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TABLE OF CONTENTS – TECHNICAL

MONDAY TECHNICAL PAPERS AND ABSTRACTS

Monday, August 9, 2021

TP-MON-2B EMC Management – EMC Effects (Sponsored by TC-1) 13:30 - 15:30

Chair: Tom Braxton, Shure Incorporated, Bolingbrook, IL, USA

13:30 **Proposals for Change in Automotive EMC Standardization and Engineering Practices** 1
Alastair R. Ruddle, Anthony J.M. Martin, Mark Emery
HORIBA MIRA Ltd., United Kingdom

Abstract: Current automotive EMC engineering practices have served the industry well over many decades. In more recent years, however, the nature of vehicle electronic systems has begun to develop in ways that are leading to fundamental changes in the nature of road vehicles. The speed and nature of these changes are now becoming such that traditional assurance approaches based on prescriptive standards are beginning to struggle to keep pace with emerging technological changes. It is considered that moving towards the goal-based assurance and risk-based engineering approaches that are already used in other aspects of the engineering of complex systems would provide the basis of more sustainable assurance and engineering processes for automotive EMC engineering in the future.

13:55 **Selection Methodology of Risk Assessment Techniques for Electromagnetic Resilience** 7
Acássio Matheus Roque[1], Carlos Antonio França Sartori[1,2]
[1]*University of São Paulo, Brazil;* [2]*Pontifícia Universidade Católica de São Paulo, Brazil*

Abstract: The growing use of electrical and electronic technologies has intensified the electromagnetic environment at the same time as new technologies tend to be more susceptible to electromagnetic interference (EMI). This is a major concern for the application of electrical and electronic equipment in safetyrelated systems since faults and malfunctioning caused by EMI can affect human and environmental safety. In this context, the achievement of functional safety regarding electromagnetic disturbances, known as electromagnetic resilience, is mandatory to prevent the occurrence of incidents and accidents. The process to reach electromagnetic resilience is based on many steps, in which the risk assessment is one of high importance. Although many risk assessment techniques have been studied and general rules for their selection have been developed, little effort has been done to establish a method to evaluate the suitability of risk assessment techniques for electromagnetic resilience. This paper introduces a proposal for a framework to select risk assessment techniques suitable for electromagnetic resilience. The definition of criteria is based on the literature research concerning the fundamental difficulties encountered in the electromagnetic resilience field. The formulation of the selection problem and the comparison analysis between the selected risk assessment are performed using the Analytical Network Process (ANP) method. To illustrate the methodology, it is performed an application comparing two well-known risk assessment methods: failure mode and effect analysis (FMEA) and failure tree analysis (FTA).

TP-MON-3B Electromagnetic Environments in Safety Critical Situations (Sponsored by TC-3) 13:30 - 15:30

Chair: Karen Burnham, Electro Magnetic Applications, Inc., Lakewood, CO, USA
Co-Chair: Qiaolei Huang, Amazon Lab126, Sunnyvale, CA, USA

13:30 **Near Field Exposure Conditions of UHF-RFID Systems in Smart Healthcare Environments** 13
Silvia Miguel-Bilbao[1], Jose A. Hernandez[2], Oscar J. Suarez[3], Pablo Marina[1], Victor M. Febles[2], Luis E. Rabassa[2], Samuel Suarez[2], Jolanta Karpowicz[4], Patryk Zradzinski[4], Krzysztof Gryz[4], Erik Aguirre[5], Victoria Ramos[1]
[1]Instituto de Salud Carlos III, Spain; [2]Hospital Universitario de Canarias, Spain; [3]Secretaría de Estado de Telecomunicaciones e Infraestructuras Digitales, Spain; [4]National Research Institute, Poland; [5]Universidad Pública de Navarra, Spain

Abstract: Short range wireless RFID technology has many applications in socialcare and healthcare environments, having to coexist with other sources of electromagnetic (EM) radiation and even with patients' implanted devices. This work provides an overview of exposure conditions in near EM field conditions and evaluates this exposure. The near EM field conditions by RFID reader is discussed based on the results of measurements inside an anechoic chamber under strict experimental conditions, and numerical modelling with simulation software. The obtained results were considered with respect to the human EM exposure evaluation principles and exposure limitations provided by the relevant international guidelines and regulations. In areas close to the RFID reader, the local exposure to EM radiation has the near field nature, i.e. the impedance of EM field significantly differs from the far field (free space). Evaluating human exposure requires measurements of the electric and magnetic field strength, or even the numerical modelling of Specific Energy Absorption Rate (SAR). It was found that a near field nature of EM radiation near an RFID reader ranges several times longer when the operator is present nearby, compared to the same emitting device considered alone in the empty space. This is of significance when evaluating EM exposure of humans (patients or health care personnel, especially users of medical implants) if, for any reason, they are less than 50 cm away from an RFID reader, especially when emission from it exceed 2 W.

13:55 **Research on Emergency Call System Adaptability to Actual Electromagnetic Environment** 19
Yue Zhang, Yifu Ding, Xu Zhang
China Automotive Technology and Research Center Co., Ltd., China

Abstract: Research on the performance of emergency call system in the actual electromagnetic environment is of great significance to ensure the reliable operation of the system. Based on the analysis of the emergency call system connectivity and communication quality, the actual electromagnetic environment signal collection and playback are carried out, and the connectivity and communication quality of the emergency call system in actual electromagnetic environment are tested and verified. The test results show that some performance indicators of the emergency call system will be affected by the actual electromagnetic environment signal, which provides a reference for the electromagnetic compatibility quality assessment of emergency call system and the formulation of relevant standards.

TP-MON-4B Testing Techniques and Shielding Principles of Systems (Sponsored by TC-4) 13:30 - 15:30

Chair: William Wantz, IV, Spira Manufacturing, San Fernando, CA, USA

13:30 **Imaging Distributed Sources with Sparse ESM Technique and Gaussian Process Regression** 23
Jiangshuai Li, Victor Khilkevich, Ruijie He, Yuanzhuo Liu, Jiahao Zhou
Missouri University of Science and Technology, USA

Abstract: Emission source microscopy (ESM) technique can be utilized for the localization of electromagnetic interference sources in complex and large systems. In this work, a Gaussian process regression (GPR) method is applied in real-time to select sampling points for the sparse ESM imaging. The Gaussian process regression is used to estimate the complex amplitude of the scanned field and its uncertainty allowing to select the most relevant areas for scanning. Compared with the random selection of samples the proposed method allows to reduce the number of samples needed to achieve a certain dynamic range of the image, reducing the overall scanning time. Results for simulated and measured 2D scans for multiple and distributed emission source are presented.

13:55 **Magnetic Field Leakage Reduction and Efficiency Enhancement of Wireless Power Transfer by using Side-Positioned Coil Array** 29

Zhiyuan Gu[1], Liping Yan[1], Xiangyong Mou[2], Xiang Zhao[1], Richard Xian-Ke Gao[3]
*[1]Sichuan University, China; [2]Chengdu University of Information Technology, China; [3]A*STAR, Singapore*

Abstract: A side-positioned coil array printed on a PCB slab effectively suppressing the magnetic field leakage of a magnetic resonant wireless power transfer (WPT) system while preserving good transfer efficiency is presented in this paper. Based on a basic two-coil WPT system working at 6.78 MHz, a slab with four coils printed on both sides is proposed and fabricated. The effect of the slab on the magnetic field shielding and power transfer efficiency is investigated through physical experiment, when the slab is placed at the side of the WPT system. The magnetic fields around the WPT with and without the slab are measured by a magnetic probe under the control of a 3D scanning system. The measured results show that the proposed coil array reduces the magnetic field leakage by an average of 6.42 dB without degrading the transfer efficiency, instead it improves the efficiency of the WPT system at an average of about 27%.

14:20 **Common Mode Mitigation by Applying Absorber with Genetic-Algorithm Optimized Cross-Section to Microstrip Pair** 33

Ruijie He[1], Xu Wang[1], Victor Khilkevich[1], Paul Dixon[2], Onyekachi Eloagu[2]
[1]Missouri University of Science and Technology, USA; [2]Laird Performance Materials, USA

Abstract: At the post-design stage, applying absorber to transmission lines is a cost-effective and efficient way to improve the EMI behavior of a product. This work presents an optimized shape of absorber that can be applied to a microstrip pair. The presented shape is an outcome of Genetic-Algorithm Optimization. It mitigates EMI by increasing common mode insertion loss of the microstrip pair while maintaining the differential mode signal integrity. Measurements are conducted to prove the superiority of the optimized shape of absorber.

14:45 **VO2 Thin Film as a Temperature Activated Electromagnetic Shield** 38

Quentin Tricas[1], Philippe Besnier[2], Xavier Castel[1], Claire Le Paven[1], Patrice Foutrel[3]
[1]Université de Rennes 1, France; [2]INSA Rennes, France; [3]Safran Electronics and Defense, France

Abstract: This communication presents the fabrication, characterization and performance of a vanadium dioxide (VO2) thin film deposited on a c-cut sapphire substrate, and used as an electromagnetic screen whose shielding effectiveness is controlled through heating/cooling. The film is first deposited at high temperature on the substrate using a radiofrequency magnetron sputtering technique, and is then annealed in-situ in pure dioxygen atmosphere, to obtain the required oxide stoichiometry. The screen shielding effectiveness is measured using the nested reverberation chamber method at room temperature and at 75°C. At 65°C, VO2 undergoes an insulator to metal transition and the material conductivity drastically increases, resulting in a significant shielding effect of the VO2 layer at microwaves (2 – 34 GHz). The experimental results are in accordance with theoretical values predicted by an analytical model. The VO2-based electromagnetic shield is therefore a promising solution to protect sensitive electronics from high intensity radiated field by using the temperature rise as the trigger to rapidly improve the shielding effectiveness of the screen. On the contrary, cooling down the screen is possible if shielding is no longer necessary.

TP-MON-5B Machine Learning/Cloud Computing 1 (Sponsored by TC-9 and TC-10) 13:30 - 15:30

Chair: Tianjian Lu, Google, Mountain View, CA, USA
Co-Chair: Yansheng Wang, Google LLC, Santa Clara, CA, USA

13:30 **Machine Learning-Based Verilog-A Modeling for Supply Induced Jitter Sensitivity of High-Speed Memory Interface: Two Layer PCB Case Study** 44

Michael Chang
HTC Corporation, Taiwan

Abstract: With the ever-increasing demand for both highperformance and high-integrated chips, it is becoming more and more difficult to meet the power distribution network (PDN)- related target specifications. This paper provides the Verilog-A model of supply-induced jitter-aware sensitivity for analyzing supply noise induced timing jitter in DDR high speed interface integrated in cost-effective two-layer circuit board to perform the jitter generated by the supply noise in the time domain compared to present general analysis methods. During design phase, the effort of power distribution network optimization takes place very first to define the floor plan of die, package and circuit board. We propose a Verilog-A model with the skill of vector fitting and neural network for the efficient methodology of timing budget calculation when double data rate (DDR) interface works simultaneously in highly integrated system at early design stage. The goal is to provide adequate performance for cost-effective and system solution and achieving on system-level success.

13:55 **Optimization of Joint Equalization of High-Speed Signals using Bayesian Machine Learning** 48

N. Dikhaminjia[1], G. Tsintsadze[1], Z. Kiguradze[2], J. He[2], M. Tsiklauri[2], J. Drewniak[2], A. Chada[3], B. Mutnury[3]

[1]Ilia State University, Georgia; [2]Missouri University of Science and Technology, USA; [3]Dell Inc., USA

Abstract: The paper elaborates an efficient algorithm for optimization of joint Feed-Forward Equalization (FFE) and Decision Feedback Equalization (DFE) for non-return-to-zero (NRZ) and 4 level pulse amplitude modulation (PAM-4) signals using Bayesian Machine Learning approach previously introduced for NRZ by authors and expanded for PAM-4. A new optimal covariant function and hyper-parameters has been selected for the Bayesian optimization. Cost function for the Bayesian optimization is chosen based on eye height. The proposed method was compared to the conventional Least Mean Square (LMS) method and showed significant improvement. Test cases were performed for several data rates of NRZ and PAM-4 signals with crosstalk and injected jitter. Test results show that the proposed algorithm is the more effective the higher data rates are considered.

14:20 **Distributed Data Processing for Large-Scale Simulations on Cloud** 53

Tianjian Lu, Stephan Hoyer, Qing Wang, Lily Hu, Yi-Fan Chen

Google, USA

Abstract: The computational challenges encountered in the large-scale simulations are accompanied by those from dataintensive computing. In this work, we proposed a distributed data pipeline for large-scale simulations by using libraries and frameworks available on Cloud services. The building blocks of the proposed data pipeline such as Apache Beam and Zarr are commonly used in the data science and machine learning community. Our contribution is to apply the data-science approaches to handle large-scale simulation data for the hardware design community. The data pipeline is designed with careful considerations for the characteristics of the simulation data in order to achieve high parallel efficiency. The performance of the data pipeline is analyzed with two examples. In the first example, the proposed data pipeline is used to process electric potential obtained with a Poisson solver. In the second example, the data pipeline is used to process thermal and fluid data obtained with a computational fluid dynamic solver. Both solvers are in-house developed and finite-difference based, running in parallel on Tensor Processing Unit (TPU) clusters and serving the purpose of data generation. It is worth mentioning that in this work, the focus is on data processing instead of data generation. The proposed data pipeline is designed in a general manner and is suitable for other types of data generators such as fullwave electromagnetic and multiphysics solvers. The performance analysis demonstrates good storage and computational efficiency of the proposed data pipeline. As a reference, it takes 5 hours and 14 mins to convert simulation data of size 7.8 TB into Zarr format and the maximum total parallelism is chosen as 10,000.

