3)

Technical Papers **3:30pm - 5:30pm**
Room: Gallery Overlook E
Co-Chair: Karen Burnham, *Electro Magnetic Applications, Inc., Lakewood, CO, USA*
Co-Chair: Frederick Heather, *Lexington Park, MD, USA*

3:30pm **Statistics of Electromagentic Fields within Aperture-Coupled, Nested Reverberant Cavities** 401
Marshall D. Sowell, James C. West
Oklahoma State University, USA

Abstract: An empirical study has been performed to measure the statistics of the fields excited within the inner cavity of overmoded, nested cavities when a small chamber is weakly coupled to a large chamber. Both the external and internal cavities were mechanically tuned during measurements. Two distributions were fit to the measured fields, the double-Rayleigh and exponential. The goodness-of-fit of each distribution was evaluated using rigorous statistical tests. The double-Rayleigh distribution gave a poor fit to the measured field statistics under all conditions considered. The exponential distribution gave a good fit at higher frequencies and with large coupling, indicating that the two chambers are acting as one resonant cavity. These results suggest that a more accurate statistical description is needed when high-precision results are required.

4:00pm **An Alternative Perspective on Time Domain Electromagnetic Field Measurement in Hospital Environment** 407
Ridvan Aba[1], Robert Vogt-Ardatjew[1], Frank Leferink[1,2]
[1]Universiteit Twente, Netherlands; [2]Thales Nederland BV, Netherlands

Abstract: Electromagnetic environment characterization of complex environment such as a hospital is a challenging issue due to the dynamic characteristics like field fluctuations over time as well as space, and multiple interference sources within. This paper proposes an alternative perspective on electromagnetic environment characterization depending on E-field probe measurements. A hospital is known to be a semi-reverberant, and often undermoded environment. For this reason, in this paper, it is considered to be similar in behavior to a vibrating intrinsic reverberation chamber (VIRC), operating in undermoded region. The measurements were performed using 3-axis E-field probes at nine different locations inside a VIRC. It was aimed to characterize the environment using 3-axis E-field probe measurement results by considering the concept of ergodicity. Finally, the probability distributions were observed.

WE-PM-F EMC Measurements, Techniques, Test Instrumentation and Facilities, Standards and Regulations and Measurement Uncertainty (Sponsored by TC-2)

Technical Papers **1:30pm - 5:30pm**

Room: Gallery Overlook F

Chair: Thomas Fagan, *Aerospace Corporation El Segundo, CA, Vail, AZ, USA*

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

1:30pm **Coaxial versus Bifilar Transmission Lines as Constituents of Transmission-Line Transformers and Baluns** 425

James McLean

TDK Corp., USA

Abstract: A broad and useful class of transmission-line transformers (TLTs) is based on the series/shunt interconnection of commensurate, two-conductor transmission lines combined with integral common-mode (CM) chokes. Therefore, such a section of uniform transmission line with integral CM choke has aptly been termed a "fundamental building block" of this class of TLTs. Various transmission-line geometries for this building block can be employed provided the characteristic impedance and phase velocity of the desired mode satisfy the requirements of the design procedure. In particular, both bifilar transmission line and coaxial transmission line geometries are frequently used interchangeably. However, published analyses of this "building block" treat the bifilar geometry exclusively. We show that the characteristics of the fundamental building block when implemented with coaxial transmission line are quite different from those obtained when bifilar transmission line is employed. This has implications for many transformer, balun, and hybrid designs. Two new models are presented for the coaxial "building block": one which is appropriate when the CM structure behaves in a lumped manner and one when it behaves in a distributed manner. We show analytically the effect of the shield on TLT operation, specifically for a simple 3-port choke/current balun topology. Then, two 3-port, series-series, 1:1 baluns implemented with coaxial and bifilar media are analyzed using the model and also with a commercial finite element simulator. It is seen that little performance difference exists between the bifilar and coaxial implementations. This is shown to be due the series-series balun topology effectively employing both a coaxial delay line and an "inverted" coaxial phase inverter. The degraded performance of the latter cancels the performance gain obtained by the former.

2:00pm **Implementation of a Method for Measuring Low-Frequency Radiated Electromagnetic Emissions in the Vicinity of a Railway Rail from Passing Rolling Stock** 431

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

Lukasiewicz Research Network - Poznan Institute of Technology, Poland

Abstract: The article presents our own software solutions for automating the measurement of emission of magnetic disturbances coming from rolling stock. The algorithm is made in LabView environment. The article presents not only the software part of the test set-up for Measuring Low-Frequency Radiated Electromagnetic Emissions coming from Passing Rolling Stock, but also the hardware part, including the dedicated measurement antennas as well as the data acquisition system.

2:30pm **Examination of the SVSWR Methods Using the Monte Carlo Method** 436

Alexander Kriz

Seibersdorf Labor GmbH, Austria

Abstract: Site Voltage Standing Wave Ratio (SVSWR) based EMC test site validation methods for the frequency range 1 to 18 GHz are analyzed with the Monte Carlo method. Simulations with a simple ray tracing simulation model are performed with certain assumptions for chamber size and absorber return loss. Since none of the methods define a measurand a proposal is given which can be applied to several measurement methods. This creates a possibility to compare the different methods but leads to negative systematic errors. The magnitude of the systematic error depends on the site validation method itself. The higher the number of measurement points of a method the lower is the systematic error. Another outcome of the Monte Carlo simulation is the repeatability for each method. It can be shown that the repeatability is improved by the application of a post processing filter as proposed by the Time Domain SVSWR method. A second approach to improve the repeatability is a large number of measurement points.

3:30pm **Noise Source Impedance Extraction Method of Switched-Mode Power Supply (SMPS) in PC according to the Frequency Range** 443

Jaewon Rhee[1], Hyunwoong Kim[1], Kwanguk Chu[2], Seungyoung Ahn[1]
[1]Korea Advanced Institute of Science and Technology, Korea;
[2]Electronics and Telecommunications Research Institute, Korea

Abstract: Impedance is essential information in solving electromagnetic compatibility problems. This paper proposes a method to measure the noise source impedance of a switched-mode power supply (SMPS) in a PC under operating conditions. Unlike previous research, impedance measurements at low frequencies below 1 MHz increase the received signal using the proposed dual current probe (DCP) method. In particular, unlike conventional research, this method can increase accuracy by increasing the number of wire turns without an amplifier or attenuator. Therefore, the proposed noise source impedance extraction method can be used to solve electromagnetic compatibility (EMC) problems such as electromagnetic interference filter design or to analyze the influence of external electromagnetic pulse.

4:00pm **Development of 2D Near Field Scanner for Electromagnetic Noise Visualization** 448

Akihiro Tatsuta[1], Shinichi Tanimoto[1], Shinkuro Fujino[1], Taiga Miyai[2],
Shota Nakamura[2], Satoshi Yagitani[2]
[1]Panasonic Connect Co., Ltd., Japan; [2]Kanazawa Daigaku, Japan

Abstract: In the development of electronic equipment, noise source identification techniques are generally used to solve EMC problems. However, conventional noise analyzers has poor portability and the operation is complicated which moves the position of the electromagnetic (EM) field sensor two- or three-dimensionally. In this paper, we developed a stacked metasurface absorber that absorbs EM waves from the 100 MHz or less to GHz-band and a compact visualization system that can intuitively sense EM waves in a two-dimensional plane in real time using the metasurface absorber. We visualized the EM noise radiated from commercial products and identified the noise sources with our developed system.

4:30pm **The Impact of Cable Support Material on Conducted Susceptibility Test Results** 454

John G. Kraemer
Collins Aerospace, USA

BEST EMC PAPER FINALIST

Abstract: The material used to support cables above the ground plane during EMI compliance tests can influence test results, as well as constitute an item which can lead to differences between test and electromagnetic (EM) field simulation results. The paper shows RF Conducted Susceptibility (CS) test results, with explanations of the observed trends, associated with three common cable suspension materials. Additionally, 4-port S-parameter measurements are made on a shielded wire supported by different materials; follow-on RF CS simulation in an advanced circuit solver using the data confirms the trends seen in the EMI compliance test results. It is shown how these processed S-parameter measurements can be used to determine the effective relative permittivity of the support material as a homogenous background material to allow its proper consideration when using popular 2.5D cable effects-focused EM field solver tools. Other factors influencing apparent test repeatability and correlation between EM field simulation and test results are also discussed.

5:00pm **Analyzing Repeatibility during Air Discharge ESD Tests** 460

Mohit Gopalraj, Thane Sanford
Analog Devices Inc., USA

Abstract: Analyzing variabilities that occur during Air Discharge ESD tests is a tough ordeal. Variables such as environmental conditions, test setup, different ESD guns, ESD gun approach speeds and angles can all cause discrepancies in test results. This paper recommends a verification method to record and analyze variability involving the air discharge method prior to test. The use of a robot arm is explored as well.

WE-PM-G Recent Advancements in HPEM, HEMP, and IEMI Protection – A Global Perspective (Sponsored by TC-5)

Tutorial **1:30pm - 6:00pm**

Room: Gallery Overlook G

Chair: Tara Kellogg, *ETS-Lindgren, Cedar Park, TX, USA*

Co-Chair: Chaouki Kasmi, *Technology Innovation Institute, Abu Dhabi, United Arab Emirates*

Session Abstract: Despite the threats posed by High-Power Electromagnetic (HPEM), High-Altitude Electromagnetic Pulse (HEMP), and Intentional Electromagnetic Interference (IEMI), insufficient emphasis has been placed on the design development of HEMP/IEMI hardening solutions in order to mitigate the potential risk to "critical infrastructures". The focus on the resiliency of critical infrastructures is increasing globally with governments and industries placing more urgency on the need for protection from the effect of HPEM, HEMP, and IEMI. Even with the heightened emphasis on protecting critical infrastructures, industries continue to struggle to quantify the threat posed by HPEM, HEMP, and IEMI and to identify cost effective yet viable protection solutions.

Speakers in this tutorial will address the challenges to those industries considered "critical infrastructure", such as utilities (power, water, gas) and services (data, financial, communication). The tutorial includes an overview of filtering power and signals to harden facilities. An example will be shared of an HPEM/HEMP/IEMI grid hardening solution with a focus on overall resiliency - including the design, deployment, and cost benefit analysis. The tutorial also provides a global review by experts from industry and government, who will discuss their respective R&D activities and test methodologies. Attendees will receive a global overview on HPEM/HEMP/IEMI protection solutions currently being implemented in the United States, Europe, South America, and the Middle East.

High Power Electromagnetics: Effects Detection and Classifications through System Instrumentation

C. Kasmi[1], F. Vega[1], N. Mora[2], J. Lopes-Esteves[3]
[1]Directed Energy Research Centre, United Arab Emirates; [2]National University of Colombia, Colombia; [3]ANSSI, France

Protection with Power/Signal Filters for HPEM Applications including the New MIL-STD-188-125-1A HEMP Requirement

Sergio N. Longoria
ETS-Lindgren, USA

Electrical Grid HPEM/HEMP/IEMI Mitigation Strategies

Ryan Marietta
CenterPoint Energy Inc., USA

Tolerance Values and Confidence Level of HEMP System Tests

Frank Sabath
Bundeswehr Research Institute for Protective Technologies and NBC Protection, Germany

THURSDAY – AUGUST 3, 2023

TH-AM-AtE

Ask the Experts Panels 10:30am - 12:00pm

Room: Exhibit Hall
Chair: Alistair Duffy, *De Montfort University, Leicester, England, UK*

Session Abstract: Bring your questions or simply listen and learn!

ML/AI in EMC and SIPI: Opportunities and Road Blocks

PLANNED PANELISTS INCLUDE:

- Richard Gao Xianke, *A*STAR Institute of High Performance Computing, Singapore*
- Lijun Jiang, *City University of Hong Kong, Lijun*
- Moein Nazari, *Cadence, USA*
- Steve Scearce, *Cisco, USA*

Abstract: It seems that everyone is talking about AI these days! Even within our EMC and signal and power integrity communities, machine learning and artificial intelligence are starting to be used as serious tools to solve challenging problems. However, the knowledge base within this domain is developing but not yet well established. The EMC Society is keen to change this by building conversations and sharing information. If you have expertise in ML/AI, have "dabbled" or are simply "AI curious", please join this panel session where we will address your questions and listen to your experience about where there are immediate opportunities within the EMC and SIPI domain and what are the obstacles that will limit our collective ability to utilize these tools.

TH-AM-ED2 Selection of Magnetic Shielding for Optimizing NFC/RFID Systems (Sponsored by TC-4)

Experiment/Demonstration 10:00am - 12:00pm

Room: Exhibit Hall Exp Demo 2
Chair: Jacob Dixon, *International Business Machines Corp, Rochester, MN, USA*
Co-Chair: Gabriel Alcala, *University of California Riverside, San Diego, CA, USA*

Selection of Magnetic Shielding for Optimizing NFC/RFID Systems

Victor Martinez Garcia
Würth Elektronik GmbH & Co. KG eiSos, Germany

Abstract: The characterization of FSFS effectiveness is analysed as a function of the sheet thickness in this contribution. This is performed with the aim of determining which is the optimum thickness value to retune an NFC antenna to its original operation frequency value (13.56MHz) when it is affected by a near conductive surface.

A finite element method (FEM) simulation model is designed and corroborated with the experimental results to evaluate the performance of different FSFS thicknesses in terms of resonant frequency shift, magnetic field strength and communication distance.

This contribution studies the influences of different setups, on a demotool, of conductive surfaces close to the transmitting antenna and how they change its behaviour.

The results obtained show that the magnetic field strength is significantly attenuated, and the communication distance is highly shorted. Therefore, besides selecting a material that provides high reflection and low losses at 13.56 MHz, it must be considered the thickness to ensure the greatest communication effectiveness. Consequently, the use of a wrong FSFS thickness could lead to shifting the resonance frequency to lower values than expected, detuning the communication.

TH-AM-ED3 A Recently Developed Gating Library for Enhanced Post-Processing (Sponsored by TC-6)

Experiment/Demonstration **10:00am - 12:00pm**

Room: Exhibit Hall Exp Demo 3

Chair: Jacob Dixon, *International Business Machines Corp, Rochester, MN, USA*

Co-Chair: Gabriel Alcala, *University of California Riverside, San Diego, CA, USA*

A Recently Developed Gating Library for Enhanced Post-Processing

Yibo Wang[1], Andrew Shyne[2]

[1]ETS-Lindgren, USA; [2]The Boeing Company, USA

Abstract: Gating is a well-known technique to remove or isolate responses in a multiple reflective environment. The gating technique is widely used in vector network analyzers (VNAs). In this demonstration, we will first discuss the implementation of the gating function in commercial VNAs, and then highlight the benefit of applying the post-processing function as a software library. A software library has been developed recently to provide users with the convenience, flexibility and control of the process rather than relying on the limitations of VNAs. Users have the flexibility to process the measurement data anytime anywhere. The library can seamlessly integrate with conventional programming languages such as Matlab, Python and C. Apart from its convenience, the library has numerous applications that cannot be readily obtained using the gating function of VNAs. In the demonstration, the vector response will be measured between two antennas at a given distance. The antenna response will be gated in real time. We will utilize the library using a Matlab script and select the gate, e.g. gate center, gate width, gate type, gate shape, and edge treatment. Next, three cases will be demonstrated to show the benefits of the gating library compared to the time gating function within a VNA. For each case, we will use the library to process data in real time. The three cases include: 1. Time domain gating for antenna planar near field measurement; 2. EMC chamber VSWR debugging; and 3. Spectrum mode filtering for an antenna extrapolation range.

TH-AM-ED4 VIRC: Shake It Till You Make It!

Experiment/Demonstration **10:00am - 12:00pm**

Room: Exhibit Hall Exp Demo 4

Chair: Jacob Dixon, *International Business Machines Corp, Rochester, MN, USA*

Co-Chair: Gabriel Alcala, *University of California Riverside, San Diego, CA, USA*

VIRC: Shake It Till You Make It!

Vasso Gkatsi, Robert Vogt-Ardatjew

University of Twente, Netherlands

Abstract: This E&D focuses on presenting a portable vibrating intrinsic reverberation chamber (VIRC) setup to explain the basic concepts of reverberation chambers (RCs). As opposed to conventional, rigid-wall RCs, a VIRC is made from a flexible conductive material and therefore can be easily transported to perform both radiated emission and immunity tests on site, yet their underlying functionalities are similar. By performing a series of experiments, this E&D intends to educate the viewers for whom the statistical aspects of the techniques used in RCs are still a mystery, or would like to expand their understanding of this measurement technique.

TH-AM-B Getting to the Root of It: Tools and Techniques to Enhance Root Cause Analysis (Sponsored by TC-1)

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

Room: Gallery Overlook B

Chair: Ryan Kidwiler, *American Association for Laboratory Accreditation, Frederick, MD, USA*

Co-Chair: Megan McConnell, *American Association for Laboratory Accreditation, Frederick, MD, USA*

Session Abstract: A2LA will provide a hands-on workshop and training for test laboratories, TCBs, and other organizations performing a root cause analysis. The workshop will discuss the importance of performing an in-depth root cause analysis and the role it plays in improving quality and sucess in your organization. Attendees will also learn about useful tools and techniques for performing an effective root cause analysis which can be implemented across various fields and industries. The second half of the workshop will include a hands-on activity in which attendees will breakout into smaller groups and have the opporutnity to perform their own root cause analysis using the tools and techniques provided in the training. Each group will be provided with a nonconformance and scenario for a which a root causes analysis will need to be performed. Each group will share the results of their analysis and all attendees will discuss. The workshop will end with a brief Q&A.

Getting to the Root of It: Tools and Techniques to Enhance Root Cause Analysis
Ryan Kidwiler, Megan McConnell
A2LA, USA

TH-ALL-D High Power Electromagnetics, ESD and Transients, EMP, IEMI and Lightning, Geomagnetic Storm EMC (Sponsored by TC-5)

Technical Papers **8:00am - 5:30pm**

Room: Gallery Overlook D

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

8:00am **Early-Time Electromagnetic Pulse Response Validation of Surge Arrester Models** 466
Tyler Bowman, Thomas Kmieciak, Laura Biedermann
Sandia National Laboratories, USA
BEST EMC PAPER FINALIST

Abstract: High-altitude electromagnetic pulse events are a growing concern for electric power grid vulnerability assessments and mitigation planning, and accurate modeling of surge arrester mitigations installed on the grid is necessary to predict pulse effects on existing equipment and to plan future mitigation. While some models of surge arresters at high frequency have been proposed, experimental backing for any given model has not been shown. This work examines a ZnO lightning surge arrester modeling approach previously developed for accurate prediction of nanosecond-scale pulse response. Four ZnO metal-oxide varistor pucks with different sizes and voltage ratings were tested for voltage and current response on a conducted electromagnetic pulse testbed. The measured clamping response was compared to SPICE circuit models to compare the electromagnetic pulse response and validate model accuracy. Results showed good agreement between simulation results and the experimental measurements, after accounting for stray testbed inductance between 100 and 250 nH.

8:30am **Electromagnetic Pulse Propagation Modeling and Measurements of a Termination Cabinet** 472
Tyler Bowman, Ian Timmins, Nathan Strachen
Sandia National Laboratories, USA

Abstract: This work developed a methodology for transmission line modeling of cable installations to predict the propagation of conducted high altitude electromagnetic pulses in a substation or generating plant. The methodology was applied to a termination cabinet example that was modeled with SPICE transmission line elements with information from electromagnetic field modeling and with validation using experimental data. The experimental results showed reasonable agreement to the modeled propagating pulse and can be applied to other installation structures in the future.

9:00am **HFSS Enables the Simulation of Electromagnetic Pulses and Predicts its Effects** 473
Shahid Ahmed
Ansys, Inc., USA

Abstract: We have considered a full-wave three-dimensional transient simulation of EMP propagation and interaction in real-time. Also, we have adopted a hybrid approach by combining a full-wave frequency domain simulation with the circuit where the EMP exposure has been accounted for through the scattering parameters. This hybrid approach greatly reduces the solve time and provides high-fidelity simulations of induced voltage or current across any component, which otherwise would have been difficult. Any geometry can be modeled for real-life applications, and frequency-dependent material properties can be considered. A comprehensive study illustrating various real-life case studies will be presented.