TP-MON-6B Computational Electromagnetics I (Sponsored by TC-9) 13:30 - 15:30

Chair: Shaowu Huang, Marvell Technology Group Ltd, Santa Clara, CA, USA

13:30 **Optimization of PDN Decoupling Capacitors for EMI Reduction based on Deep Reinforcement Learning** 59

Chanjong Lee[1], Sangyeong Jeong[1], Jingook Kim[1], Jun-Bae Kim[2], Jeong Don Ihm[2]

[1]Ulsan National Institute of Science and Technology, Korea; [2]Samsung Electronics Co. Ltd., Korea

Abstract: The reinforcement learning (RL) is applied to the optimization of decoupling capacitors on power distribution network (PDN) for reduction of radiated emissions (REs). A small-size parallel-plates PDN structure containing two ICs is modeled as equivalent lumped-circuits, and far-field REs due to the structure are calculated using closed-form expressions. The closed-form expressions are validated with the full-wave simulation results. The environment with a proper reward system for RL is proposed by using the closed-form REs expressions. The proposed RL environment is tested with two design examples for Q-learning and deep reinforcement learning (DRL). The learning results are converged to optimal policies very efficiently, which satisfy the RE regulation with minimum number of decaps for the given PDN structures.

Best EMC Student Paper Finalist

13:55 **A Deep Learning based Macro Circuit Modeling for Black-Box EMC Problems** 64
Yang Jiang, Richard Xian-Ke Gao
*A*STAR, Singapore*

Abstract: In this paper, a deep learning-based macro circuit model approach for black-box electromagnetic compatibility (EMC) problems is proposed. The concept of the partial element equivalent circuit (PEEC) method is deployed in constructing the circuit topology in the full-space mesh of a black-box device. The mesh-based circuit model can serve as a powerful tool in solving the emission and immunity of the system-level EMC problems. A physics based deep neural network (DNN) is designed and optimized with the electromagnetic and circuit theories. The approach is validated by a proof-of-concept numerical example. The training and validation data are obtained by solving simplified PEEC models of randomly generated routes on a pre-defined mesh set of a black box problem. Good agreement and efficiency are observed.

TP-MON-7B Printed Circuit Board Technology and SI Design 2 (Sponsored by TC-10) 13:30 - 15:30

Chair: Zhifei Xu, Kandou Bus, Lausanne, Switzerland
Co-Chair: Francesco de Paulis, University of L'Aquila, L'Aquila, L'Aquila, Italy

13:30 **Single Pair Ethernet for the Industrial Internet of Things: Accurate Line Modeling** 68
Matthias Hampe, Thomas Müller, Alexander Stieler
Ostfalia Hochschule für angewandte Wissenschaften, Germany

Abstract: In this work an accurate simulation model for Single Pair Ethernet (SPE) transmission line LEONI Dacar 546-V is derived. This model takes into account the frequency dependence of all per-unit-length parameters. Here, different measurement setups have been developed in order to obtain the per-unit-length parameters in the frequency range 0Hz − 1.0GHz. Based on the derived model, accurate simulations can be performed in the future, particularly in the fields of Automotive Ethernet, Internet of Things (IOT) and Industrial Internet of Things (IIOT).

13:55 **Linear Periodic Time Varying Filtering of Cyclostationary Signals in Transmission Lines** 72
Yuriy Kuznetsov[1], Andrey Baev[1], Maxim Konovalyuk[1], Anastasia Gorbunova[1], Johannes A. Russer[2]
[1]Moscow Aviation Institute, Russian Federation; [2]Technical University of Munich, Germany

Abstract: Theoretical and experimental evaluation of the cyclostationary random data transferring process corrupted by the individually and jointly cyclostationary crosstalk interference added by stationary noise with possible deterministic component of the synchronizing clock signal is presented. The interference and the message signals were measured by the real time digital oscilloscope and autocorrelation functions were evaluated by synchronous cyclic averaging procedure. The analyzed periodic two-dimensional impulse response of the time-varying filter allows to obtain the output random process with the same cyclic frequency at the output of the filter by separation of orthogonal stationary waveforms constituting the input cyclostationary random process (CSRP). The filtering of the observed measured random process was implemented by cyclic Wiener filter, estimating the message from the measured random signal. The evaluation of two-dimensional autocorrelation function and eye diagrams at the output of the cyclic filter showed significant reduction of the independent interference components in the estimated message signal.

14:20 **An Optimized Transition Structure for Solving Reference Ground Discontinuities in SIW Filter Integration** 78
Haojie Wu, Jiankan Weng, Xinglin Sun
Zhejiang University, China

Abstract: Substrate integrated waveguides (SIW) have been widely used in the design of high-performance narrowband filters and the integration of microwave circuits in recent years, owing to their high quality factor and easy planarization. In the design of single-board integration, in order to achieve high quality factor and narrow-band SIW filter, a low-cost and effective method is to increase the thickness of the substrate layer within a certain range to achieve lower insertion losses. However, with the switching of the reference ground planes, a discontinuous return path will be induced. Improper handling of the structure will give rise to additional losses and radiation which will lead to EMC issues. In this paper, a method is proposed to extend the inner ground at the discontinuous section to form a stepped transition structure to achieve good signal transmission performance. The simulation results show that at 10GHz, the center frequency of SIW in our design, the proposed transition structure has 1.8dB lower insertion loss as well as 40.14dB higher return loss than the structure of direct interconnection at the discontinuous section.

TP-MON-8B Power Electronics EMI Control via Optimal Modulation and Driving Schemes (Sponsored by SC-5) 13:30 - 15:30

Chair: Cong Li, GE Global Research, Niskayuna, NY, USA

13:30 **A VSFPWM Method of Three-Phase CSI for EMI Mitigation based on DC Current Ripple Prediction** 83

Ruodong Wang, Kang Liu, Dong Jiang
Huazhong University of Science and Technology, China

Abstract: Pulse-width-modulation (PWM) is one of the main reasons of electromagnetic interference (EMI) in switching power converter. The level jump, high di/dt and dv/dt of output square-wave voltages or currents caused by the switching process of active components like IGBT or MOSFET lead to the increase in harmonics near switching frequency, its multiples and even higher. And frequency variation is an effective method to mitigate EMI. A variable switching frequency pulse-widthmodulation (VSFPWM) method for three-phase current source inverter (CSI) is introduced in this paper. Based on the ripple prediction of DC current, switching frequency is designed to be updated in DSP in every interruption period to keep the ripple current of DC inductor constant. Both simulation and experiment results show that the application of VSFPWM in CSI can significantly reduce switching losses and suppress differential mode (DM) EMI noises.

13:55 **A Novel Common-Mode Voltage Reduction Method of MMC: Pulse Sequential Connection Carrier Phase-Shifted SPWM** 89

Jiaxin Wang[1], Hong Li[1], Zuoxing Wang[1], Zhaoyi Chu[1], Bo Zhang[2]
[1]Beijing Jiaotong University, China; [2]South China University of Technology, China

Abstract: The switching of the sub-modules (SMs) of modular multilevel converter (MMC) causes a common mode (CM) voltage to ground at the neutral point of the AC side of the MMC, which will affect the normal operation of the system. For instance, the CM voltage in MMC will damage the motor bearing and cause the conducted electromagnetic interference (EMI) problem seriously. In order to reduce the CM voltage in MMC, this paper proposes a novel modulation method of pulse sequential connection (PSC) carrier phase-shifted sinusoidal pulse width modulation (CPS-SPWM), under which the CM voltage of the MMC is zero theoretically. The correctness and effectiveness of the reduction method are validated by the 5- level MMC simulation platform.

14:20 **A Critical Assessment of Open-Loop Active Gate Drivers under Variable Operating Conditions** 94

Erica Raviola, Franco Fiori
Politecnico di Torino, Italy

Abstract: Active gate drivers have been investigated in power circuits to reduce unwanted over-voltages and over-currents, whilst keeping the transients fast. Indeed, the use of such a kind of driver avoids the triggering of oscillations related to high frequency parasitic resonant circuits, which affect adversely the electro-magnetic interference delivered by power modules. However, in the case of fast power switches, the driver is working in an open-loop manner, and the modulation pattern is fixed. This paper assesses the effects of different operating conditions on the switching waveforms of an AGD-driven power transistor. More precisely, load current, input voltage and temperature variations were investigated on an open-loop active gate driver comprised in a Buck converter. Experimental results suggest that the AGD is no longer effective in damping the unwanted oscillations under a significant change of the operating conditions.

14:45 **Frequency-Selective Reduction of Power Electronic Switching Noise by Applying Synthesized Gate Signals** 100

Caroline Krause, Andreas Bendicks, Stephan Frei

Technische Universität Dortmund, Germany

Abstract: The high-frequency switching of power transistors in electronic systems can be a significant source of electromagnetic emissions (EMI). Simple measures like reducing the high-frequency disturbances by introducing an additional gate resistor lead to an increase of the switching losses. This creates a conflict of interests between the reduction of disturbances and high system efficiency. More complex active gate drivers offers improved compromises between EMI and efficiency. Avoiding steep switching slopes, overshoots or sharp edges are typical measures. The whole spectrum is modified this way and efficiency is still affected. In many cases, only a narrow banded modification of the spectrum might be needed to avoid the excitation of critical system resonances. This can be reached by a target signal-oriented control of the gate of the transistors. In the target signal the critical RF components should be reduced. Maximum control of the target signal is possible with fully synthesized gate signals. The reduction of some harmonics in the switching spectrum may lead to overshoots in time domain due to the Gibbs phenomenon. These overshoots may violate the physical limits of a transistor and cannot be realized. In this work, a method is presented to determine the target signal considering all physical limits. The found approach is applied in simulation to the signal of the drain-source voltage of a boost converter to reduce the harmonics in the FM broadcasting range. The gate control signal is determined for this application.

Best EMC Paper Finalist

TUESDAY TECHNICAL PAPERS AND ABSTRACTS

Tuesday, August 10, 2021

TP-TUE-1A Emissions (Sponsored by TC-2) 11:00 - 13:00

Chair: Thomas J. Fagan, Aerospace Corporation, Vail, AZ, USA

11:00 **Prediction of Radiated Emissions by Applying Multipole-Network Theory to a Measurement Setup** 106

Alexander Engeln, Kai-Uwe Rathjen, Stefan Dickmann

Helmut-Schmidt-Universität, Germany

Abstract: A CISPR 25 radiation measurement setup is decomposed into the device under test itself and its surroundings including the antenna. The latter part is described by scattering parameters relating the connecting ports of the device to the antenna. In this way the antenna voltage can be predicted knowing the internal behaviour of the device. It can be shown that the method is applicable for devices including linear networks.

11:25 **Methods for Investigating Influence Parameters in the Measurement Setup for Radiated Emissions according to CISPR 25** 110

Jan Schabel[1], Michael Zerrer[2], Martin Kull[2], Michael Beltle[1], Stefan Tenbohlen[1]

[1]Universität Stuttgart, Germany; [2]mk-messtechnik GmbH, Germany

Abstract: This work examines methods to evaluate the impact of different measurement setups on the radiated emissions measurement according to CISPR 25. Besides using a real device under test, swept measurements with a vector network analyzer and the artificial excitation of the wiring harness with a broadband impulse are discussed. The investigations evaluate the reproducibility of measurements using CISPR 25 setup. This paper concludes that of the methods investigated, the most suitable is the one in which the wiring harness is excited with a broadband impulse.

11:50 **Auto Focus for Far Field Source Localization using Emission Source Microscopy** 115
Ling Zhang, Shaohui Yong, Yuanzhuo Liu, Victor Khilkevich
Missouri University of Science and Technology, USA

Abstract: Emission source microscopy (ESM) is a useful technique to locate emission sources contributing to far-field radiation. The focusing distance can affect image qualities and confuse the localization of radiation sources. This paper adopts the autofocus method in image processing to calculate the optimal focusing distance with the best image quality. The proposed methodology was verified using a numerical simulation as well as a measurement. Also, calculating the contrast of a local source region shows better noise immunity. This autofocus algorithm in ESM can easily obtain the exact distance between the radiation sources and the scanning plane and can be used to localize sources in 3D space.