9:30am **Wire Mesh Radiated EM Shielding Effectiveness: Time Domain Measurement and Theory Verification** 474
Edward B. Savage, William A. Radasky
Metatech Corporation, USA

Abstract: It is well known that solid metal sheets provide good electromagnetic (EM) shielding effectiveness, and simple basic EM theory predicts the shielding of metal sheets. However, the same cannot be said about metal wire mesh, which is sometimes used instead for shielding. Here we cite one theory for wire mesh shielding. We then present a new time domain approach for measuring the shielding. The measurement approach has advantages over the traditional method. We then give some measurement results, and compare these with theory.

10:30am **Reconstruction of Sound Information Leakage Signals Obtained from Multiple Demodulation Methods** 480
Taiki Kitazawa, Seiya Takano, Yuichi Hayashi
Nara Institute of Science and Technology (NAIST), Japan
BEST EMC PAPER AND BEST STUDENT PAPER FINALIST

Abstract: Speakerphones used in remote work environments have been reported to leak audio information through electromagnetic (EM) emanations. A method to improve information reconstruction quality has been proposed by simultaneous measurement of multiple leakage channels. However, acquiring sufficient reconstruction quality is difficult when the number of observable channels is limited due to limitations of measurement resources. In this study, we propose a method to increase the number of leakage channels virtually in order to reconstruct audio information with sufficient quality, even if observable channels are limited. We assume that leaked EM waves are modulated by multiple schemes and simultaneously extract audio information from a single leakage channel by amplitude and frequency demodulation methods. Furthermore, we synthesize audio signals obtained from different demodulation methods by a phase-aligned-spectrum-averaging method and indicate that the improvement in the reconstruction quality is comparable to measuring multiple leakage channels.

11:00am **Detecting Hardware Trojans on Inter-IC Serial Data Links through Capacitance Sensors** 485
Masahiro Kinugawa[1], Yuichi Hayashi[2]
[1]The University of Fukuchiyama, Japan; [2]Nara Institute of Science and Technology, Japan

Abstract: Threats that cause electromagnetic information leakage by inserting Hardware Trojans (HT) into the signal traces around components on the printed circuit board have been reported. This threat occurs not only at the manufacturing stage but also in transit and the field, unlike HTs against ICs. This paper proposes the detection and monitoring method for the HT insertion on the inter-IC serial data link, which transmits sensitive information among the above-mentioned threats. The implementation uses only a microcontroller and does not require external analog components.

11:30am **Fundamental Study on the Effect of the Duty Ratio of Clock Signal on Side-Channel Leakage** 486
Daisuke Fujimoto, Shinpei Wada, Yuichi Hayashi
Nara Institute of Science and Technology, Japan

Abstract: In this paper, we firstly evaluate the effect of power supply noise due to clock signal on information acquisition to accurately acquire side-channel information from the cryptographic devices that radiates in the same frequency band as the clock signal. The result shows that the leakage evaluation result changes according to the duty cycle of the clock signal.

12:00pm **Enhanced Modulation Degree of Leakage Wave Induced by IEMI via Nonlinear Circuit Elements** 487

Shugo Kaji, Daisuke Fujimoto, Yuichi Hayashi
Nara Institute of Science and Technology (NAIST), Japan

Abstract: This paper proposes a method to improve the modulation degree of the leakage wave in the threat of electromagnetic information leakage induced by intentional electromagnetic interference. Since the leakage wave from the target device occurs with the same frequency as the continuous wave (CW), the modulation degree of the leakage wave is decreased. This paper shows that the propagation of two CWs to nonlinear circuit elements inside the device causes frequency conversion, generating the leakage wave with a frequency different from the injected CWs. This method prevents degradation in the accuracy of information extracted caused by decreased modulation degree of the leakage wave.

2:00pm **Coupling Path Analysis for Smart Speaker Intentional Electromagnetic Interference Attacks** 488

Tanner Fokkens, Shengxuan Xia, Aaron Harmon, Chulsoon Hwang
Missouri University of Science and Technology, USA

Abstract: This paper shows an improved understanding of the coupling path for intentional electromagnetic interference (IEMI) attacks on smart speaker devices. This includes a method for finding the ideal attack angle and locating the region sensitive to the coupled EMI. In previous works, it was shown to be possible to send RF commands to a smart speaker and have these commands be interpreted as voice commands by the microphone. However, the attack still had some limited understanding in terms of the coupling path location and long-distance attack potential. Using the improved understanding of the attack, a longer attack distance is achieved (6 meters) with only 6.5 Watts of power.

2:30pm **Towards HPEM Pulse Characterization by Nonlinearly Loaded Narrowband Antenna Arrays** 495

Robert Michels[1], Sven Fisahn[2], Martin Schaarschmidt[2], Frank Gronwald[1]
[1]University of Siegen, Germany; [2]Bundeswehr Research Institute for Protective Technologies and CBRN Protection, Germany

Abstract: In this contribution the general idea of both detecting and characterizing short high power electromagnetic pulses by means of nonlinearly loaded narrowband antenna arrays is presented. To this end, aspects of electromagnetic pulse response of nonlinearly loaded antennas are reviewed first. It is pointed out that short high power electromagnetic pulses can generate a rather long lasting dc voltage at a nonlinearly loaded antenna terminal which depends both on the pulse characteristics and the antenna itself. The corresponding dependencies are nontrivial and analyzed by means of numerical simulation methods. Results are shown which indicate the feasibility of obtaining electromagnetic pulse characteristics from multiple dc voltages which are recorded by multiple antennas that form a receiving antenna array.

3:00pm **Design and Construction of an Arbitrary Pulse Compressive Amplifier** 499

Cody Goins, Aaron Harmon, Victor Khilkevich, Daryl Beetner
Missouri University of Science and Technology, USA

Abstract: Compressive pulse amplifiers are a class of amplifiers that convert long low amplitude signals into very broadband pulses of high amplitude, yielding a very high instantaneous peak power output pulse. However, in the realm of electronic immunity and susceptibility testing, very broadband short pulses are not always desired. This work presents a design for a compressive amplifier that is aimed at creating arbitrary pulsed signals of varying bandwidths. Limitations of the achievable gain and methods used are discussed.

4:00pm **ESD Behavior of RF Switches and Importance of System Efficient ESD Design** 504

Seyed Mostafa Mousavi[1], Emil Tauber[2], Amin Pak[2], David Pommerenke[2], Daryl Beetner[1], Ketan Shringarpure[2], Benjamin Lee[3], Warwick Ka Kui Wong[2]

[1]Missouri University of Science and Technology, USA; [2]Technische Universität Graz, Austria; [3]Google LLC, USA; [4]Google LLC, Taiwan

Abstract: RF switches are typically used in the RF front-end of portable devices such as antenna or matching tuners to improve the RF link performance. They are usually the first active devices after the antenna and are vulnerable to primary or secondary ESD discharges to the antennas. This paper investigates the ESD behavior of one of the high frequency switches used in the RF-front-end of portable devices and expresses the importance of the ESD pulse that passes through the switch and reaches the next stage in the RF path, possibly damaging the next stage.

4:30pm **Characterization and Modeling of Sparkless Discharge to a Touch Screen Display** 510

Jianchi Zhou[1], Cheung-Wei Lam[1], Zhekun Peng[2], Daryl Beetner[2], David Pommerenke[3]

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

Abstract: Although corona discharge to a touchscreen display is not associated with the spark, it could cause soft and hard failures due to electromagnetic coupling to sensitive electronics beneath the glass. Experimental data were obtained to characterize these sparkless discharges and an equivalent circuit model was constructed to predict the resulting coupling to touchscreen electronics. Measurements and simulation indicate that a thinner glass and a higher touchscreen indium-tin-oxide (ITO) sense trace impedance both lead to higher ESD risk by delivering higher energy into the sensing IC. A CST co-simulation model is proposed and is shown to model the displacement current accurately. Charge movement and dissipation on the glass surface is represented using a disk with conductivity proportional to the reciprocal of radial distance. Dust figure measurements were used to study the effects of the glass type, glass thickness and voltage level on the corona discharge and the current coupled to the touchscreen patch on the display. These results can be used to drive full wave co-simulation models which try to anticipate the impact of sparkless discharges on the touchscreen electronics.

5:00pm **Numerical Modeling and Finite Element Analysis of Metamaterial-Based Wireless Power Transfer** ..... N/A

Webster O. Adepoju[1], Indranil Bhattacharya[1], Olufunke Mary Sanyaolu[3], Ismail Fidan[1], Ranger Buchanan[1]

[1]Tennessee Technological University, USA; [2]GasFleet Engineering Limited, Nigeria

Abstract: This paper presents an equivalent circuit model to emulate the behavior of a Metamaterial (MM)-based Wireless Power Transfer (WPT) system. For this purpose, the electromagnetic finite element simulation of the proposed system is conducted in ANSYS High Frequency Structure Simulator (HFSS). In addition, the numerical analysis of the proposed structure is explored to evaluate the system transfer characteristics. The power transfer efficiency of the proposed structure is represented by the transmission scattering parameter (transmission and reflection coefficients). While some methods, including interference theory and effective medium theory, have been exploited to explain the physics mechanism of MM-based WPT systems, some of the reactive parameters and the basic physical interpretation have not been clearly expounded. In contrast to the existing theoretical model, the proposed approach focuses on the effect of the system parameters and transfer coils on the system transfer characteristics coupled with its effectiveness in analyzing complex circuits. A numerical solution of the system transfer characteristics, including the scattering parameter, and power transfer efficiency, is performed in a Matlab simulation environment. The calculation results based on numerical estimation validate the full-wave electromagnetic simulation results, effectively verifying the accuracy of the analytical model

TH-ALL-E Power Electronics EMC, Power Conversion, Automotive, Aerospace, Medical, Consumer Electronics (Sponsored by SC-5)

Technical Papers **8:00am - 5:30pm**

Room: Gallery Overlook E

Chair: Chulsoon Hwang, *Missouri University of Science and Technology, Rolla, MO, USA*
Co-Chair: Cong Li, *GE Global Research, Atlanta, GA, USA*
Co-Chair: Shuo Wang, *University of Florida, Gainesville, FL, USA*
Co-Chair: Liu Dehong, *Mitsubishi Denki Kabushiki Kaisha, Chiyoda-ku, Japan*

8:00am **Investigation of Common-Mode EMI in Three-Phase Split-Phase Inverter** 522
Abdul Basit Mirza, Abdul Muneeb, Sama Salehi Vala, Fang Luo
Stony Brook University, USA

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Abstract: Compared with the traditional two-level (2L) inverter, two-level Split-Phase topology (2L-SP) provides better cross-talk immunity without deadtime between the top and bottom devices. From the Common Mode (CM) EMI perspective, split inductors in 2L-SP tend to increase the CM noise path impedance and decrease the dV/dt across the device during the switching transition due to the interaction between split inductors and the semiconductor device's parasitic capacitance. This phenomenon, in turn, reduces the dV/dt of the CM voltage, making 2L-SP topology a promising candidate with lower CM emission for Wide Band Gap (WBG) devices-based 2L inverters, switching at high frequency. However, the CM EMI of 2L-SP and its comparison with 2L have yet to be analyzed comprehensively. This paper investigates conducted CM EMI emission of a SiC-based 2L-SP three-phase inverter with SPWM. At first, the derivation of the CM equivalent circuit model through frequency domain analysis is presented. This is followed by a comparative study of CM emission of 2L-SP three-phase inverter on a hardware prototype for different values of split inductance. The results show that increasing split-inductance significantly lowers the CM magnitude with a maximum reduction of 17.85 dB.

8:30am **Simulation-Based Approach for Boost Converter Using Black-Box Modelling for System Level EMC Analysis** 529
Adish Kaushal[1,2], Suraj R. Rao[2], A. Devi[2], Joe Sivaswamy[2], D. Gope[2], Shanthi P[1]
[1]Simyog Technology Pvt. Limited, India; [2]R.V. College of Engineering, India; [3]Simyog Technology Pvt. Ltd., India

Abstract: With the development of faster and denser electronic networks in today's automotive industry, EMC Compliance tests have become more stringent. Therefore, it is proving to be difficult to predict and mitigate these System-level emissions. Hence, frontloading is an excellent approach to analyzing and monitoring the EMI/EMC performance from the design stage (Pre-prototype) to the verification stage (post-Prototype), allowing a cost-effective resolution of any upstream issues. A major pain point faced by EMC engineers is the lack of accurate models for Integrated Circuits, currently IBIS models and SPICE simulations are being taken to model the ICs behavior which are not useful at higher frequency ranges. Therefore, the motivation of this work is to develop a DC-DC Boost converter IC model using the Nonlinear IC-Emission Modelling method and to analyze different EMI mitigation methods to reduce the PCB emissions during the design phase. The proposed model is implemented on the DUT with the Boost converter IC fabricated on the PCB. The System-level-simulation using the ICEM model is validated with measurement.

9:00am **Using Full Wave 3D Simulation to Evaluate Buck SMPS EMC Emissions** 535
Patrick DeRoy[1], Anisha Dok[1], Hemanthchender Sreeperumbudur[2], Nicklas Koeller[3], Alexander Pearson[3], Scott Mee[3], Bogdan Adamczyk[4]
[1]Analog Devices Inc., USA; [2]Analog Devices India Private Limtied, India; [3]E3 Compliance, USA; [4]Grand Valley State University, USA

Abstract: This paper demonstrates the use of 3D electromagnetic (EMC) modeling to simulate the conducted emissions of a switched-mode power supply (SMPS). The simulations are performed using CST Studio Suite from Dassault Systemes and measurements of a fully functional SMPS converter are performed according to CISPR25 (an automotive test specification). The simulations are compared to the measurements and demonstrate a reasonable level of correlation. Several SMPS design modifications are evaluated using simulation and compared to measurements. The benefits of using simulation early in the development process to help prevent EMC failures is highlighted.

9:30am **Reduction of CM Conducted Emission with a Small Dummy Leg and the Delay Compensation Technique** 542

Erica Raviola[1], Michele Roman[2], Luca Zai[2], Franco Fiori[1]
[1]Politecnico di Torino, Italy; [2]Eldor Corporation S.p.A., Italy

Abstract: Passive EMI filters are usually placed at the input of power circuits to attenuate the conducted emission delivered. However, their volume may not be negligible, especially when targeting power automotive applications. The output delay compensation technique may or may not reduce the CM conducted EMI at low frequency, as a fine alignment of the output voltage phases should be achieved. This paper aims at improving the already proposed technique by exploiting a small dummy leg. In such a way, switching losses and cost of the auxiliary circuit required to implement the delay compensation technique can be reduced. From the circuit analysis, it was found that the small dummy leg can achieve a 40 dB CM EMI reduction up to 5 MHz, with one seventh the switching losses of a traditional auxiliary leg.

10:30am **Susceptibility to Radio Frequency Interference of eGaN Power Switching Legs** 548

Franco Fiori
Politecnico di Torino, Italy

Abstract: Power switching circuits like those used in inverters and DC-DC converters are usually investigated with the purpose of increasing the power efficiency or lowering the electromagnetic emissions. Considered that, the reliability of such modules is also a key aspect, especially in safety critical applications, this work focuses on the susceptibility of such circuits to radio frequency interference. To this purpose, an e-mode GaN power switching leg in a real application environment is considered. A circuit comprising the nominal active and passive components, their stray inductances and capacitances as well as those due to the PCB wiring is presented. The effect of radio frequency interference injected into the output terminal by means of a bulk current injection clamp is analyzed with the purpose of evaluating the risk that such interference propagated through the circuit could induce temporary or permanent failures.

11:00am **Analytical Approach of the High Susceptibility Frequencies of a Battery Management System during Direct Power Injection. Methods of Improvement.** 554

Badr Guendouz[1], Kamel Abouda[1], Alexandre Boyer[2], Sonia Ben Dhia[2], Olivier Tico[1], Jeremy Ruau[1]
[1]NXP Semiconductors, France; [2]Laboratoire d'Analyse et d'Architecture des Systemes du CNRS, France

Abstract: When it comes to the electromagnetic interference (EMI) immunity of a Battery Management System Integrated Circuit (BMS IC), Printed Circuit Board (PCB) traces and external components (ECs) arrangement define the high susceptibility frequencies (HSF) of the IC during Direct Power Injection (DPI) tests. This work first aims at defining the root causes of those HSF in a realistic and measurement correlated environment, then, formulating them in order to provide a realistic prediction in the early design stages. Moreover, the configuration of the ECs raises a crucial tradeoff between the overall price of the system and the immunity of the IC. This work, then, also aims at analyzing this tradeoff and proposing alternative configurations of the ECs that reduce the overall price but also lead to lower injection levels during DPI.

11:30am **Reactive Shielding Method for Wireless Power Transfer Systems with High Power Transfer Efficiency Using Frequency Split Phenomena** 560

Changmin Lee[1], Seongho Woo[1], Yujun Shin[2], Jaewon Rhee[1], Seungyoung Ahn[1]
[1]Korea Advanced Institute of Science and Technology, Korea; [2]Keimyung University, Korea

BEST EMC PAPER FINALIST

Abstract: EMI reduction could be achieved using the method suggested by the wireless power transmission system. Leakage magnetic fields occur in the process of transmitting power wirelessly from the transmitter part to the receiver part. This leakage magnetic field negatively affects the human body or other electronic devices. The previous reactive shielding method could reduce the leakage magnetic field, but it had the disadvantage of reducing the power transfer efficiency (PTE). Using frequency split phenomena from the over-coupling, the reactive shielding method can reduce the EMI components with high PTE WPT system. In this paper, a reactive shielding method that can reduce the magnetic field while increasing PTE is proposed. In addition, a method for calculating a coupling coefficient for designing a structure in which magnetic field reduction can be maximized is also proposed. The theoretical analysis based on each part's impedance strongly correlates with the measurement results. As a result of the experiment, the PTE is increased by about 3.9%, and EMI components at odd harmonic frequency can be reduced by up to 8.85 dB in a 20 W-WPT system. Also, the proposed method can be applied when the other WPT system to be shielded is determined.

12:00pm **Review on Modeling and Emissions from EMI Filters in Power Electronics: Inductors** 566
Yanwen Lai, Shuo Wang, Yirui Yang, Qinghui Huang, Zhedong Ma
University of Florida, USA

Abstract: The issue of electromagnetic interference (EMI) is a critical and complex matter in power electronics. In the current landscape of rapidly evolving power electronics applications, high switching frequencies are widely adopted to reduce the size of devices and components, increase power density, and improve overall efficiency. Magnetic components, such as inductors, play vital roles in power converters and EMI filters. Consequently, many researchers have focused on studying inductors in EMI filters to enhance equipment performance. Building upon existing research, this paper will begin by presenting the fundamental inductor model and various methods for optimizing inductor design. Subsequently, the impact of inductors on conducted EMI in converters will be discussed. Lastly, this paper will introduce the radiation model of inductors, including near magnetic field and near electric field radiation.

2:00pm **Analysis and Modeling of the Near Magnetic Field Distribution of Toroidal Inductors** 573
Yirui Yang, Qinghui Huang, Yanwen Lai, Zhedong Ma, Yimeng Liu, Shuo Wang
University of Florida, USA

Abstract: The near magnetic field produced by magnetic components may compromise the performance of nearby devices. This paper analyzed the near magnetic field distribution around toroidal inductors. The mechanism of the field's origination was studied in this article and modeled with the combination of magnetic dipoles and quadrupoles with clear physical meaning. Intuitive conclusions were drawn from the model and verified by simulation and experiments.

2:30pm **dV/Dt Impact on Turn-to-Turn Overvoltage Distribution in Motor Windings** 579
Yalda Azadeh[1], Abdul Basit Mirza[1], Kushan Choksi[1], Xiaolong Zhang[2], Fang Luo[1], Kiruba S. Haran[2]
[1]Stony Brook University, USA; [2]University of Illinois Urbana-Champaign, USA

Abstract: Cable connected motor winding insulation is prone to failures owing to standing wave overvoltages (OV), caused by switching transition dV/dt. Standing wave is impacted by the motor drive system differential mode and common mode impedance interactions, as well as excitation frequency dV/dt. Winding and cable impedance create a complex combination of resonances and antiresonances. Wide band gap power electronics generate high dV/dt that exacerbates the OV phenomenon. According to the literature, the overvoltage across the motor winding is not distributed evenly between the turns. First turns are reported to be under higher overvoltage where OV is lower and more similar for the subsequent turns. However, in this paper with the accurate HF modeling of the motor drive system, the overvoltage distribution across the turnto-turn (TT) of the motor winding for different dV/dt is investigated. It is proved that the voltage distribution trend does not remain constant. First, it is due to the different resonances across different TT in an unsymmetric network of drive system. Second, according to the trapezoidal waveform, different dV/dt excitation introduces different bandwidth of the secondary harmonics contributed to the OVs. So, not always the first turn is under highest voltage. Not clear understanding of the OVs could cause insulation overdesign for the first turns or easier degradation of the lateral turns. In this regard, this paper gives a guideline to study the system in regards of impedance interactions with excitation dV/dt in the WBG applications. Therefore, based on this study the appropriate insulation or filtering design to alleviate the OVs can be decided. The ground truth experimental validation for high frequency modeling of the system under test is provided.