Best EMC Paper Finalist

12:15 **Radiated Emission Tests for High-Frequency Router Systems in Class A: Discussion and Improvement** 119
Wei Zhang, Zhekun Peng, Xu Wang, DongHyun Kim, James Drewniak
Missouri University of Science and Technology, USA

Abstract: The standards for radiated emissions (RE) test in FCC Part 15 and CISPR 32, and the related literature concerning the limit line extrapolation, testing methods and challenges in the RE test are reviewed herein. In particular, factors to be considered during the RE test for the equipment in Class A operating above 10 GHz are discussed including: 1) possibilities to miss the maximal electric field (Emax); 2) specifications of the 2 dB rule; 3) falloff factors in the conversion between the measured electric (E) field at closer distances (1 m or 3 m) to 10 m. Methods that might be considered for improvement are proposed to increase the confidence of the multi-modular systems in passing/failing the RE standard and compliance with other devices in terms of: 1) according to 2 dB rule, 63.1% of the optical modules are proposed to represent the radiation of the fully loaded router system; 2) statistical falloff factors are needed in converting the E field at 1 m/3 m to 10 m at high frequencies (> 10 GHz); and, 3) specific limit lines are preferred at high frequencies for router/multi-modular systems.

Best EMC Student Paper Finalist

TP-TUE-2A Calibration (Sponsored by TC-2) 11:00 - 13:00

Chair: Ahalya Srikanth, Ford Motor Company, Lasalle, ON, Canada
Co-Chair: Ghery Pettit, Pettit EMC Consulting, Olympia, WA, USA

11:00 **Design of High-Frequency Differential Line for Ex Probe Calibration** 125
Yu Tian, Yu Du, Zi-Jian Zhou, Tian-Hao Song, Ze-kai Hu, Xing-Chang Wei
Zhejiang University, China

Abstract: This paper describes a new design of high-frequency differential line for Ex/Hz probe calibration. Both simulation and measurement results show that it can generate a pure transverse electromagnetic field up to 30GHz.

11:25 **Application of a Calibration Procedure for EMC Analysis with an Open Directional Coupler** 126
Teresa Tumbrägel, Hanno Rabe
Volkswagen AG, Germany

Abstract: Automotive tests concerning electromagnetic compatibility are usually performed as hardware tests in late development stages. Because the electromagnetic environment in vehicles becomes increasingly complex, changes in these late development stages become more time consuming and financially challenging. In this paper a general calibration method for contactless electromagnetic compatibility analysis is applied with a new type of open wave coupler for the frequency range of 300 kHz to 300 MHz. It is found that the procedure lacks accuracy in the determination of phase information. An additional calibration step is proposed in order to gain the correct phase information.

11:50 **Spectral Response of Electromagnetic Field Sensor Calibration Setups** 131
Fernando Albarracin-Vargas, David Martinez, Gideon N. Appiah, Juan Galvis,
Chaouki Kasmi, Nicolas Mora
Technology Innovation Institute, United Arab Emirates

Abstract: This work presents a comparative analysis on the spectral response of two versions of the cone and ground plane calibration setups-for electromagnetic field sensors.

12:15 **Research on an EMC High and Low Voltage Coupling Test Method** 132

Junjie Ma, Zhe Xu, Dengyu Zhang, Haipeng Li
China Automotive Technology and Research Center Co., Ltd., China

Abstract: At present, the electromagnetic compatibility(EMC) high and low voltage coupling network test for automotive electrical sub-assembly(ESA) in the standard only requires the use of an adapter to connect the network and the test sample, in other words, the impedance matching is not considered. In practice, if the impedance does not match, accuracy and consistency of test results cannot be guaranteed. But it is difficult to achieve impedance matching in the whole frequency band. In view of the above problem, this paper proposes an impedance matching method for high-low voltage coupling test, by isolating indirectly contact between the test system and the sample, which reduces test errors and improves the accuracy of test data caused by impedance mismatch. The experimental results prove that this method can effectively solve the shortcomings of the existing high and low voltage coupling EMC test technology of electric vehicle ESA, and provide a reasonable test idea for accurately testing the electric vehicle ESA high and low voltage coupling network test method.

TP-TUE-4A Space EMC (Sponsored by TC-8) 11:00 - 13:00

Chair: Jim Lukash, Lockheed Martin Space Systems, Palo Alto, CA, USA
Co-Chair: Jen Dimov, NASA, Bowie, MD, USA

11:00 **Statistical Field Model for Performance of Localized RF Absorption Blankets in a Payload Fairing** 136

P.G. Bremner[1], M. Bahadorzadeh[2], J.C. West[2], C.F. Bunting[2], S. Kabiri[2]
[1]Robust Physics, USA; [2]Oklahoma State University, USA

Abstract: In the space community, there is increasing interest in adaption and augmentation of launch fairing thermal-acoustic blankets, to also control electromagnetic environment threats. This paper reports on the development of simulation methods to both optimize blanket materials for RF absorption and to provide quantitative guidance on their minimal spatial deployment inside the fairing. A stochastic power-balance model with multiple connected sub-cavities is used to map the reverberant electric field in the fairing when RF absorbing blankets are applied only locally – ie only partial coverage of the fairing wall. The sub-cavity Q factors resulting from different RF absorption blanket materials is calculated from published reflection loss data and a field incidence correction factor. Comparison with model-scale test data, verifies that the model correctly predicts the electric field attenuation of different absorber materials. The model also correctly predicts the spatial distribution of the field and the improvement in shielding effectiveness.

Best EMC Paper Finalist

11:25 **Design and Fabrication of a Model Launch Fairing for EMC Measurements** 142

Shabir Kabiri[1], Mehdi Bahadorzadeh[1], James C. West[1], Charles Bunting[1], Paul G. Bremner[2]
[1]Oklahoma State University, USA; [2]Sonelite, Inc., USA

Abstract: A launch vehicle payload fairing scale model has been designed, fabricated, and tested to investigate the reverberant electromagnetic fields within launch vehicle fairings. The fairing scale model uses a mechanical stirrer to attain statistically uniform fields within the fairing cavity. A removable payload model and payload adapter model are included in the fairing to study the interactions of fields with these structures. The layering of the fairing walls, use of shielding gaskets, and field probes to measure the cavity fields are described. The quality factor is measured when the fairing cavity is empty and when the surrogate payload and payload adapter models are added. The quality factor of the empty fairing measured from about 32 dB at 1 GHz to 41 dB at 6 GHz. The Q values dropped approximately 2 dB across the band when the payload and payload adapter models were placed in the fairing cavity. Measurements of Q at different probe positions within the fairing yielded similar results.

11:50 **Electric Field Excited in a Model Spacecraft Fairing through Internal and External Source Excitation** 148

Mehdi Bahadorzadeh[1], Charles F. Bunting[1], James C. West[1], Shabir Kabiri[1], Paul G. Bremner[2]
[1]Oklahoma State University, USA; [2]Robust Physics, USA

Abstract: The electric field levels established at various points within a modeled rocket fairing under different excitations are measured. Both interior sources placed within different fairing sub cavities and exterior excitation was used. The effect of the addition of different absorbers on the electric field level in different sub cavities was investigated as well. The shielding effectiveness of the fairing within the different fairing sub cavities was considered. The relation between the total surface of absorber and the electric field level studied. In addition, the electric field level excited inside the fairing under external illumination was numerically simulated. The laboratory measurements were verified through comparison with the simulation results.

TP-TUE-5A IEMI Generators and Modeling (Sponsored by TC-5) 11:00 - 13:00

Chair: Mike McInerney, Consultant, Champaign, IL, USA
Co-Chair: Frank Sabath, Bundeswehr Research Institute for Protective Technologies and NBC Protection, Garstedt, Germany

11:00 **A Lightweight, Compact, High Voltage Hyperband Antenna for IEMI Testing** 154
John F. Dawson[1], Richard Hoad[2], Barney Petit[2], Tim Rees[2], Martin Robinson[1], Simon Bale[1], Mark Hough[1], Linda Dawson[1], Andy Marvin[1], Iain Will[1]
[1]University of York, United Kingdom; [2]QinetiQ, United Kingdom

Abstract: A robust lightweight antenna for testing immunity of equipment to intentional electromagnetic interference (IEMI), based on a planar Vivaldi design, is described, along with simulated and measured test results.

11:25 **A 1.3GHz, High Voltage Mesoband Dipole Antenna Antenna for IEMI Testing** 155
John F. Dawson[1], Tim Rees[2], Barney Petit[2], Richard Hoad[2], Simon Bale[1], Mark Hough[1], Linda Dawson[1], Martin Robinson[1], Andy Marvin[1], Iain Will[1], S.J. Porter[1]
[1]University of York, United Kingdom; [2]QinetiQ, United Kingdom

Abstract: A resonant dipole antenna for testing immunity of equipment to intentional electromagnetic interference (IEMI) is described, along with simulated and measured test results which are in good agreement and demonstrate the high voltage operation.

11:50 **A 150MHz, High Voltage Mesoband Dipole Antenna for IEMI Testing** 156
Simon Bale[1], Richard Hoad[2], Barney Petit[2], Tim Rees[2], Martin Robinson[1], Mark Hough[1], Stuart Porter[1], Linda Dawson[1], Andy Marvin[1], John F. Dawson[1], Iain Will[1]
[1]University of York, United Kingdom; [2]QinetiQ, United Kingdom

Abstract: An antenna for testing immunity of equipment to intentional electromagnetic interference (IEMI) is described, along with simulated and measured test results which show a good agreement and demonstrate the high-voltage operation.

12:15 **The Method of Modal Parameters for the Single and Double Segments of the Wires with Symmetrical Geometry and the Singularity Expansion Method** 157
Sergey V. Tkachenko, Felix Middelstaedt, Ralf Vick
Otto-von-Guericke-Universität Magdeburg, Germany

Abstract: The previously developed Method of Modal Parameters (MoMP) was applied to calculate the Singularity Expansion Method (SEM) poles of the single and double wire segments with symmetrical geometry: straight wire, circular wire, and helix wire, which are important for EMC practice. The symmetry leads to the simplification of the conesponding formulas for matrix elements and allows to obtain SEM poles of the first, second and third layers, which conespond both to the known analytical results and numerical data. Moreover, for the first layer of the poles one can use a simplified variant of the method taking into account only diagonal elements of the p.u.l. impedance matrix.

TP-TUE-6A Power Integrity Analysis and Design 2 (Sponsored by TC-10) 11:00 - 13:00

Chair: Kinger Cai, Intel Corporation, Palo Alto, CA, USA
Co-Chair: Bumhee Bae, Samsung Electronics, Suwon-si, Korea (the Republic of)

11:00 **Gauss-Newton Method for Fast Analysis of PDNs with Arbitrarily Shaped Power-Ground Plane Pairs** 158
Ihsan Erdin
Celestica Inc., Canada

Abstract: A Gauss-Newton (G-N) based method is developed for the analysis of power delivery networks (PDN) with arbitrarily shaped parallel-plate power/ground plane pairs. The proposed method allows for power integrity (PI) assessment in a few iteration steps, providing significant speed-up in comparison to alternative methods. The proposed method is tested on a practical example which includes a 16-pin ball-grid array (BGA) device and the results are observed in good agreement with those obtained from a numerical electromagnetic (EM) simulator.

11:25 **VRM Modeling for Platform FastPI upon SPIM** 162

Xingjian Kinger Cai, Wei Qian, Chi-te Chen, Kundan Chand
Intel Corporation, USA

Abstract: The formula of Lvr and Rvr is 1st time derived in industry for a VRM with Adaptive Voltage Positioning (AVP)[1]. The simulation is elaborated with a largely dependent CPU power delivery network (PDN) for holistic platform FastPI upon SPIM, to facilitate platform PI design flexibility, and review & sign-off.

11:50 **Optimal Power Distribution Network Design for High-Performance Solid-State-Drive based on Novel Target-Impedance Extraction Method** 163

Jinwook Song, Chunghyun Ryu, Sangho Park, Donggon Jung, Jaeyoung Shin, Youngmin Ku
Samsung Electronics Co., Ltd., Korea

Abstract: In this paper, we proposed a novel methodology to offer power distribution network (PDN) design guide for PCB power integrity (PI) design for high performance solid-statedrive (SSD). Compared with conventional target-impedance (Z) formulated by current profile of a chip power model (CPM), the proposed methodology utilizes a measurement based current spectrum and a hierarchical PDN-Z model. In order to solve the fundamental limitations of the narrow-banded CPM current model, we successfully measured the PCB-level current of memory packages consisting of the SSD device and converted the measured current values to the chip-level current values using Y-matrix of the hierarchical PDN-Z model consisting of a PCB, a test interposer, a package, and a chip. High-capacity SSD devices are too expensive to make PCBs for design of experiments to test device performance with current measurement. Therefore, we made a test interposer to measure cost-efficiently a current spectrum for each specific powerdomain of a unit package such as a DRAM, a NAND, and a SSD controller that all consisting of a SSD device without disturbing SSD's normal operations.