3:00pm **Measurement, Analyses and Discussion on Noise Induced on Gate Driver Logic Signal Traces in Medium Voltage SiC-based Power Converters** 585
He Song, Dushan Boroyevich
Virginia Polytechnic Institute and State University, USA

Abstract: The fast-switching speed of the silicon-carbide (SiC) devices, along with the needs for higher power, higher voltage, and higher power density, gives rise to more salient EMI challenges. Unlike the converter-level noise emissions, the noise inside the power converter (such as that on gate drivers) has no standard to follow, however, the gate driver is prone to be false triggered by the noise. Based on the noise propagation model proposed in the prior study, this paper shows more detailed noise measurements and quantitative analysis for the noise propagation between the PCB grounds and logic signal traces on gate driver PCB, and reveals more influential factors of the noise propagation. Several practical approaches to ensure measurement fidelity are adopted, and noise measurement and analyses under more practical test conditions are conducted and discussed to provide general design guidelines. The methodology is further expanded to be more generic by including other di/dt sources inside a power converter.

4:00pm **Multi-Objective Design of Filter Installed in Brush Motor by Artificial Neural Network Accounting for Cable Length** 591

Shohei Kan, Norikazu Takahashi, Masaki Himuro, Akito Mashino, Kengo Iokibe, Yoshitaka Toyota
Okayama University, Japan

Abstract: In the design process of automotive products, it is often necessary to find solutions that simultaneously satisfy multi-objective performance goals, which can sometimes include requirements that conflict. Such redundant solutions are expected to cover a wider feasible range of design parameters and meet an assortment of different lead time and price goals. In this work, we apply an artificial neural network (ANN)-based machine learning algorithm to determine the cable length and design ranges of an EMI filter for an automotive-brush-motor system. We were able to find at least three interval solutions that satisfy the performance requirements, including a single interval solution obtained by our previous approach using Preference Set-based Design.

TH-ALL-F EMC Measurements, Techniques, Test Instrumentation and Facilities, Standards and Regulations and Measurement Uncertainty (Sponsored by TC-2)

Technical Papers **8:00am - 5:30pm**

Room: Gallery Overlook F

Chair: Thomas Fagan, *Aerospace Corporation El Segundo, CA, Vail, AZ, USA*

Co-Chair: Sarah Seguin, *Resonant Frequency, Maple Grove, MN, USA*

8:30am **Accurate Measurement and Control Sytem for RF Broadband Power Amplifier** 592

Maxime Schutz[1], Jean-David Bertaux[1], Ludovic Bacqué[2]
[1]INOVEOS, France; [2]Prâna Recherche et Développement, France

Abstract: A new measurement system has been developed for broadband RF power amplifiers dedicated to EMC applications. The system allows the power output of the amplifier to be measured while correcting the variations of broadband coupler's frequency response. This is achieved by measuring, simultaneously, the power and the frequency of the RF signal. These measurements are made using a developed broadband RF frequency meter and a power detector. Tests are presented and carried out using industrial amplifiers to evaluate the proposed solution. Measuring the RF signal frequency passing through the amplifier is an additional information that allows more accurate power level measurement and improves the monitoring of the amplifier.

9:00am **Joint Radio-Frequency Transmission and DC Resistance Measurements of a T-slot Interlocking Metasurface** 596

Jon W. Wallace, Jeffrey A. Osterberg, Benjamin Young, Philip J. Noell, Brad L. Boyce
Sandia National Laboratories, USA

BEST EMC PAPER FINALIST

Abstract: Simultaneous DC resistance and radio-frequency (RF) transmission measurement of interlocking metasurfaces (ILMs) is proposed to characterize ILM shielding properties and gauge the level of ILM contact present in an RF fixture. This joint information is useful to determine whether the in-fixture results are representative of RF properties that would be present in practice. Future RF modeling work could also benefit from having correlated DC resistance and RF properties. The method is demonstrated for a T-slot ILM, where transmission is measured in a WR-340 fixture in the 2 to 3.7~GHz range. The results show that the technique is valuable for identifying cases where the RF properties measured in an RF fixture may not be representative of the properties of a free sample or a sample subject to external forces. An experiment with many ILM mating cycles suggests that wear of the ILM features can degrade shielding performance dramatically, indicating a need for low-wear ILMs and practices that minimize wear.

9:30am **Analysis on Extraction of Potential Radiated Emission Limit Line for Data Center Equipment from 10 GHz to 40 GHz** 602

Zhekun Peng[1], Wei Zhang[1], Jong-Hwa Kwon[2], DongHyun Kim[1]
[1]Missouri University of Science and Technology, USA; [2]Electronics and Telecommunications Research Institute, Korea

Abstract: The radiated emission (RE) potential limit line for router system is analyzed from 10 GHz to 40 GHz based on CISPR TR 16-4-4 standard. Statistical data is collected for the limit line extraction from measurement, numerical analysis, 3D full-wave simulation and literature studies. All the factors considered in limit line calculation are analyzed for data center equipment operation. The result of extracted potential limit line shows the rising limit line between 10 GHz and 40 GHz frequency band for potential future radiated emission limit line above 40 GHz targeted for high-speed equipment radiated emission. This paper is not a standard document, but provides insight to the trend for future limit lines above 40GHz.

10:30am **Analysis on the Effect of Averaging Duration on Radio Frequency Dosimetry in Residential Environments** 608

Reza Asadi[1], Hadi Aliakbarian[2], Amir Sahraei[2], Reza Yazdani[1], DongHyun Kim[1]
[1]Missouri University of Science and Technology, USA; [2]KN Toosi University of Technology, Iran

Abstract: The potential hazards of electromagnetic waves have raised concerns in related authorities to propose standards and limit lines on the electromagnetic field levels. Most of the radio frequency (RF) dosimetry measurement procedures referred to in safety compliance standards, suggest 6-minute averaging, in addition to spatial averaging, which can be time-consuming for primilary measurements. Measurement analysis in residential environment in this paper demonstrates that lowering the time interval of measurements to about 30 seconds, which suggests the possibility of reducing the measurement time with minimal reduction to measurement accuracy. For all measurement results shown in this paper, having a 30-second averaging time, the relative error, compared to 6-minute averaging and spatial averaging, is less than 5% for radio frequency (RF) level in the environment. This paper provides a potential solution to pre-compliance RF dosimetry process with less required time and cost.

11:00am **A Real-Time Microwave Camera Prototype with Zero-Bias Diode Detectors for EMI Source Imaging** 614

Xin Yan, Liang Liu, Victor Khilkevich
Missouri University of Science and Technology, USA

BEST EMC PAPER FINALIST

Abstract: Emission source microscopy (ESM) could be utilized to localize the Electromagnetic Interference (EMI) sources that contribute to the far-field radiation. In those cases, the electrical field over a two-dimensional plane is collected by mechanical scanning, resulting in a long measurement time and the presence of mechanical errors. In this work, a microwave camera based on a two-dimensional array of elliptical slot antennas and diode detectors is presented. Multiplexers are utilized to access the output of each detector and the scanning of the whole array could be done multiple times per second.

11:30am **Issues on AC Mains Cable Termination by CMAD** 619

Kunihiro Osabe[1], Nobuo Kuwabara[2], Hidenori Muramatsu[1]
[1]VCCI Council, Japan; [2]VCCI Council, Japan; [3]Kyushu Institute of Technology, Japan

Abstract: A common mode absorption device (CMAD) is listed in CISPR16-1-4 for use in terminating the mains cable of equipment under test (EUT) to improve measurement reproducibility in radiated disturbance tests. However, there are several issues in the termination of CMAD, such as differences in terminating impedance from that in real-world conditions, the need to maximize disturbance levels, and invalidation of CMAD characteristics due to cable type. This paper addresses these issues and suggests specifying termination impedance using a Very High-Frequency line impedance stabilization network (VHF-LISN) as a termination device for AC mains cable in lieu of CMAD.

12:00pm **Effects and Usage of Isolated Probes for Balanced Differential Measurement in RF Immunity Testing** 620

Md Kamruzzaman Shuvo[1], Patrick DeRoy[1], Pete Sealey[2], Abhishek Ramanujan[3], William Dixon[4]
[1]Analog Devices Inc., USA; [2]Analog Devices Ltd., UK; [3]Analog Devices International, Ireland; [4]Tektronix Inc., USA

Abstract: This paper examines the use of a galvanically isolated probe with high CMRR for measurements of differential noise in the presence of external RF noise injection during the RF conducted immunity (BCI) test. The probe is investigated in detail to understand the effects of its asymmetries, and a workaround for maintaining measurement integrity is presented.

2:00pm **Wall Shaking Amplitude Effects on Vibrating Intrinsic Reverberation Chamber Characteristics** 622

Makoto Hara[1,2], Jianqing Wang[1], Frank Leferink[3]
[1]Nagoya Institute of Technology, Japan; [2]Kawasaki Heavy Industries, Ltd., Japan; [3]University of Twente, Netherlands

Abstract: The vibrating intrinsic reverberation chamber characteristics, such as goodness-of-fit to Rayleigh distribution and spatial field uniformity, have been investigated by measurements according to the wall shaking amplitude as stirring conditions. The measurement results contribute to derive a guideline for VIRC design for the practical applications.

2:30pm **Using Modeling and Simulation to Enhance E3 Test Validity** 623

Rajendra Khadka[1], Marsellas Waller[1], Lloyd Riggs[1], Steve Wong[2]
[1]US Army Redstone Test Center, USA;[2]AFRL/RCM, Wright-Patterson AFB, USA

Abstract: In implementing electromagnetic vulnerability (EMV) testing on operational manned and unmanned air and ground vehicles fielding a variety of avionics and communication systems, the test as spelled out in MIL-STD-464D [1] and ADS-37A-PRF [2] requires test labs to operate the high-power source amplifiers/antennas very near the test item to reach required peak and RMS test levels for Electromagnetic Environmental Effects (E3) testing. Questions naturally arise concerning the efficacy of such testing with respect to both the manner of coupling of the fields to the electronics system of the air or ground vehicle as well as the levels required to achieve reasonable confidence in the coupling effect.