Best SIPI Paper Finalist

12:15 **Novel Methodology for Validating SIMPLIS based VR Models for Server Platform Power Delivery Prediction** 168

Judy Amanor-Boadu[1], Hannah Homer[1], Daniel Mauricio Garcia Mora[2], Pavan Kumar[1], Tammie Bard[3]
[1]Intel Corporation, USA; [2]Intel Corporation, Mexico[3]Infineon Technologies Americas Corp., USA

Abstract: Voltage Regulators (VR) use non-linear features to mitigate large transient droops and overshoots, to enable high server processor performance. VR behavior due to non-linear features is complex, and can no longer be modeled using simple linear modeling methods. Accurately modeling VR behavior in conjunction with Power Delivery Networks (PDN) in server platforms is becoming a necessity to predict, optimize, explore, and identify performance impacts when changes are made to design parameters, such as processor current (Iccmax), decoupling capacitor solutions, and VR components. Inaccurate VR models can potentially lead to inaccurate predictions which in turn lead to increased design time, board spins, and either performance degradation or oversized and costly decoupling capacitor solutions. Thus, it is imperative to be confident in determining whether a VR model is accurate before it is used for design and prediction purposes. This paper presents a detailed methodology to validate and qualify VR models to be able to accurately model the VR behavior even after changes are made to the design parameters. The method can be used along with various platform PDNs ranging from a complex processor network to a simple Point of Load (POL) VR. The methodology pioneered in this paper has been successfully applied to qualify over 20 VR models, ensuring correlation between experimental measurements and simulations using SIMulation of Piecewise LInear Systems (SIMPLIS) circuit simulator. Correlation results are presented from four case studies to demonstrate the effectiveness of the proposed methodology.

TP-TUE-7A Power Electronics EMI Modeling and Measurement II (Sponsored by SC-5) 11:00 - 13:00

Chair: Zheng Luo, Monolithic Power Systems, San Jose, CA, USA

11:00 **A Bias Tee for Broadband Measurement of Power Electronic Components** 174
Michael Fuchs, Christoph Maier, David Pommerenke
Technische Universität Graz, Austria

Abstract: Bias tees are an important tool for many applications including vector network analysis. When trying to measure power electronic components with large DC currents and voltages at low frequencies, however, one quickly encounters the limits of the devices of common manufacturers. As accurate understanding and modeling of power electronic components becomes increasingly important for the study of their electromagnetic emissions, so do broadband measurements with bias tees. This paper describes the composition of such a special bias tee in terms of the necessary geometries and circuitry. Measurements of the characteristics of the presented tee show good results in a frequency range from 9 kHz to 500MHz at DC currents up to 10A (30A for a short time) and voltages up to 500V. Vector network analysis of passive filter structures under load thus also becomes possible for power electronic components in a broad frequency range.

Best EMC Paper Finalist

11:25 **Analysis on Common to Differential Mode Conversion within Automotive Communication Systems** 180
Carina Austermann, Stephan Frei
Technische Universität Dortmund, Germany

Abstract: Communication systems with high data rates like CAN FD and Automotive Ethernet are increasingly used in automobiles. New safety-critical driving assistance functions can be realized with the help of these bus systems, but data transmission has to be very reliable. Road vehicles are a challenging electromagnetic environment because of the high density of electric and electronic devices. Power electronic systems can be very close to communication systems. The typical cable type for automotive communication systems is the unshielded twisted wire pair. Common mode disturbances cannot be reduced by this cable type. Due to unavoidable asymmetry in the communication system electromagnetic coupling can also induce critical differential mode voltages. For this reason, the immunity of communication systems to electromagnetic interferences has to be investigated in detail. In this paper, simulation models are presented and validated by measurements to quantify cable coupling to CAN FD and 100BASE-T1 Automotive Ethernet. Both, common and differential mode voltages caused by cable coupling are investigated. Based on measurements and simulations critical influencing parameters on mode conversion are discussed.

11:50 **Noise-Source Parameter Identification Considering Switching Fluctuation of DC-DC Converter** 186
Shuqi Zhang, Taishi Uematsu, Kengo Iokibe, Yoshitaka Toyota
Okayama University, Japan

Abstract: This paper proposes noise-source parameter identification of the noise-source equivalent-circuit model for predicting conducted noise while considering the switching fluctuation of a DC/DC converter. We decomposed measured conducted noise into ripple noise, turn-on spike noise, and turnoff spike noise to prevent the accuracy degradation in the parameter identification. The predicted conducted noise spectra show the error with the measurement was within 3 dB up to 200 MHz, which is more accurate than that in our previous study.

12:15 **An Immunity Estimation Technique for In-Vehicle CAN-FD** 187
Miyuki Mizoguchi, Takeshi Yoneyama, Yoshiroh Hirata
Soken, Inc., Japan

Abstract: It is a well-known fact that a lot of Electronic Control Units (ECUs) and high-speed communication Local Area Networks (LANs) are necessary for Advanced Driver Assistance System (ADAS). Original equipment manufacturers (OEM) are interested in introducing CAN-FD on vehicles for its high data rate and low data arbitration phase. Meanwhile, ensuring immunity performance is one of the main issues in the CAN-FD using differential signals. In this paper, we define a CAN-FD Transceiver ICs' immunity criterion and their selection method.

TP-TUE-8A Passive Component Modeling and Measurement Techniques (Sponsored by TC-10) 11:00 - 13:00

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

11:00 **Time Domain Reflectometry Accuracy Control for via Characterizations in High Speed Links** 188

Tao Wang, Brian Brecht
Teradyne Inc., USA

Abstract: The time domain reflectometry (TDR) is a very popular tool for high speed link characterizations. However, its modeling and simulations for vias constantly face accuracy challenges due to vias' small dimension and fast rise time. While many existing papers discussed discontinuity analysis of transmission lines, in this paper, we focus on the accuracy control methods in TDR modeling and analysis for vias in PCBs for high speed signal integrity (SI). There are many practical factors affecting the via impedance result in TDR, such as frequency domain simulation setups, TDR window selections, rise time, bandwidth, etc. Based on the principal analysis, we propose a practical calculation flow for a via's TDR modeling process, and provide a TDR interpretation approach by jointly using different window functions to justify the correct locations and impedance values of the via structures. Highly oscillatory TDR responses are also discussed to guide the real TDR practice. According to our search, there is very little in literature describing similar techniques to solve a via's TDR analysis accuracy issues. The proposed method can also be used on other small feature's TDR analyses.

11:25 **Electric Property Analysis and Wire Placement Optimization of Automotive Wire Harness** 189

Tadatoshi Sekine, Takumi Ito, Shin Usuki, Kenjiro T. Miura
Shizuoka University, Japan

Abstract: This paper describes an analysis and optimization technique for understanding and effective design of an automotive wire harness. In the analysis phase, the multiple linear regression analysis is used to reveal the relationship between an electric property of the wire harness and its cross-sectional shape. Subsequently, we perform coarse and fine optimization processes with the knowledge obtained in the prior analysis phase to efficiently determine the optimal placements of the wires so that a crosstalk voltage is reduced. The proposed technique and knowledge obtained from results will contribute the future automotive EMC/SIPI design.

11:50 **Li-Ion Cell Impedance Measurement using Open/Short/Load Compensation for De-Embedding** 190

Herbert Hackl[1,2], Martin Ibel[1,2], Thomas F. Landinger[3], David Pommerenke[1,3], Bernhard Auinger[1,2]
[1]Silicon Austria Labs GmbH, Austria; [2]Technische Universität Graz, Austria;
[3]Infineon Technologies AG, Germany;

Abstract: Knowledge of battery cell impedance is crucial for the design of many modern applications, as well as for predicting their electromagnetic compliance. For detailed 3D simulation of battery packs, single cells are commonly replaced with simplified bodies enhanced by internal impedance data obtained from measurement on real cells. Thereby it is necessary to exclude all influence of the measurement setup, i.e. to de-embed the cell impedance from exterior properties. In this work, two approaches are presented to extract the impedance of an 18650 Lithium-ion (Li-ion) cell from within a battery holder on a printed circuit board (PCB), using Open/Short/Load compensation (OSLC) and a copper cylinder as reference. By adding components in series and parallel to the cell, it is verified that the extraction result is not impacted by PCB circuitry, and also that the cell's impedance is load-independent. Eventually, the test setup including Li-ion cell is replicated as electromagnetic (EM) simulation project. Two measurement-based methods to model the cell are compared, suitable for both 3D or circuit simulation. The frequency range under consideration is from 9 kHz to 1 GHz, whereas the presented approach proves reliable up to 200 MHz.

12:15 **Lumped Circuit Model and VNA Measurement of the RF Impedance of a Bypass Network** 196

Federico Sordi, Lorenzo Capineri, Carlo Carobbi
Università degli Studi di Firenze, Italy

Abstract: In this work, a method is presented to predict the radiofrequency impedance of a practical implementation of a bypass network. Circuit models of both ceramic and electrolytic capacitors are introduced, whose parameters are derived from manufacturers' specifications. Mounting inductance of capacitors is accounted for through estimates of vias and microstrips inductance. Predictions are confirmed by vector network analyzer (VNA) measurements through an incremental process of comparisons in which the number of parallel capacitances of the bypass network is progressively increased. A simple technique to remove the residual (after VNA calibration) series inductance introduced by the radiofrequency connectors used to connect the VNA ports to the printed circuit board hosting the bypass network is presented. An insight into the low-frequency behavior of ceramic capacitors of large capacitance (in the tens of microfarad range) is also offered. Measurements confirm the reliability of the lumped circuit model of the bypass network up to about 400 MHz for a printed circuit board (PCB) sized 15 cm x 11.3 cm. Above this frequency distributed phenomena and radiation cause measurements to significantly deviate from predictions. The bypass network impedance behavior is essentially described, up to the frequency limit of validity of the lumped model, by a simple but effective series circuit consisting in a large capacitance of the order of 1 mF , an inductance of the order of 0.07 nH and a resistance of the order of 0.5 m .

SS-TUE-A EMC Diagnostics of Complex Systems 11:00 - 13:00

Chair: Vladimir Mordachev, Belorusskij Gosudarstvennyi Universitet Informatiki i Radioelektroniki, Minsk, Belarus

11:00 **Frequency-Independent Asymptotes of System Parameters of Urban Cellular Communications at Multipath Propagation of Radio Waves** 202

Vladimir Mordachev
Belorusskiy Gosudarstvennyy Universitet Informatiki I Radioelektroniki, Belarus

Abstract: Frequency-independent relationships for estimating a following number of system parameters of cellular communications under the conditions of multipath propagation of radio waves in urban canyons and the presence of intrasystem interference are obtained: the required equivalent isotropic radiated power (EIRP) of subscriber stations, the maximum data transmission capacity of the uplink radio channel, the maximum distance of qualitative communication, and also the permissible level of intranetwork radio interference at given requirements for communication range and data transfer rate of uplink radio channel taking into account the accepted restrictions on EIRP of subscriber radio equipment. Together with the frequencyindependent component of the electromagnetic background near the earth's surface, created by electromagnetic radiations of subscriber stations located outside the breakpoint vicinity of the observation point, these dependencies form a family of asymptotes that provide ample opportunities for system analysis and diagnostics of solutions and scenarios for the implementation of 4G/5G/6G systems and services in various conditions, taking into account the quality of frequency-spatial planning and the intra-system EMC design of radio networks of cellular (mobile) communications.

11:25 **Fast EMC Diagnostics of Complex On-Board Radio Systems with use of Experimentally Refined Worst-Case and Conditionally Worst-Case Models of "Transmitter-to-Receiver" Interactions** 208

Eugene Sinkevich[1], Vladimir Mordachev[1], Alexey Galenko[1], Yauhen Kharasheuski[2], Mikalai Panchanka[2], Viktar Bobra[2]
[1]*Belorusskiy Gosudarstvennyy Universitet Informatiki I Radioelektroniki, Belarus;*
[2]*Research Institute of Automation Facilities, Belarus*

Abstract: An improved computationally efficient technique for EMC diagnostics of radio equipment of complex on-board radio-electronic systems is presented. The first improvement is based on the use of worst-case and conditionally worst-case mathematical models to describe unwanted electromagnetic (EM) interactions between transmitters and receivers of the system, which allows to detect all potentially dangerous interactions rapidly and avoid second-type errors when assessing the danger of these interactions. The second improvement concerns the iterative refinement of worst-case and conditionally worst-case models of potentially dangerous interactions (including models of transmitter radiation spectra, receivers susceptibility characteristics, amplitude-frequency characteristics of decoupling antenna filters and EM spurious couplings between antennas of on-board system) by the use of both numerical simulation methods and measurements to improve the accuracy of EMC diagnostics. The third improvement is associated with the use of an extremely effective technique of discrete nonlinear behavior simulation of radio receivers' operation in a severe EM environment formed by a set of powerful EM radiations from radio transmitters of the analyzed on-board system and a variety of external EM fields generated by various radio systems of different services.

11:50 **Analysis of EMC between Medical Short-Range Devices and Equipment of Wireless Systems** 214

Aliaksandr Svistunou[1], Vladimir Mordachev[1], Eugene Sinkevich[1], Ming Ye[2], Arthur Dubovik[1]
[1]*Belorusskiy Gosudarstvennyy Universitet Informatiki I Radioelektroniki, Belarus;*
[2]*Huawei Technologies Sweden AB, Sweden*

Abstract: The analysis of EMC between medical short range devices of body area network system, capsule endoscopy system, active implant system and wireless equipment of mobile stations of cellular communications (LTE and 5G), RLAN equipment, NB IoT sensors operating inside a hospital building is performed. The integrated interference margin is used as a criterion of EMC. Results of the analysis show the following: 1) the equipment of wireless systems can create the interference to all considered types of medical short range devices (as well as medical short range devices can create the interference to receivers of the wireless systems) in case of allocation of emitters and receptors inside the same room or in neighboring rooms; 2) in order to ensure EMC of considered systems, it is advised to set more stringent requirements on characteristics of susceptibility of the medical equipment to radiofrequency electromagnetic fields created by wireless equipment of 4G/5G networks as well as on spurious emissions of transmitters of wireless systems. The results can be used in diagnostics of intersystem EMC in order to ensure safety of use of mobile wireless telecommunication equipment regarding medical vital devices in conditions of mass distribution of 4G/5G wireless information services in hospitals.

12:15 **Experimental Studies of Spectrum Masks of 5G Base Station Transmitter Operating in DSS Mode to estimate Feasibility of Accommodation of 5G Network within 4G Frequency Channels** 220

Valery Tikhvinskiy[1], Victor Koval[2], Pavel Korchagin[2], Altay Aitmagambetov[3]
[1]*University of Communications and Informatics, Russian Federation;* [2]*Geyser-Telecom Ltd., Russian Federation;* [3]*The International Information Technology University, Kazakhstan*

Abstract: One of the most attractive ways to quickly deploy 5G networks when new frequency bands are not yet available to local operators is to do it on the basis of Dynamic Spectrum Sharing (DSS) solution. The DSS mode provides 5G network with access to 4G spectrum resource and the use of a single-frequency broadcast network in which one part of OFDM-signal resource blocks is used to transmit LTE (4G) resource blocks, and the other part is used to transmit 5G resource blocks. Bearing in mind that 4G operator has a relevant spectrum license to transmit LTE signals, it is necessary to show that the spectrum mask of the combined frequency channel accommodating both 4G and 5G OFDM-signal resource blocks does not exceed authorized bandwidth and ensures EMC between LTE and 5G networks. Thus, the aim of the authors was to conduct experimental studies of spectrum masks of the combined 4G/5G frequency channel for different LTE channel bandwidths in real operating conditions of 5G base stations operating in the DSS mode and demonstrate that EMC is feasible.

TP-TUE-1B Cables and LISN (Sponsored by TC-2) 13:30 - 15:30

Chair: Ross Carlton, ETS-Lindgren, Cedar Park, TX, USA

13:30 **Validity of Mains Cable Termination by VHF-LISN for Radiated Emission Measurement Compared with the Conventional Test Condition** 226

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

Abstract: In this article, we introduce an alternative terminating condition for the AC mains cable of Equipment Under Test (EUT) with appropriate common mode impedance by VHF-LISN in radiated emission measurements at test sites. In Round Robin Testing (RRT) conducted by CISPR SC-A/I joint ad hoc group 6 (JAHG6), inter-laboratory reproducibility was significantly improved by setting terminating conditions for the AC mains cable of EUT, thus, reflecting the same results as those of previous RRT conducted by CISPR/SC-I. However, since only a conventional comb generator was employed, differences in radiated emission of EUT with and without AC mains cable termination by VHF-LISN were not clear. In this RRT, we performed actual product measurement (prepared by ten participating laboratories) and compared the accumulative probability distributions of radiated emissions by using two types of VHF-LISN of different termination impedances and without a termination device (deemed as the actual operating condition). From the investigation results, mains cable termination with VHF-LISN of a specific common mode impedance was deemed to be valid for radiated emission measurement.

13:55 **Coupling Analysis Under Lightning Indirect Effects for Cable Bundles with Different Ground Plates in Unmanned Aerial Vehicles** 232

David Ramos Somolinos[1], Carolina Morales Blanco[2], Daniel López Sanz[1], Borja Plaza Gallardo[1], David Poyatos Martínez[1]

[1]Instituto Nacional de Técnica Aeroespacial, Spain; [2]Procesia, Spain

Abstract: It is increasingly common in aerospace industries to take advantage of novel composite materials in their manufacturing processes to improve performance and reduce costs. Obtaining the electromagnetic (EM) characterization of these materials or a combination of them is essential to ensure safety and EM compatibility. In this paper, a laminate of the central fuselage of an aircraft developed at INTA is recreated. This aircraft is called MILANO and it is mostly made of Carbon Fiber Composite (CFC). The same material is used for the laminate. Besides, another metallic plate is built in order to compare the performance of the former one with respect to a Perfect Electric Conductor (PEC). The main goal of this work is studying the coupling between the cable bundles embedded in the MILANO and how is this affected by the different materials of the ground plate (metal and CFC). Two kind of tests are carried out: S-parameters measurents and injection of Lightning Indirect Effect (LIE) waveforms. Sparameters results are then obtained through simulation too and compared with both the metallic and the CFC sample.

TP-TUE-2B Electromagnetic Environments in Mobile and Transportation (Sponsored by TC-3) 13:30 - 15:30

Chair: Frederick William Heather, US Navy, Lexington Park, MD, USA

13:30 **Simulation and Measurement of Multi-Source Electromagnetic Environment of Urban Rail Transit Communication Room** 238

Jiaqi Wang[1], Yinghong Wen[1,2], Wenxuan Wei[1], Jie Ren[1,2]

[1]Beijing Jiaotong University, China; [2]Beijing Engineering Research Center of EMC and GNSS Technology for Rail Transportation, China

Abstract: The safety of the equipment in the communication room is the basis to ensure the reliable operation of the urban rail transit. Therefore, it is of great significance to investigate the complex electromagnetic field distribution and radiation level in the communication room. On the basis of investigation, the typical interference sources and their transmission routes are explored first. The influence of each interference source on the internal electromagnetic environment is simulated and analyzed, which shows good consistency with the measured.

13:55 **Approaching User Exposure Assessment using Broadband versus Frequency-Selective Methods: IEEE 802.11ax Mobile Device Emitted Field** 243

Annamaria Sârbu[1], Simona Miclăuș[1], Emil Șorecău[2], Paul Bechet[1]

[1]Nicolae Bălcescu Land Forces Military Academy, Romania;
[2]Technical University of Cluj Napoca, Romania

Abstract: We have approached user exposure to EMF originated from an IEEE 802.11ax client (mobile phone) by using both broadband and frequency selective measurement instrumentation. All the measured field strengths were situated below the ICNIRP and IEEE reference levels for public safe exposure. Higher field levels were observed during file upload followed by file download and then video streaming. Following, we propose an original algorithm for similarity evaluation of the two measurement system readings based on cross-correlation and dynamic time warping (DTW) algorithm. We observed clear differences between probes in general, and between their ability to correctly follow the field strengths amplitude time dynamic. The proposed algorithm offers a series of advantages compared to traditional response time investigation. While the temporal response of the used broadband field probe appears to be adequate for 802.11ax signals, the amplitude resolution exhibits a serious drawback for measuring low field levels associated with some Wi-Fi applications like video streaming.

14:20 **Improvement of EM Diffusion Performance of Checkerboard Structure in 28 GHz Band** 249

Yasutaka Murakami, Jerdvisanop Chakarothai, Katsumi Fujii

National Institute of Information and Communications Technology, Japan

Abstract: Recently, 5G wireless communications system has been deployed in 28 GHz band. Due to high propagation loss of EM waves, there are few paths which can reach receiving antenna when a blockage exists. In order to increase number of propagation paths and increase EM coverage for the system, checkerboard structures for diffusing EM waves emitted from transmitting antenna has been designed. The EM diffusion performance for different number of scattering elements was numerically evaluated and it was found that EM diffusion performance can be significantly improved by inverting the reflection phase of one element in the checkerboard pattern.

TP-TUE-3B Conducted Emissions (Sponsored by TC-7) 13:30 - 15:30

Chair: Flavia Grassi, Politecnico di Milano, Milano, Italy
Co-Chair: Francinei L. Vieira, Leibniz Universitat Hannover, Hannover, Germany

13:30 **Electromagnetically Interfered Energy Metering Resulting from Droop of Current Transducers** 250
Bas Ten Have, Niek Moonen, Frank Leferink
University of Twente, The Netherlands

Abstract: Non-linear equipment is increasingly being used in household situations to increase the efficiency of the power consumption of equipment. This results in conducted electromagnetic interference problems due to the switching of the equipment, which draws pulsed currents with high peak values and fast rising slopes. Accordingly, static energy meters, used to measure the energy consumption in households, show misreadings in conjunction with such pulsed currents. Therefore, a control meter is under construction which is used to validate the readings of an installed static energy meter. When validating the control meter, energy metering errors were found resulting from current droop of the current transducers. The droop in the current response multiplied with the voltage resulted in large energy metering errors of 38%. While no issues where found for linear, resistive, loads. This shows the need for pulsed immunity tests to validate energy measurement systems, because linear tests have not shown to be problematic.

Best EMC Paper Finalist

13:55 **Power Converter Impedance and Emission Characterization Below 150 kHz** 255
Per Thaastrup Jensen[1], Pooya Davari[2]
[1]Force Technology, Denmark; [2]Aalborg University, Denmark

Abstract: IEC standardization is preparing general conducted emission limits for grid connected power converters in the frequency range between 2 kHz and 150 kHz, which has until recent years only been regulated for some categories of equipment. With the necessity of analyzing and estimating power converter behavior, this paper proposes a black-box modeling approach suitable for this new frequency range of interest. A method for measuring the dynamic power converter impedance when powered and in operation has been developed and proven in practice by superposition of a multi-tone signal onto the AC input voltage to the power converter under different load conditions. Later, through extraction of the noise source, an equivalent circuit diagram of the power converter is developed which can be used for emission estimation and further analysis such as EMI filter designing. The provided experimental results showed high accuracy of the proposed method and its suitability in estimating EMI

14:20 **Reduction of Mode Conversion of Differential-Mode Noise to Common-Mode Noise by Printed Circuit Board Modification for Unbalanced EMI Filter Network** 261
Srinath Penugonda[1], Zhifei Xu[1], Yuandong Guo[1], Muqi Ouyang[1], Minho Kim[2], Junesang Lee[2], Jungrae Ha[2], Hyewon Lee[2], Sangwon Yun[2], Jun Fan[1], Hongseok Kim[1]
[1]Missouri University of Science and Technology, USA; [2]Mando Corporation, Korea

Abstract: This paper presents a method for the reduction of mode conversion from differential-mode (DM) noise to common-mode (CM) noise in an unbalanced EMI filter. The unbalanced nature in the EMI filter is a result of not incorporating all the required filter components due to space and cost constraints or due to the parasitic impedances of a printed circuit board (PCB). It is demonstrated that the reduction of mode conversion from DM noise to CM noise can be achieved by modifying the current path on the ground (GND) layer of the PCB of the unbalanced EMI filter. The currents on the GND layer are guided to take a longer route by introducing a “cutout” to the ground plane in the PCB, which increases the impedance of the current path on the GND layer. This approach does not require additional components to the EMI filter for the reduction of CM noise due to the mode conversion. Simulations show that the cutout decreases the CM noise converted from the DM noise by at least 4 dB in the AM radio frequency band (530 kHz – 1.8 MHz).

14:45 **Near Field Considerations for Modeling Harness in Low Frequencies** 265
Anargyros T. Baklezos[1,2], Theodoros N. Kapetanakis[1], Ioannis O. Vardiambasis[1], Christos N. Capsalis[2], Christos D. Nikolopoulos[1]
[1]Hellenic Mediterranean University, Greece; [2]National Technical University of Athens, Greece

Abstract: Limited knowledge regarding modeling cables in extremely low frequency (ELF) regime can be found in literature. This work aims to provide insights for accurate modeling of harness routing, as required in various ESA’s studies for space science missions regarding electromagnetic cleanliness considerations. More precisely, this work considers a straight cable path as an infinitesimal dipole source when modeled in the ELF region and studying the implications on the resulting electric field in close proximity to the source.

TP-TUE-4B Testing and EMC Application of Composite Materials (Sponsored by TC-4) 13:30 - 15:30

Chair: William Wantz, IV, Spira Manufacturing, San Fernando, CA, USA

13:30 **3D Printed Electromagnetic Absorber Built with Conductive Carbon-Filled Filament** 266

Rui Mi[1], Wei Zhang[1], Kaustav Ghosh[2], Sameer Walunj[2], Qian Liu[2], Jacques Rollin[2], Philippe Sochoux[2], David Pommerenke[3], Victor Khilkevich[1]
[1]Missouri University of Science and Technology, USA; [2]Juniper Networks Inc., USA; [3]Technische Universität Graz, Austria;

Abstract: This article presents a method for manufacturing a frequency selective surface (FSS) using the 3D printing technology, including material characterization, design, fabrication, and evaluation. The FSS design is based on a three-layer structure. The first layer is a 3D printed lossy material, the second layer is an air gap, and the third layer is a ground plane. By changing the geometrical parameters of the 3D printed layer, it is possible to tune the frequency of the absorption band of the FSS.