3:00pm **Investigation of Reducing Test System Dependence for Automotive Ethernet EMC Evaluation** 624

Yusuke Yano, Hideki Iwasaki, Jianqing Wang
Nagoya Institute of Technology, Japan

Abstract: To reduce test system dependence in the electromagnetic compatibility test of automotive Ethernet, we experimentally investigated the CM (common mode) termination impedance matching. The resistance of CM termination on a board, which simply emulates communication equipment, was changed to match the CM characteristic impedance of a cable, and the matching condition was evaluated by S-parameter. The result shows that good matching can be obtained at frequencies below 3 MHz. It is also found that a mismatch occurs at frequencies above 3 MHz due to parasitic capacitance around a UTP connector on the board.

4:00pm **Power Amplifiers Harmonic Emission Measurement Comparison Using RE103 and CE106 Methods** 625

Islem Yahi, Edrees Almansoori, David Martinez, Chaouki Kasmi, Felix Vega
Technology Innovation Institute, United Arab Emirates

Abstract: This paper presents the experimental analysis of the harmonic levels of a power amplifier system, the measurement is based on the two methods described in the MIL-STD-461, the CE106 conducted emissions and the RE103 radiated emissions methods. The objective is to make multiple analyses, mainly on the comparability of the two measurement methods results, but also the impact of the antennas, the modulation, or the performance related to the amplifier topology on the harmonics content level.

TH-AM-G Low Frequency EMC, Power EMC, Conducted Emission, Transportation and Electrical Vehicles, Grid (Sponsored by TC-7)

Technical Papers **8:00am - 12:30pm**

Room: Gallery Overlook G

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

Co-Chair: Petre-Marian Nicolae, *University of Craiova, Craiova, Romania*

8:30am **Analysis of LF Disturbances and Immunity Improvement Techniques for Automotive Distance Ranging Sensors** 626

Raffi Kalayciyan, Michael Kunz, Harry Litz, Özkan Palabiyik, Bastian Hafner, Philipp Maurer, Frédéric Boyron

Valeo Schalter und Sensoren GmbH, Germany

Abstract: This paper presents improvement potentials and noise mitigation techniques at the use case of ultrasonic distance ranging sensors for automotive applications. The key element of the product development for improved immunity behavior against noise sources in the low frequency band of below 200 kHz was the fusion of chip level noise quantification using system plausibility check features with the electromagnetic compatibility design optimization of electromechanical sub-components. For this purpose, empirical and 3D simulation data are generated and analyzed. In addition, radiated immunity measurement methods are presented for the final component evaluation of the low frequency electric and magnetic immunity performance below 200 kHz.

9:00am **Common Mode Current Estimation for Filter Design for Non-ideal Back EMF of a PMSM** 632

Patrick Koch[1], Niek Moonen[1], Frank Leferink[1,2]

[1]Universiteit Twente, Netherlands; [2]Thales Nederland BV, Netherlands

Abstract: This paper describes different modeling steps to estimate Common Mode (CM) currents with a Permanent Magnet Synchronous Machine (PMSM) as load, dependent on the cable constellation and cable length. Which is load with a non-ideal load inducing a non-Ideal Back Electromagnetic Force (EMF). The effects of these 3 different parameters on the CM current have been simulated. It can be observed that the cable length and constellation have an impact on the emissions of the CM current. If a symmetrical Back EMF is applied, it does not contribute to CM emissions, which should be considered in the design of the Electromagnetic Interference (EMI) filter.

9:30am **Non-invasive Identification of a Degraded Passive Filter Component** 638

Ivan Struzhko[1], Robert Vogt-Ardatjew[1], Frank Leferink[1,2]

[1]Universiteit Twente, Netherlands; [2]Thales Nederland BV, Netherlands

Abstract: The development of modern technology makes the use of low-pass filters increasingly necessary to protect sensitive equipment from the impact of high-frequency noise. However, filters are often exposed to harsh operating conditions that can cause a significant influence on the condition of the filter components themselves. Affecting any element of the filter will result in a change in the performance of the filter as a whole. Therefore, it is possible to determine the nature of changes that occurred in a damaged filter from the changes in its performance. This paper presents an application of the previously proposed method for identifying the culprit filter component using a simple combination of measurements and simulations. A simple filter, in which one component was changed to mimic its degradation, was selected as a case study. Measurements in common mode were made to estimate the magnitude of that effect in terms of insertion loss (IL). Monte Carlo simulations with variable component values were performed to fit the IL of the damaged filter and identify the culprit component. It is shown that the proposed approach can be used as a tool for finding the possible cause of changes due to filter damage.

10:30am **A Frequency-Domain Model of Common-Mode and Differential-Mode Sources in Three Phase Diode Rectifier Systems** 643

Zhaoqing Zhang, Andrea Zingariello, Gerd Griepentrog
Technische Universität Darmstadt, Germany

Abstract: This paper develops a frequency domain model to estimate the spectra of the conducted emissions caused by three phase diode rectifiers. Based on Fourier analysis, the common and differential mode excitation sources generated by the grid side voltage including harmonics are derived in the frequency domain. The Non-linear behaviour of three phase rectifiers and the influence of input harmonics are investigated. Calculated emission spectra are validated with time-domain simulations and laboratory measurements. The results show a good agreement. The proposed method allows emission spectra to be predicted without a specialist circuit simulators and the results can also be used for further study of filter design and defining new harmonics standards.

11:00am **Using the Wavelet Packet Transform to Evaluate Weights of Clustered Harmonics Using Lookup Tables** 649

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

Abstract: The paper deals with an original technique used to evaluate the weights of sets of harmonic orders (H1 and H2) clustered in an almost exclusive manner to pairs of terminal nodes from a Wavelet Packet Tree (WPT). The total harmonic contribution (SH1H2) of such harmonics can be retrieved from the analyzed signal by using original computational techniques. The total root mean square of SH1H2 can be used to deduce, by using a lookup table, a larger set of possible solutions in terms of harmonic weights for H1 and H2. This set can be afterward reduced by imposing conditions related to the energies of the associated terminal nodes, making use of another table. The final selection of the approximated solution relies on harmonic phase-shifts estimations provided by solutions of linear systems. The technique requires a highly acceptable small runtime while considering less complicated operations and is a good alternative for analysis of periods with non-symmetric half-periods.

11:30am **Optimization of Ferrite Structures in Inductive Power Transfer System for Electric Vehicles** 654

Yao Pei[1,2], Lionel Pichon[1,2], Mohamed Bensetti[1,2], Yann Le Bihan[1,2]
[1]Université Paris-Saclay, France; [2]Sorbonne Université, France

Abstract: The paper presents a fast multiobjective optimization procedure to improve the design of inductive power transfer systems for electric vehicles. It relies on the combination of metamodeling techniques with a topology optimization process. The approach is applied to a practical system developed in the laboratory. Numerical predictions show that the global volume of ferrite can be strongly reduced while keeping rather the same transmission performances as the initial structure. The influence of a conductive shielding placed above the receiver is also analyzed.

12:00pm **Simulation Based Approach for Low Frequency Electromagnetic Field (EMF) Exposure Assessment** 655

Nitin Parsa, Varittha Sanphuang
Ford Motor Company, USA

Abstract: This paper discusses the simulation technique to estimate the low frequency Electromagnetic Field (EMF) exposure using weighted peak method (WPM). A simulated model of three-axis isotropic magnetic field probe was developed and validated. Furthermore, a simulation-based EMF exposure method was developed and validated with a commercially available exposure level tester instrument. In both the cases mentioned above, seat heater coils were used as a source to generate the magnetic fields.

TH-ALL-H Signal and Power Integrity, Interconnects, Modeling and Characterization, Crosstalk, Jitter, Noise (Sponsored by TC-10)

Technical Papers **8:00am - 5:30pm**

Room: Gallery Overlook H

Chair: Tao Wang, *Missouri University of Science and Technology, San Diego, CA, USA*
Co-Chair: Francesco de Paulis, *University of L'Aquila, L'Aquila, Italy*
Co-Chair: Wei Zhang, *Missouri University of Science and Technology, Rolla, MO, USA*
Co-Chair: Chulsoon Hwang, *Missouri University of Science and Technology, Rolla, MO, USA*
Co-Chair: Sungwook Moon, *Foundry Business Division, Samsung Electronics Co. Ltd., Hwaseong-si, Korea (the Republic of)*
Co-Chair: Kundan Chand, *Meta Platforms Inc, Bothell, WA, USA*

8:00am **Novel Pinout and Padring Architecture to Reduce Noise Coupling** 656
Rishi Bhooshan, Pawan Gupta, Swapnil Tiwari, Ajay Kumar Sharma
NXP Semiconductors India Pvt Ltd, India

Abstract: With technology shrinking and higher integration of multiple functionality of high speed interfaces imposes challenges to reduce the noise coupling at system level to meet the power integrity and signal integrity specification. This requires multi-layer PCB with multiple ground plane, multiple VSS layer in the package, large number of VSS balls/pins and large number of VSS pads at the die level to reduce the overall noise coupling in the system. This leads to increase die size and package size and hence the cost. Here in this paper we propose a novel method of pinout and padring architecture without increasing VSS pads at die level and VSS pins/balls (hence saves cost) to reduce the overall noise coupling in the system to meet the signal integrity and power integrity (SIPI) requirement for the high speed interfaces. This has been implemented in automotive Soc in C40 technology for RGMII interface and Si is working fine.

8:30am **Modeling Power Supply and Ground-Bounce Induced Jitter for a Voltage-Mode Driver Circuit Driving Long Transmission Lines** 657
Vinod Kumar Verma, Dinesh Junjariya, Jai Narayan Tripathi
Indian Institute of Technology Jodhpur, India

BEST SIPI PAPER FINALIST

Abstract: This work presents an efficient approach to estimate power supply and ground-bounce induced jitter for a voltage-mode driver (VMD) circuit driving long transmission lines. Considering the spatial and temporal components of long transmission lines, a semi-analytical method is used to determine jitter at the differential output response of VMD. It uses slope-based method to model the timing uncertainty and requires only one-bit simulation for the estimation of jitter. The results obtained from the proposed method are compared with the results obtained using SPICE based simulator to validate the proposed methodology for estimating jitter.