Best EMC Paper Finalist

13:55 **Literal Solutions for Optimal Design of Microwave Absorbing Composites** 272

Alessandro G. D'Aloia, Marcello D'Amore, Maria Sabrina Sarto
Sapienza University of Rome, Italy

Abstract: This paper proposes a new approach for the optimal design of microwave absorbing composites backed by a PEC layer and characterized by frequency dependent permeability and permittivity. The reflection coefficient is expressed as a function of the difference between the absorber hyperbolic input impedance and the free space wave impedance, considering an impinging plane wave with either normal or oblique incidence angle. The impedance matching condition for the selected frequency and incidence angle is solved in terms of literal expression of the optimal thickness, which is compared with the one quarter wavelength thickness given by a new accurate expression. The optimal thickness is used for the design of microwave absorbers made by dielectric-magnetic and dielectric composite materials. The frequency spectra of the absorber input impedances and reflection coefficients are computed in the frequency range from 2 GHz up to 18 GHz and for an incidence angle ranging between 0° and 30°. The obtained results prove the validity of the literal expression of the composite optimal thickness which explicitly shows the crucial parameters for the absorbing performances, obscured in common numerical procedures.

14:20 **Analysis of EMI Shielding Effectiveness for Plastic Fiber Composites in the 5G Sub-6 GHz Band** 278

P.A. Martinez[1], J. Victoria[2], J. Torres[1], A. Suarez[1], A. Alcarria[2], A. Amaro[1], B. Galindo-Galiana[3], C. Losada-Fernandez[3], V. Ramirez-Monsell[3], B. Lopez-Rius[3]
[1]Universitat de Valencia, Spain; [2]Würth Elektronik eiSos GmbH & Co. KG, Germany; [3]Plastics Technology Centre AIMPLAS, Spain

Abstract: The study and modeling of EMC are becoming more critical than ever due to the ubiquitous presence of electronic circuits in all aspects of our lives. Specifically, it is crucial to extend these studies to the new frequencies that, in a few years, will be a reality in modern telecommunications systems, such as 5G and its derived technologies. A specific critical field where the proper EMI shielding has been ensured to avoid EMC problems is the electric autonomous vehicles (EAVs). The huge number of electronics systems in new vehicles will dramatically extend the demands on the EMI shielding solutions used to attenuate the radiated emissions that could affect circuits in the vehicle. Metals or metal alloys are the most common EMI shielding materials since they demonstrate adequate shielding capacity against EMI. However, polymers have become up-and-coming materials for EMI shielding with the characteristics of lightweight, flexibility, cost-effective, easy processing, and resistance to corrosion. Consequently, it is necessary to develop EMI shielding materials based on polymers, plastic materials, and fiber composites that ensure compliance with the different standards that regulate 5G and the proper operation of possible systems susceptible to the intentional and unintended signals generated by this new technology. This contribution focuses on characterizing different composite structures' performance based on fibers combined with conductive materials in terms of shielding effectiveness, covering the 5G sub-6 GHz frequency range.

14:45 **SE and HEMP Testing a Conductive Concrete Shielded Enclosure** 284
Lim Nguyen[1], Matthew Bergstrom[2], David McGaw[3]
[1]University of Nebraska-Lincoln, USA; [2]Omni-Threat Structures, USA;
[3]American Business Continuity Group, USA

Abstract: This paper reports shielding effectiveness (SE) and high-altitude electromagnetic pulse (HEMP) testing of a conductive concrete shielded enclosure. Test results demonstrate that the concrete structure can provide substantial pulse attenuation below the susceptibility levels of electronic equipment.

TP-TUE-5B Coexistence of Wireless Systems (Sponsored by TC-12) 13:30 - 15:30

Chair: Shuo Wang, University of Florida, Gainesville, FL, USA
Co-Chair: Qiaolei Huang, Amazon Lab126, Sunnyvale, CA, USA

13:30 **Analysis on EMC influencing Factors of Electric Vehicle Wireless Charging System** 285
Li Jiang, Haiming Liu, Xu Zhang
China Automotive Technology and Research Center, China

Abstract: This paper analyzes the structure of the electric vehicle wireless charging system, and uses actual samples to illustrate the severity of its EMC performance. Based on radiation emission test, the reference test set-up is given. Then, the coil offset, output power and other factors analyzing the EMC performance of the wireless charging system are verified based on actual product, which illustrate the necessity of prescan test.

13:55 **Near Field Scanning based Characterization for Wireless Coexistence** 291
Qiaolei Huang, Johns George, Chen Chen, Duck Ho Bae
Amazon Lab126, USA

Abstract: In this paper, a near field scanning based method is utilized to characterize wireless coexistence issues in design of a practical electronic device. This device supports multiple wireless communication radios. Based on near field, the radiation at the intermodulation frequency when two different radios both operate are evaluated. Reduction of scanned near field is proved to be an effective method to predict far field reduction.

TP-TUE-6B SI/PI/EMC Co-Simulation and Co-Design (Sponsored by TC-10) 13:30 - 15:30

Chair: Sungwook Moon, Foundry Business Division, Samsung Electronics Co. Ltd., Korea (the Republic of)
Co-Chair: DongHyun Kim, Missouri University of Science and Technology, Rolla, MO, USA

13:30 **SI Considerations in Flexible Channels on High-Speed Intra-Panel Interface for Large-Size Flat Panel Display Applications** 292
Jinho Kim, Jihyun Lee, Seonha Lee, Jungsun Yoo, Sungwook Moon, Kil-Hoon Lee, Hyun-Wook Lim, Jaeyoul Lee
Samsung Electronics Co. Ltd., Korea

Abstract: In large-size flat panel display modules for TV applications, signaling channels designed on flexible printed circuit (FPC) cable or chip-on-film (COF) package are incomparably shorter than source PCBs, but they can play a significant role in determining overall signal integrity (SI) performance. This work analyzes interconnection designs on FPC cable and COF package in terms of impedance matching and crosstalk. It also provides channel design considerations and design guidelines for better SI performance in flexible channels on high-speed interface for large-size LCD TV applications.

13:55 **Active EMI Noise-Canceling System** 293

Mart Coenen
EMCMCC, The Netherlands

Abstract: With the increase of active power conversion using higher switching (PWM) frequencies, the need for filtering and shielding increases proportionally to minimize crosstalk and to adhere EMC compliance. As power conversion is often done without galvanic separation, every measure taken on either side; supply and/or load has an immediate impact on the other. Circuit optimization can be done for pre-defined EMI test environments which then often fails in prnctical installations. EMI noise reduction solutions need to be created which are adaptive and self-optimize to their environment. Additionally, compared to conventional filtering, active EMI noise cancellation can be compact, cheap, unconditional stable, power and crosstalk reduction efficient. As such, active EMI noise cancellation will eliminate the need for heavy stiff shielded cables, large and heavy inductances and capacitor banks, used in filter stages, and as such save weight and volume. This paper is the result of the ongoing research on an active EMI noise cancelling concept [1] as presented at EMC Europe 2018 in Amsterdam. This project has been carried out under the European Project H-2020, ESCEL, I-Mech which ran from 2017 and was successfully accomplished 2020 [10-11].

TP-TUE-7B Active and Passive EMI Filter Techniques (Sponsored by SC-5) 13:30 - 15:30

Chair: Mingchang Wang, Kegify Ltd., Waterloo, ON, Canada

13:30 **Modeling and Stability Analysis of Digital EMI Filter** 297

Junpeng Ji[1,2], Gang Li[1], Wenjie Chen[2], Fengjiao Cheng[1], Shuo Wang[3]
[1]Xi'an University of Technology, China; [2]Xi'an Jiaotong University, China; [3]University of Florida, USA

Abstract: Smaller size and lower loss are always the target of EMI filter which suppresses EMI emitted by power electronics converter. Digital EMI filter (DEF) is the best solution to suppress the conducted EMI in size and loss, especially for highpower converters. However, for current DEF model, it is not enough to describe the filtering ability. The model which can describe DEF stability is absent. To cope with these, this paper proposes a modeling technique about filter and stable behavior of DEF system. In proposed technique, the insertion gain model can accurately describe the filtering behavior, and the loop gain model can predict the stability of DEF system. Experimental testbed based on a Boost converter as EMI interference is built. Experimental results validate that the proposed model can successfully predict the stability and performance of DEF system.

13:55 **Switching Noise Reduction of Synchronous DC-DC Buck Converter based on Smart Power Stages by Minimizing Parasitic Inductances** 301

Lingling Zhao[1], Min Sun[1], Fei Xu[2], Qi Huang[1], Siming Pan[1]
[1]University of Electronic Science and Technology of China, China; [2]Chongqing University, China

Abstract: This paper introduces the smart power stage (SPS) chip for synchronous buck converter which has the feature of minimized parasitic inductances. Through analyzing the drain-source voltage of switching MOSFETs based on the parasitic inductances in one switching interval, the switching noise is obtained. Compared with the buck converter using discrete switching components, SPS built buck converters have greatly improved the voltage stress, eliminating false triggering pulses and increasing efficiency. Simulation results and experimental platforms of SPS-buck and DSC-buck were established to verify the correctness of the theory.

14:20 **FPGA-based Adaptive Notch Filters for the Active Cancellation of Varying Electromagnetic Emissions of Power Electronic Inverter Systems** 307

Tobias Dörlemann, Andreas Bendicks, Stephan Frei
Technische Universität Dortmund, Germany

Abstract: In many modern power electronic systems, fastswitching semiconductor devices are used to reduce switching losses. Due to steep switching waveforms and high switching frequencies, significant electromagnetic disturbances can be emitted. In contrast to conventional passive filter components, active cancellation methods are based on the controlled destructive interference between a noise signal and a corresponding anti-noise signal. Adaptive notch filters revealed themselves as a promising active EMI cancellation concept for periodic noise signals. In this work, adaptive notch filters are regarded in context of slowly time-varying periodic noise signals, e.g. pulse-width modulated signals as common in inverters. The corresponding noise signals consist of switching harmonics and adjacent sideband harmonics. Therefore, the notch filter's bandwidth comes into focus and an analytical approximation for the ideal adaptive notch filter's bandwidth is discussed. With help of this approximation, the adaptive notch filter can be parametrized specifically to a given noise spectrum and other requirements. The capability of the parametrization strategy and the adaptive notch filter itself are shown by simulation and measurement.

14:45 **An EM-Circuit Co-Simulation Model to Predict Insertion Loss in a Busbar-PCB type EMI Filter** 313

Kwangho Kim[1], Hwang Hee[2], Wansoo Nah[1]
[1]Sungkyunkwan University, Korea; [2]LS Automotive Corp., Korea

Abstract: Recently, a busbar-PCB structure for the installation of EMI filter has been used widely, especially in the automotive industry, which accommodates large current for driving electric motors. In this paper, an EM-circuit cosimulation model is proposed to efficiently estimate the insertion loss in a busbar-PCB type EMI filter. The developed cosimulation model was applied to a prototype busbar-PCB filter, and the predicted data proved to coincide very good to the measured insertion loss in common mode and differential mode up to 100 MHz, which confirms the validness of the proposed method.

TP-TUE-8B Jitter/Noise Modeling and Analysis (Sponsored by TC-10) 13:30 - 15:30

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

13:30 **Analysis of Power Supply Induced Jitter of High Speed Output Buffer with On-Die Low-Dropout Voltage Regulator** 318

Yin Sun[1], Junho Joo[1], Jongjoo Lee[2], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]SK Hynix Inc., Korea

Abstract: In this paper, a methodology to analyze the power supply induced jitter (PSIJ) of high speed output buffer with on-die low-dropout (LDO) voltage regulator is presented. The approach relies on separate analysis of the LDO block and the buffer block. The total system level PSIJ analysis is achieved by combining the stand-alone results together. The AC analysis of power supply rejection ratio (PSRR) of LDO is performed. The loading effect of the buffer is also included. The PSIJ sensitivity analysis of the output buffer is obtained by transient analysis varying the frequency of sinusoidal power rail noise. The system PSIJ sensitivity analysis is completed by multiplying the LDO block PSRR response with the buffer block PSIJ sensitivity. This procedure allows designer to evaluate the system PSIJ with fewer and faster simulations. The contribution of different blocks can be clearly revealed. The proposed approach is validated through Hspice simulation of the entire system level circuit. Reasonably good accuracy has been achieved with the proposed analysis method.

13:55 **Efficient Estimation of Noise Suppression Amount in Power Bus with Decoupling Capacitors using Lossy Resonator Filters** 323

Sho Kanao, Kengo Iokibe, Yoshitaka Toyota
Okayama University, Japan

Abstract: To estimate the amount of noise suppressed by lossy resonator filters (LRFs) in a power bus with a decoupling capacitor, we used an equivalent circuit model considering the effect of the capacitor to know the suppression mechanism using the LRF. The discrepancy between the model and a full-wave simulation was approximately 2 dB.