9:00am **SI/PI Co-design of 12.8 Gbps HBM I/O Interface Using Bayesian Optimization for PSIJ Reduction** 662
Taein Shin[1], Hyunwook Park[1], Daehwan Lho[1], Keunwoo Kim[1], Boogyo Sim[1], Seongguk Kim[1], Jihun Kim[1], Seonguk Choi[1], Jiwon Yoon[1], Jinwook Song[2], Sunghoon Chun[2], Joungho Kim[1]
[1]Korea Advanced Institute of Science and Technology, Korea; [2]Samsung Electronics, Korea

Abstract: In this paper, we propose SI/PI co-design method using Bayesian optimization (BO) for power supply noise induced jitter (PSIJ) reduction in 12.8 Gbps high bandwidth memory (HBM) I/O interface. PSIJ is becoming significant SI/PI problem as the operating speed increased, in particular HBM with huge I/O counts. SI/PI co-design is needed for accurate PSIJ prediction since it is determined according to the not only power domain such as power distribution network (PDN) and jitter sensitivity of circuit, but also channel loss. First, PSIJ is modeled analytically. Each target design parameters are RLC circuit components of interposer and on-chip for PDN, circuit delay of I/O driver for jitter sensitivity, and physical dimensions of interposer for channel. Then, these eleven design parameters are optimized in the continuous space based on PSIJ value using BO. As a result, SI/PI co-design is effectively performed through PSIJ-based BO, and the system-level trend of each I/O interface component can also be analyzed. Also, the proposed method based on BO is verified to outperform compared to random search (RS) algorithm.

9:30am **Experimental Method for Measuring the Jitter Sensitivity Function of SERDES IP Circuits** 668

Joonhyun Kim, Seonha Lee, Seungki Nam, Jungil Son, Sungwook Moon
Samsung Electronics Co. Ltd., Korea

Abstract: This work proposes an experimental method to measure the jitter sensitivity function (JSF) of SERDES IP circuits. The noise monitoring position of the test chip is designed to directly measure the on-chip power noise. By controlling the output amplitude of an external function generator through PDN impedance adjustment, a constant power noise can be applied to the circuit. Finally, the JSF can be evaluated by measuring the total jitter increase and on-chip power noise. The measurement results show that the H0 value of the JSF measured from 10 MHz to 100 MHz is within the expected range considering the silicon's corner conditions.

10:30am **PI Design for 3DIC Implementaion** 669

Sungwook Moon, Minseok Kang, Duhyoung Ahn, Seungki Nam
Samsung Electronics Co. Ltd., Korea

Abstract: It is challenging to design the target power integrity (PI) performance of a power supply when implementing 3DICs. To address this issue, we propose a design optimization method to improve PI characteristics from a system perspective. As a result, we observed a 53% improvement in overall IR drop characteristics by optimizing PI resource and using package decoupling capacitors in the system-level power delivery network (PDN).

11:00am **A Thermal-Aware DC-IR Drop Analysis for 2.5D IC** 670

Shengxuan Xia[1], Baris M. Dogruoz[2], Yansheng Wang[2], Songping Wu[2], Siqi Bai[2], Chulsoon Hwang[1], Zhonghua Wu[2]
[1]Missouri University of Science and Technology, USA; [2]Rivos Inc., USA

BEST SIPI STUDENT PAPER FINALIST

Abstract: With the trend of higher integration, 3D/2.5D IC solutions such as CoWoS (Chip-on-wafer-on-substrate) have become more popular in recent years. Power integrity (PI) is always a critical part of the design especially when the power consumption requirements are important specs for high-performance computing. DC-IR drop is one of the criteria within power integrity considerations. However, ordinary electrical-only simulation for DC-IR drop will be an underestimation because it neglects the copper conductivity dropping due to the temperature rising. Thus, an engineering solution for electrical-thermal co-simulation is important to help to provide both an accurate PI analysis and the proper mitigations of the IR drop along the power rails. This paper uses a 2.5D IC chiplet as an example to conduct the thermal-aware DC-IR simulation workflow. By iterating and exchanging the power map and temperature map files between an electrical simulator and a thermal simulator, detailed layer-by-layer IR drops and the temperature map results can provide good insights for efficiently mitigating the IR drop for PI by establishing a better cooling condition in thermal solution.

11:30am **On-Silicon Capacitor Sharing Technique Based on Package Power Merging for PDN Optimization** 676

Wei Liu, Guang Chen, Lei Hua, Jenny Xiaohong Jiang
Intel Corporation, USA

Abstract: In this paper, the on-die decoupling capacitor (OPD) sharing from package technique is presented for power delivery network (PDN) design optimizations with next generation Field-Programmable Gate Array (FPGA). The paper mainly focuses on AC coupling noise mitigation technique among channels for transceiver power delivery design on large FPGA packages. With the proposed method, on-package decoupling capacitor (OPD) can be eliminated to enable small-size, low-cost packages without compromising package noise performance for transceiver power rails. Package layout schemes, power sharing techniques within different layers, and comparison among sharing within different layers to alleviate noise coupling between channels to mitigate voltage droop and overshoots are presented and analyzed in detail. The power integrity (PI) challenges lying with high-speed transceivers on FPGAs is analyzed and enablement solutions on package level are proposed to meet noise specifications without additional costs. An accurate noise simulation methodology and package routing optimization method in noise optimization is essential to an efficient system evaluation and demonstrated in this paper.

1:30pm **Simplified Analysis for Silicon Capacitors** 682

Jungil Son, Kunwoo Ku, Seungki Nam, Joonhyun Kim, Sungwook Moon
Samsung Electronics Co. Ltd., Korea

Abstract: As chips become more powerful, the power density increases, resulting in increased voltage noise. Several capacitor solutions have been proposed to mitigate this problem, one of which is silicon capacitors. In the development of complex and expensive silicon-based processes, early-stage simulation-based design optimization is required to address manufacturing challenges. In this work, we propose a method to accurately and quickly model silicon capacitors, especially integrated stacked capacitors (ISCs), to predict their characteristics.

2:00pm **Machine-Learning-Based Optimization of Tx Equalization Parameters of a High-Speed Channel** 683

Feng Ling[1], Yufeng Dan[1], Changhua Wan[1], Kevin Cai[2], Bidyut Sen[2]
[1]Xpeedic, USA; [2]Cisco Systems, Inc., USA

Abstract: We propose a machine-learning-based optimization approach for the Tx equalization. Our target is practical high-speed channels used in systems requiring industrial communication protocols. We adopted Random Forest as our basic machine learning algorithm and applied it to low, medium, and high loss channels with 3-tap and 5-tap Tx equalization architectures. Our machine-learning-based optimization results showed the outstanding efficiency and accuracy of the approach.

2:30pm **Undesired-resonance Analysis and Modeling of Differential Signals Due to Narrow Ground Lines Without Stitching Vias** 688

Chaofeng Li[1], Yuandong Guo[1], Yuanzhuo Liu[1], Siqi Bai[2], Bichen Chen[2], Srinivas Venkataraman[2], Xu Wang[2], DongHyun Kim[2]
[1]Missouri University of Science and Technology, USA; [2]Facebook Inc., USA

Abstract: Undesired resonances on high-speed differential signals are studied in this paper, which is caused by the adjacent narrow ground line without stitching vias. Due to space limitations in the high-speed channel layouts of certain package applications, the ground (GND) line is often narrow and has insufficient stitching vias, potentially causing undesired resonance in high-speed differential signals. In this study, these undesired resonances were investigated using 3D simulations, revealing that they can be modeled as parallel-coupled half-wavelength resonance. The resonance frequency of the parallel-coupled half-wavelength resonance structure can be predicted well using the formula based on the GND line length. Moreover, three potential solutions to undesired resonance are proposed, providing a practical guide for GND line routing in specific applications.

3:30pm **Power Delivery Measurement Correlation for Mixed Reality Rigid Flex Systems** 693

Kundan Chand[1], Grace Yu[1], Steve Sandler[2]
[1]Meta Platforms Inc., USA; [2]Picotest.com, USA

Abstract: It is difficult to measure and correlate power delivery network (PDN) for Mixed Reality (MR) Systems with Rigid Flex printed circuit (RFPC) designs using conventional techniques. This is due to high density routing and the small form factor. Traditional hybrid EM simulators are used to model PDNs for rigid single stackup PCBs, however these solvers run into limitations when working on multi-zone (MZ) or multi-stackup rigid flex designs. Moreover, accurate dynamic chip current simulation capability is lacking, which leads to errors in on-chip PDN droop correlation. This paper investigates various simulation best practices and measurement methods to achieve good correlation for power delivery of Mixed Reality Systems. Overall, this paper provides a valuable contribution to defining a PDN correlation flow of multi-zone RFPCs used in mixed reality design and has implications for the design of future MR systems.

4:00pm **A Physics-Based Genetic Algorithm for Decap Optimization in Power Distribution Networks** 698

Ling Zhang[1], Li Jiang[1], Shurun Tan[2], Yuru Feng[1], Hanzhi Ma[1], Da Li[1], ErPing Li[1]
[1]Zhejiang University, China; [2]Zhejiang University/University of Illinois at Urbana-Champaign Institute, China

BEST SIPI PAPER FINALIST

Abstract: Efficiently finding the optimal decoupling capacitor (decap) solutions for power distribution networks (PDNs) with an enormous search space has always been challenging. This paper presents a physics–based genetic algorithm (GA) that can rapidly converge to the optimal decap solutions. Firstly, the priority of the decap locations is determined by calculating and comparing their physical inductances. Then, an initial solution is obtained by selecting the best decap types to be sequentially placed on the prioritized decap locations. Subsequently, a GA is developed to find solutions better based on the initial solution by progressively removing the decap ports with lower inductance-based priorities. The proposed physics-based GA demonstrates a much faster convergence to higher-quality solutions than the existing decap optimization approaches, and is robust and powerful to handle real-world applications.

4:30pm **An Innovative Power Delivery Solution for High Power CPU Support** 704

Meng Wang[1], Yipeng Zhong[1], Xiaoning Ye[2]
[1]Intel Corporation, China; [2]Intel Corporation, USA

Abstract: In this paper, we proposed an innovative energy saving and cost effective power delivery solution by implementingan external backside busbar on server motherboard, which can reduce dc resistance of CPU core power delivery path(Rpath) to meet high power CPU server performance needs as well as reduce system power consumption .Prototype systems were built and validated by simulation and measurement with proven benefits. The design results in 30% Rpath reduction, ~10W power saving per server system, 4~5C temperature drop at CPU socket, and provide extra routing space for signals at power corridor area. For a datacenter with 200k system configured with high power 350W CPU, it can help reduce total cost of ownership (TCO) up to 9M dollars.

5:00pm **PIPPON: Improve Impedance Prediction of Power Distribution Network Using Pole Proposal Network** 705

Cheng-Hsueh Lu[1], Ling-Yu Tseng[1], Shih-Chieh Chang[1], Shih-Hsien Wu[2]
[1]National Tsing Hua University, Taiwan; [2]Industrial Technology Research Institute, Taiwan

Abstract: While it is a difficult task to model and simulate a power distribution network's (PDN) impedance profile for printed circuit boards (PCBs) with irregular board shapes and multi-layer stackup, it is a crucial process for the design and performance evaluation of the PDN. This paper proposes a new deep learning method PIPPON for PDN impedance prediction, which contains a proposal network specializing in predicting impedance profiles in the range around a pole point. The result shows that PIPPON produces more accurate results (with a 30 percent relative error reduction) than the previous deep learning method and maintains the same level of fast computation time as the previous method. Meanwhile, PIPPON focuses on impedance pole points resulting in a more accurate picture of whether the impedance profile meets the target impedance requirement. Index Terms—Impedance, Prediction, Power distribution network, PDN, Neural network

TH-PM-B Lessons Learned Creating Reliable Computational Models for SI, PI and EMC Applications (Sponsored by TC-9)

Tutorial **2:00pm - 6:00pm**

Room: Gallery Overlook B

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

Session Abstract: This tutorial will expose the attendees to the lessons learned by a number of industry experts over the years. The goal being that the attendees will benefit from the, sometimes painful, learning experiences of the presenters. Computational tools are very powerful and simulation is invaluable to the modern design engineer but there is still an art to using these tools effectively. In all disciplines, hindsight is perfect and the opportunity to learn from others is a valuable resource. This tutorial will not only show lessons learned but also expose the attendees to fundamental ways of thinking through their models to better ensure success. Examples relevant for Signal Integrity, Power Integrity and Electromagnetic Compatibility design will be shared.

Model Validation
Bruce Archambeault
International Business Machines Corp, USA

What I Wish I Knew About EMC Simulation When I First Started
Scott Piper
General Motors Corp, USA

Details That Matter: Understanding Aspects That Can Help Mitigate the Differences between Measurements and Simulated Results for SI and EMC
Juliano Mologni
ANSYS, USA

Establishing Confidence in Field Solvers
Eric Bogatin
University of Colorado Boulder, USA

Reconciling EMC and Simulation
Kyle Elsasser
Electro Magnetic Applications, Inc., USA

Winning the Lottery with Power Integrity Simulations... What are the Odds?
Heidi Barnes
Keysight Technologies Inc., USA

Important Aspects of 3D Time Domain Field Simulation: Experiences and Lessons Learned
Nivedita Parthasarathy
Dassault Systèmes, France

TH-PM-C Aeronautics and Space EMC, Aircraft, Atmospheric Environment, Drones, Spacecraft, Missiles (Sponsored by TC-8)

Technical Papers **4:00pm - 5:30pm**

Room: Gallery Overlook C

Chair: Jen Dimov, *NASA, Greenbelt, MD, USA*

Abstract: Due to interferences from pervasive electromagnetic emissions, the likelihood of irregular performance and possibly loss of control of an unmanned aircraft system (UAS) grows as small commercial drones are deployed in more applications. The UAS electromagnetic compatibility has therefore become a crucial factor to consider in UAS design and operation to minimize any potential safety issues. A UAS may experience radio frequency interference (RFI), a subset of a broader range of electromagnetic interference (EMI), through its communication link or capacitive coupling of the RF electrical field. We conducted measurements both outside and within a chamber to assess the impacts of front-door and back-door RFI on the C2 (command and control) link and the subsystem components of two distinct drone models. In this paper, we describe the measurement setup and procedures, present the results, and analyze the safe distances of the drones from RFI sources such as cellphone base stations and airport surveillance radar (ASR) under the impacts from these two types of RFI in this study.

Abstract: An empirical study has been performed to inves- tigate the radiation mechanisms that yield emissions from two- conductor transmission line circuits at microwave frequencies up to 8.5 GHz. The measured signal levels established by radiation from the test configurations within a reverberation chamber were compared with the levels radiated by a wide-band dual-ridge antenna in the same environment. Two basic test configurations were considered, one in which the transmission line segment and full feed structure, including balun and feed plate, were contained within the chamber cavity, and one in which the feed structure and feed plate could be isolated from the cavity. The measure- ments show that radiation from the line terminations dominates the emission within the cavity that contains it, including when only bulkhead SMA pin adapters were exposed to the cavity, independent of whether the line was a parallel-conductor twin- lead line or a twisted pair. Emissions from the twin-lead line exceeded that from the twisted-pair line only when the lines were passed through apertures in the chamber walls. Moment-method calculation of the radiation from an ideal, balanced twin-lead line showed overall lower emissions than that measured at the lower microwave frequencies considered. The results suggest that the emissions can be modeled by adding a radiation resistance element at the connector location to standard transmission line theory.

Abstract: All-electric aircraft (AEA) require an increased number of power converters, making it potentially more susceptible to electromagnetic interference (EMI). As aircraft rely on strict volume and weight limits, mitigation methods must be developed to minimize their impact on the overall bulkiness. The operation of a multi-converter distribution system supplied by a single dc power source is investigated in this paper. Filtering methods are typically implemented at each converter independently, however, a centralized approach is here investigated. Common and differential mode EMI levels are evaluated, resulting in the design of gamma-pi type EMI filters. The solutions are compared for centralized against localized filters, evaluating performance, variables influencing design decisions, and overall size optimization.

TH-PM-G Advanced EMC Design based on Near-field Modeling and Metasurface

Technical Papers (Special Session) **2:00pm - 5:00pm**

Room: Gallery Overlook G

Co-Chair: Richard Xian-Ke Gao, *A*STAR Institute of High Performance Computing, Singapore*

Co-Chair: Xing-Chang Wei, *Zhejiang University, China*

2:00pm **An Effective Source Reconstruction Method in a Shielding Enclosure Based on Magnitude-Only Near-Field Scanning** 730

Tian-Hao Song[1], Ze-Kai Hu[1], Qi-Han Xiao[1], Dong-Feng Guo[2]

[1]Zhejiang University, China; [2]OPPO, China

Abstract: An effective source reconstruction method (SRM) in a shielding enclosure is proposed in this paper. Magnitude-only near-field scanning technology is employed to overcome the difficulty of precisely measuring the phase. After scanning the magnitude-only near-field of the real unknown electromagnetic interference (EMI) source in free-space, a global optimization algorithm named differential evolution (DE) method is applied to obtain the equivalent dipole model. Then, the proposed equivalent dipole model can be used to represent the unknown EMI source in the shielding enclosure. The results of the numerical and measurement examples verify the effectiveness of the proposed method.

2:30pm **An Effective EMI Source Reconstruction Method Based on Adaptive Dynamic Differential Evolution** 735

Dong-Hao Han[1], Liang-Jin Chen[2], Xing-Chang Wei[1], Tian-Hao Song[1]

[1]Zhejiang University, China; [2]State Grid Zhejiang Power, China

Abstract: In this paper, an effective electromagnetic interference source reconstruction method is proposed based on adaptive dynamic differential evolution. The performance of traditional dynamic differential evolution depends largely on the choice of the initial values. Compared with the traditional dynamic differential evolution method, the proposed method will update the hyperparameters adaptively. This hyperparameter adaptive mechanism will make the proposed method have stronger global search ability and more reliable convergence performance, thus reducing the impact of the initial values. By using the proposed method, the unknown source is replaced by equivalent dipoles based on the phaseless scanning magnetic fields. Simulation results demonstrate the effectiveness of the proposed method.

3:00pm **A PEEC-Informed Deep Learning Approach for Inverse Electromagnetic Problem in Heterogeneous Integrations** 740

Yang Jiang, Richard Xian-Ke Gao

Institute of High Performance Computing, Singapore

Abstract: In this paper, a partial element equivalent circuit (PEEC) informed deep learning approach is proposed for inverse electromagnetic scattering problems involving finite-sized dielectrics. To balance the enormous learning space and limited computation resources, a partial-relative-permittivity (PRP) model is proposed based on the compact PEEC model, which is capable to reveal the electromagnetic (EM) behavior of three-dimensional (3-D) heterogeneous structures by a 2.5-dimensional (2.5-D) representation. A tailored generative adversarial network (GAN) is developed to learn the intrinsic relation between the PRP model and the near-field information. To imitate the real-world phenomenon with adequate and accurate data, a dedicated training dataset is built numerically. With the GAN model, a PRP model can be interpreted from the measured phaseless magnetic fields at a single frequency, resulting in a broad-band c-PEEC model that is especially useful in power integrity and radiated emission analysis.

4:00pm **Transmission Line Intra-pair Skew Analysis and Management on PCIe 6.0** 746

Xinjun Zhang, Wenwu Wang, Weizhe Li, Mo Liu, Chenghai Yan, Kai Xiao, Xiaoning Ye
Intel Corporation, China

BEST EMC PAPER FINALIST

Abstract: In this paper, the impact of the intra-pair skew of printed circuit board (PCB) trace and the related compensation scheme is studied at Peripheral Component Interconnect Express (PCIe) 6.0 Pulse Amplitude Modulation 4 (PAM4) 64 Gbps speed. The skew is introduced and compensated in the actual PCB layout and modeled in mixed 2-D and 3-D modeling tools for both stripline and microstrip. The intra-pair skew modeling method is verified through correlations between simulation and measurement results. The sensitivity of the link performance to the amount of skew, and compensation location is thoroughly analyzed. PCB trace skew management guidelines for PCIe 6.0 channels are provided.

4:30pm **The Prediction of Magnetic Near-Field Distribution Characteristics Based on Artificial Neural Network** 752

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Abstract: In this paper, the magnetic near-field distribution characteristics of a printed circuit board (PCB) are predicted based on developed artificial neural networks (ANNs). ANN is capable of understanding how the trend of the radiation near-field varies when a PCB working at adjacent different frequencies, making the near-field prediction possess with higher accuracy and lower time-cost. The proposed method offers a fresh perspective on how to analyze the near-field distribution characteristics in electromagnetic compatibility (EMC) issues.