14:20 **Intended Electromagnetic Interference with Motion Detectors** 324

Arne Pahl, Kai-Uwe Rathjen, Stefan Dickmann
Helmut Schmidt University, Germany

Abstract: Electromagnetic Interference with sensors has led to various problems in the past. In this work, two sensors, a gyroscope and an accelerometer are examined with respect to their susceptibility to interference. These sensors can be found in various electronic systems like drones, mobile phones, cars, etc.. The sensors are placed in a TEM cell and a signal generator excites a sine signal with the frequency between 5MHz and 1GHz. It is shown how susceptible to electrical fields the sensor system is. Finally, the analysis of the communication between the sensor and a controller over an I²C bus shows how simple it is to disturb a sensor system.

14:45 **Root Cause Analysis for the Phase Noise of the Clock Generator** 329

Yuanzhuo Liu[1], Siqi Bai[1], Bo Pu[1], Zhifei Xu[1], Bichen Chen[2], Srinivas Venkataraman[2], Xu Wang[2], Jun Fan[1], DongHyun Kim[1]

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

Abstract: The performance of the high-speed links in the electronic system is highly dependent on the quality of the clock signal, which can be quantified by phase noise. The phase noise represents the instabilities of the signal in the frequency domain by measuring the power at various offsets from the carrier frequency. The root cause for the phase noise of the clock output at the resonance frequency is analyzed and identified in this paper. The power supply, the heat sink, and the external crystal are the main sources of the phase noise. Spurious occurs at the frequency of the power rail in the measured phase noise. The heat sink over the chip induces the conductive coupling noise to the clock. The low-frequency bump in the phase noise plot turns out to be induced by the external crystal design of the clock. More attention should be paid to the ground routing of the external crystal to ensure the quality of the clock output.

SS-TUE-B EMC Diagnostics of Complex Systems 13:30 - 15:30

Chair: Vladimir Mordachev, Belorusskij Gosudarstvennyi Universitet Informatiki i Radioelektroniki, Minsk, Belarus

13:30 **Experimental Estimation of Shielding Effectiveness of Composite Materials by use of Ultra Wideband Electromagnetic Pulses** 334

Dzmitry Tsyanenka[1], Vladimir Mordachev[1], Eugene Sinkevich[1], Leanid Lynkou[1], Aleksander Prudnik[1], Alexey Galenko[1], Wen-Qing Guo[2], Xie Ma[2], Zhe Wang[2]

[1]Belorusskiy Gosudarstvennyy Universitet Informatiki I Radioelektroniki, Belarus;

[2]China Electronics Technology Cyber Security Co., Ltd., China

Abstract: A wide set of shielding materials is used for protection of electronic systems and their critical components against the impact of Ultra Wideband Electromagnetic Pulses (UWB EMP). Widely known protection solutions are materials with polymer metalized films, the needle-punched and felt fabrics with conductive fillers, materials with ferromagnetic fillers, fabrics impregnated by electrolyte solutions such as regular water, NaCl and CaCl2 water solutions. In this paper, a technique for express in-situ measurement of UWB EMP shielding effectiveness of composite materials is developed. The shielding effectiveness of materials with complex structure is tested in framework of the developed technique by the use of Test System providing the generation of EMP with duration of 242±24 ps (at half of maximum) and rise time of 139±14 ps. The obtained value of shielding effectiveness for the EMP with the noted parameters is 15.5 dB for four layers of the needle-punched material with carbon additives impregnated by electrolyte solution, 13.9 dB for the two layers of felt fabric material with a layer of polymer metalized film, and about 12.5 dB for material with the metalized films.

13:55 **Multi-Antenna Techniques for Interference Mitigation and Control (Invited)** 340

Sergey Loyka

University of Ottawa, Canada

Abstract: A modern approach to interference mitigation and control in wireless communication systems via multi-antenna techniques is reviewed and new results are presented. While the traditional approaches are via orthogonal multiple access techniques and rely on limited radiation power and propagation path loss to ensure low interference (in case of frequency re-use as in cellular systems) and compliance to health and other norms, the modern approach makes extensive use of multi-antenna techniques and advanced signal processing to dynamically adjust its radiation pattern while meeting all the requirements and delivering high rates at the same time. The key results are presented, which make use of information-theoretic and convex optimization tools, as well as the insights they provide, which are important for practical applications.

WEDNESDAY TECHNICAL PAPERS AND ABSTRACTS

Wednesday, August 11, 2021

TP-WED-2A Reverberation (Sponsored by TC-2) 11:00 - 13:00

Chair: Carl Hager, IV, NSWC Dahlgren, Dahlgren, VA, USA

11:00 **Variability of the Mean Received Power from Several In-Band Antennas in Reverberation Chambers** 346

Gustav J. Freyer[1], Vignesh Rajamani[2]
[1]*Consultant, USA;* [2]*Exponent Inc., Austria*

Abstract: In-band antennas are used in reverberation chamber testing as receive antennas for several different functions including establishing a reference during chamber calibration and certification; establishing the desired test level and monitoring the test environment during the actual test. Historically there have been discussions about whether all in-band antennas will provide the same measured received power values in reverberation chambers or whether there will be significant differences in measured power from different antenna types. Attempts to address this issue have resulted in defining a range of antenna efficiencies with some included in compliance Standards. This paper provides test data on the measured received power from different antennas in two reverberation chambers over five different frequencies and highlights some of the differences and potential reasons for observed differences.

11:25 **Design of a Broadband Antenna for a Reverberation Chamber with Multiple Antenna Source Stirring** 350

A. De Leo, G. Cerri, P. Russo, V. Mariani Primiani
Università Politecnica delle Marche, Italy

Abstract: This paper presents the design of a broadband antenna to be used in a multiple antenna source stirring scenario. Usually, an array of monopole is placed onto the chamber's walls and the antennas are sequentially fed to perform the stirring action. But monopoles are intrinsically narrowband antennas: for this reason the use of a broadband antenna was investigated. The adopted structure is a helix antenna able to minimize the chamber volume reduction and to maximize the averaged power delivered to the chamber. Its performance was investigated by analyzing some typical RC performance indicators.

11:50 **Considerations on the Dwell Time for a Vibrating Intrinsic Reverberation Chamber** 355

Danilo Izzo[1,2], Robert Vogt-Ardatjew[2], Frank Leferink[1,2]
[1]*Thales Nederland B.V., The Netherlands;* [2]*University of Twente, The Netherlands*

Abstract: The dwell time is an important factor when conducting a radiated immunity test and shall be compatible with the response time of the device under investigation. In mode-stirred reverberation chambers, like the vibrating intrinsic reverberation chamber, the electromagnetic field is continuously stirred by the flexible, vibrating walls of the cavity and the time duration of high-strength interferences is generally unknown. Therefore, concerns have arisen regarding the proportion of time that the electromagnetic field level spends at or above the target level during the test. This study investigates, through empirical and simulated data, the expected value of this time interval, considering a threshold level equals to the quantile-80% of the field samples distribution. This information is useful for the user of the method, when considering a mode-stirred reverberation environment for devices with a well-known response time.

12:15 **Correlated Random Variables and Measurement Uncertainty in Reverberation Chambers** 361

Carlo Carobbi[1], Ramiro Serra[2]
[1]*Universita degli Studi di Firenze, Italy;* [2]*Eindhoven University of Technology, The Netherlands*

Abstract: We provide analytical expressions for the variance of the mean, variance, and Allan variance of a series of observations when taking correlation into account. Specific correlation models are adopted suitable for an insightful statistical analysis and for quantification of measurement uncertainty. An application to data measured in a reverberation chamber (RC) is also offered.

TP-WED-3A Measurement and Characterization of Electromagnetic Environments (Sponsored by TC-3) 11:00 - 13:00

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

11:00 **Estimation of Measurement Uncertainties in TEM-Cells based on Generalized Telegraphist's Equation** 362

Hoang Duc Pham[1], Katja Tüting[1], Heyno Garbe[1], Sven Fisahn[2]
[1]Leibniz Universität Hannover, Germany; [2]Bundeswehr Research Institute for Protective Technologies and NBC Protection, Germany

Abstract: This work examines the uncertainties of electric field measurements in coaxial TEM-cells with a circular cross-section. The TEM-cell can be used as a standardized field generator for probe calibration or EMC measurements. The main advantage of a coaxial TEM-cell with a circular cross-section is the inherent transverse cross-section, an enlarged frequency bandwidth, and the possibility of efficiently calculating its electromagnetic characteristics. Based on the generalized telegraphists equations, the electromagnetic fields and the TEM-cells resonance frequencies can be calculated. Using this approach, we can include various uncertainty factors into our mathematical model equation. We will derive all necessary equations for a complete uncertainty evaluation of a coaxial TEM-cell following the GUM.

11:25 **Wave Chaos in the Vibrating Intrinsic Reverberation Chamber** 368

Justin Geerarts, Ramiro Serra
Eindhoven University of Technology, The Netherlands

Abstract: In this work, we experimentally investigate the wave chaotic nature of the vibrating intrinsic reverberation chamber (VIRC).The measured normalized field intensity is confronted against different known probabilistic models in RCs, both traditional (e.g. the 22 distribution) and the distributions from wave chaos theory. A discussion on some limitations of applying the state-of-the-art chaotic models is introduced, in particular on the appropriate estimation of the modal overlap.

11:50 **Efficient Estimation of the Band-Ratio of HPEM Sources for IEME Classification** 369

Juan Galvis, David Martinez, Gideon N. Appiah, Fernando Albarracin-Vargas, Chaouki Kasmi, Nicolas Mora
Technology Innovation Institute, United Arab Emirates

Abstract: This work presents the development of an algorithm for the estimation of the band-ratio for discrete spectra. The proposed approach is compared with two additional methods in order to validate its efficiency.

TP-WED-5A Near Field Systems for Evaluation of Wireless Systems (Sponsored by TC-12) 11:00 - 13:00

Chair: Zhong Chen, ETS-Lindgren, Cedar Park, TX, USA
Co-Chair: Yuchu He, Google LLC, Mountain View, CA, USA

11:00 **Improvement on the Accuracy of Near-Field Scanning using Tangential Electric Field Probe** 370

Wei Zhang[1], Shun Liu[1], Xin Yan[1], Takashi Enomoto[2], Hideki Shumiya[2], Kenji Araki[2], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]Sony Global Manufacturing and Operations Corporation, Japan

Abstract: This paper discussed the issues about the nearfield measurement with a differential electric (E) probe. Based on the physical understanding, a method to improve the accuracy of the measured E field is proposed by suppressing the common-mode noise and eliminating the unwanted magnetic (H) field coupling. By adding ferrites around the cables that connect to the differential E field probe, suppression of the commonmode (CM) noise in the outer shield of the probe is achieved. In addition, the probe factor for the unwanted H field coupling of the E field probe is calibrated, which can be used to eliminate the H field coupling during the E field measurement. The effectiveness of the proposed method has been demonstrated in experiments. This paper provides a practical method to obtain accurate E-field measurement with a tangential E field probe, especially in the cases where the detected signal of the unwanted coupling is comparable to the wanted coupling.

11:25 **Radiated Noise Source Characterization based on Magnitude-Only Near Field** 376
Ze Sun[1], Yansheng Wang[2], Warren Lee[2], Ken Wu[2], DongHyun Kim[1]
[1]Missouri University of Science and Technology, USA; [2]Google Inc., USA

Abstract: Accurate noise source characterization is critical in increasing the accuracy of desense simulations. However, characterization of the emission sources in full-wave simulations often lacks accuracy. In this paper, a fast and accurate method to extract equivalent dipole moments of radiated noise sources is proposed. The proposed method uses the genetic algorithm to optimize the position and type of dipoles, and it also uses a back-and-forth iteration algorithm to retrieve phase based on the magnitude information of two observation planes with different heights. Compared with the traditional equivalent dipole extraction algorithms, this method can minimize the number of reconstructed dipoles and avoid the complicated and timeconsuming phase measurement. This method is verified by comparing the measurement and simulation of coupled noise from an image sensor to a nearby cellular antenna.

11:50 **Analysis of Compensation Networks for a Transcutaneous WPT System to Achieve Compliance with ICNIRP Basic Restrictions** 381
S. Cruciani[1], T. Campi[2], F. Maradei[1], M. Feliziani[2]
[1]Sapienza University of Rome, Italy; [2]University of Aquila, L'Aquila, Italy

Abstract: The paper deals with the application of the wireless power transfer (WPT) technology, based on near field inductive coupling, in implantable medical devices (IMDs). A transcutaneous WPT system is considered here to transfer a power of over 10 watts. The selection of the most adequate topology of the compensation network is a key point to mitigate the variation of physical quantities inside the human body, such as internal electric field E and specific absorption rate (SAR). An investigation is here provided to demonstrate the different behavior of each compensation topology in order to obtain compliance with ICNIRP limits in biological tissues.

12:15 **Long-Term Evolution Uplink Impacts on Aeronautical Mobile Telemetry** 386
Duncan A. McGillivray, Jack G. Sklar, M. Keith Forsyth
National Institute of Standards and Technology, USA

Abstract: The National Advanced Spectrum Communications Test Network conducted a test campaign to evaluate impacts of advanced wireless services - 3 long-term evolution uplink (1755 MHz - 1780 MHz) signals on adjacent Lband (1780 MHz – 1850 MHz) aeronautical mobile telemetry air to ground links. The test campaign applied a host of field and laboratory-collected long-term evolution uplink waveforms to an aeronautical mobile telemetry system in a highly automated, cabled testbed. We showcase the test methodology and lessons learned of a susceptibility study in the adjacent band as applied to a telemetry receiver under test.

TP-WED-6A Numerical Modeling and Simulation Techniques 2 (Sponsored by TC-10) 11:00 - 13:00

Chair: Qiaolei Huang, Amazon Lab126, Sunnyvale, CA, USA
Co-Chair: Bichen Chen, Facebook, Inc., Menlo park, CA, USA

11:00 **Order Determination of the Multiple Edge Response Method for Nonlinear Links** 387
Yuhuan Luo, Xiuqin Chu, Jun Wang, Yan Rong, Feng Wu, Wenting Guo
Xidian University, China

Abstract: As data rates of high-speed links increase, the impact of nonlinearity is becoming more and more prominent. To capture the effect of nonlinear behaviors on the system response, the multiple edge response (MER) method was proposed for nonlinear systems. High order MER can capture sufficient nonlinearity and achieve accurate results. However, it is quite time-consuming to obtain a large amount of edge responses for the higher order MER. Therefore, it is necessary to study the minimum required order of MER to estimate the system performance. In this work, a simple and efficient method based on multiple pulse responses is proposed to estimate the minimum required order of MER. The accuracy of the proposed method is validated by simulation for a nonlinear high-speed link.

11:25 **Uncertainty Quantification of a CMOS Oscillator using Stochastic Collocation Techniques** 391
Aksh Chordia, Jai Narayan Tripathi
Indian Institute of Technology Jodhpur, India

Abstract: In recent years, stochastic techniques have emerged as computationally superior techniques for Uncertainty Quantification (UQ). This paper focuses on the application of different stochastic techniques based on Stochastic Collocation (SC) for UQ. Here, the performance of different SC approaches like interpolation, regression and pseudo-spectral projection is assessed for an illustrative example of a 2:4 GHz CMOS LC oscillator. The application of these approaches for the oscillator circuit is investigated by performing the UQ of its phase noise output. The approaches are further compared with the traditional Monte Carlo simulations. The advantages and disadvantages of each of the methods clearly emerge from our study that helps in choosing the appropriate technique for modeling the uncertainty for any given similar oscillator circuit.

11:50 **Modeling of Power Supply Noise Associated with Package Parasitics in an On-Chip LDO Regulator** 395
Junho Joo[1], Yin Sun[1], Jongjoo Lee[2], Sunkyu Kong[2], Soonku Kang[2], Inmyung Song[2], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]SK hynix Inc., Korea

Abstract: In this paper, the power supply noise associated with package parasitics in an on-chip low-dropout (LDO) regulator is investigated. The on-chip LDO regulator with off-chip decoupling capacitors has power supply rail noise typically in the frequency range of few hundreds of MHz, which is related to the inductive package interconnects and the parasitic capacitance of the pass transistor. An equivalent circuit is proposed to model the power supply noise and understand the effect of inductive package interconnects. Based on the proposed equivalent circuit, the mitigation of the power supply noise from a package design perspective is discussed.

12:15 **Simplified De-Embedding for Return Loss Estimation** 400
Syed Bokhari
Fidus Systems Incorporated, Canada

Abstract: The work presented in this paper addresses two important Signal Integrity applications. First, s-parameter measurements of a DUT (denoted by D) invariably involve a Test fixture (denoted by F). De-embedding requires the sparameters of the test fixture, and an s-parameter simulator. In a second application, it is desirable to know the return loss of a link comprising several parts which again requires an sparameter simulator. During a channel system architecture phase, quick estimates are needed. These are easy to do with insertion loss, but not with return loss, and this work presents a simple approximation useful in both cases.

TP-WED-7A Power Electronics EMI Modeling and Measurement I (Sponsored by SC-5) 11:00 - 13:00

Chair: Dong Jiang, Huazhong University of Science and Technology, Wuhan, Hubei, China

11:00 **Evaluating EMI of Unshielded Cables in High Frequency GaN Inverter Application** 401
Julian Dobusch[1], Daniel Kuebrich[1], Thomas Duerbaum[1], Fabian Diepold[2]
[1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany; [2]Siemens AG, Germany

Abstract: Inverters in VSDs represent a common source of EMI. The steep voltage slopes of modern power electronics with their high frequency share can cause radiated emissions. Therefore, shielded motor cables are used to minimize these emissions. However, in order to reduce costs, unshielded cables are an attractive option. This paper analyses an inverter setup with different motor cables. A measurement setup is presented in order to investigate the proper PE connection for complying with the standards.

11:25 **Common-Mode and Differential-Mode Prediction in a Drive System by Transmission-Line Theory** 407
Andrea Zingariello, Vefa Karakasli, Gerd Griepentrog
Technische Universität Darmstadt, Germany

Abstract: In drive systems, high-frequency leakage currents with frequencies up to several 10 MHz are likely to occur due to the switching operation of power electronic systems. Those leakage currents can unintentionally affect other components such as circuit breaker or residual current breaker and are hard to predict in most applications. A new model for the evaluation of the leakage current associated with each component in a three-phase system is proposed. The simulation model is easily adjustable according to the associated frequency range and it can evaluate both common mode and differential mode current. The proposed model result demonstrates a good agreement with the measurements up to 10 MHz

11:50 **Experimental Formulation to Estimate the Power Density in the Near Field of a Linear Transmitting Antenna** 413

Luis Fernando Destro, Benjamim Galvão
IBBX Innovation, Brazil

Abstract: In order to find an estimation of the Near Field power density in the space between two half-wave dipole antennas, an empirical formulation was developed to achieve the reduced gain of the dipoles in the Fresnel region. The power density is calculated by taking the values of the wave impedance at each point in the space, which were found through the measurement results. The obtained results are helpful to the project designer prior to laboratory testing, saving time and costs. In the design of an antenna for a RF Harvesting System, once the effective area of the receiving antenna is known, the estimation of the captured energy is found in the particular case presented herein.

12:15 **Online Input Impedance Extraction of SMPS with Different Impedance of Two Power Lines to Ground** 417

Junpeng Ji[1], Tuo Li[1], Jingjie Lu[1], Peng Luo[2]
[1]Xi'an University of Technology, China; [2]Suzhou Veichi Electric Co., Ltd., China

Abstract: It is important to acquire the impedance of switched-mode power supply (SMPS) under its operating condition for designing electromagnetic interference (EMI) filter. The online impedance extraction technique has become a research hot topic. However, the result of current online measurement technique is inaccurate due to ignorance of the different impedance of two power lines to ground of SMPS. To cope with this, an online impedance extraction technique is proposed in this paper. Considering the practical characteristics of impedance of two power lines to ground, the extraction principle and method is developed based on the established measurement models. Finally, the measurement platform with SMPS and measurement device under operating condition is built. Experimental results validate that the proposed technique can extract the differential mode (DM) and the impedance of two power lines to ground.

TP-WED-8A High-Speed Link/Bus Design 2 (Sponsored by TC-10) 11:00 - 13:00

Chair: Bo Pu, Missouri University of Science and Technology, Rolla, MO, USA
Co-Chair: DongHyun Kim, Missouri University of Science and Technology, Rolla, MO, USA

11:00 **Convolutional Neural Network-based Design of EBG Structures in High-Speed Packages and PCBs** 422

Seongbo Sim, Myunghoi Kim
Hankyong National University, Korea

Abstract: We propose a method of predicting a cutoff frequency band(Stopband) of electromagnetic band gap(EBG) structure that reduces noise using Convolutional Neural Network(CNN). The stopband is predicted by using the structures of ResNet and DenseNet, which are known CNN models. This is compared and analyzed with the results of the existing method.

11:25 **An Investigation on Multiple Reflections and Group Delay Behavior in High-Speed System Designs** 423

Muqi Ouyang[1], Bo Pu[1], Kevin Cai[2], Anna Gao[2], Srinath Penugonda[1], Liang Liu[1], Bidyut Sen[2], DongHyun Kim[1]
[1]Missouri University of Science and Technology, USA; [2]Cisco Systems, Inc., USA

Abstract: In this study, the analytical solution for the group delay of a high-speed system with large impedance mismatch is derived. The accuracy and applicability of the solution are validated by comparing the calculated results between the analytical formulation and commercial tool results. Causal frequency-dependent stripline model is used in the formulation, and the derivation of analytical formulation is based on the transmissions and reflections of wave components in the highspeed channel. Therefore, the causality of the system can be ensured, and the number of transmissions and reflections considered in the calculation can be specified in the formulation. The derived analytical results indicate that multiple reflections in a system with impedance mismatch will contribute to oscillations in the group delay curve, but the minimum group delay at the valleys of the oscillations does not appear to be the minimum propagation delay of the system. The benefits of having analytical results play a critical role in identifying channel impairments in high-speed designs.

11:50 **Automated Full-Board SI Scan for High-Speed Applications up to 112Gb/s and Beyond** 429
Kevin Cai[1], Anna Gao[1], Bidyut Sen[1], Joshua Wan[2], Feng Ling[2]
[1]Cisco Systems Inc., USA; [2]Xpeedic Technology, Inc., USA

Abstract: With the signal speeds doubling for every generation, PCB design is becoming more and more challenging. The high-speed signal is getting more sensitive to the board layout impairments due to the dense placement of components. Therefore, a comprehensive scan including geometry, crosstalk, and noise coupling is necessary to ensure a quality eye at the receiver end for the concerned high-speed nets at 56Gb/s and beyond. In this paper, we offer a complete and automated full-board SI scan methodology. With such a methodology, subtle board layout defects are quickly pinpointed, including ground coverage, via stub length, trace necking, power via to signal via/trace spacing, and ground via to signal via distance, etc. Moreover, high-speed return loss and crosstalk scan in connector and ASIC pin fields are also implemented in an automated way with the help of the fast EM solver technology. As a result, the goal to have a confident PCB sign-off for the high-speed signals is achieved.

SS-WED-A Advanced Methods to Model, Evaluate, and Measure Electromagnetic Interference at Low Frequency in Transportation and Renewable Energy Systems 11:00 - 13:00

Chair: Waseem Wafik Elsayed, Universiteit Twente Faculteit Elektrotechniek Wiskunde en Informatica, Zielona Góra, Lubuakie, Poland
Co-Chair: Abduselam Hamid Beshir, Politecnico di Milano, Milan, Italy

11:00 **The Effect of Stray Capacitance to the Common Mode Current on Three-Phase System** 430
Muhammad S. Alamsyah[1], Francinei L. Vieira[1], Heyno Garbe[1], Sebastian Koj[2]
[1]Leibniz Universitat Hannover, Germany; [2]IAV GmbH, Germany

Abstract: The common-mode (CM) current phenomena is one of many problems in the EMC world due to the radiated magnetic field caused by it. A power transmission line with a delta-connection both generator and load normally do not have a connection to ground to establish a line for the return current. To determine the CM current, finding the stray capacitances to the ground is highly important because they are used as the return path for the CM current. In this paper, the investigation of predicting the CM current flowing through the stray capacitances will be done at a three-phase equivalent system of a wind turbine (WT). The wind turbine body is the place where the CM current flows, due to the stray capacitances between the power cables and the WT body around it. The CM current can be determined using the current magnitudes in a pointer-image method, which has a good agreement for CM current prediction and it might become a very useful tool applicable to measurements.

11:25 **Electromagnetic Fields on 3-Phase Induction Motor using Finite Element Analysis** 434
Douglas Nascimento[1,2], Robert Smolenski[1], Hermes Loschi[1,2,3], Flavia Grassi[4],
Lu Wan[4], Abduselam H. Beshir[4]
[1]University of Zielona Góra, Poland; [2]University of Twente, Poland; [3]University of Nottingham, United Kingdom; [4]Politecnico di Milano, Italy

Abstract: Electromagnetic fields of a 3-phase induction motor, i.e., electric and magnetic fields and current density, are highly influenced by its geometry, conductor material (conductivity, magnetic permeability, electric permittivity, and nonlinearity), and boundary conditions applied (interface between conductors and dielectrics). Through Finite Element Analysis (FEA), the behavior of electromagnetic fields can be predicted. Thus, favoring the electromagnetic interference mitigation techniques of the 3-phase induction motor. Therefore, this paper presents numerical modeling with FEA, based on COMSOL, as an early pre-compliance tool to investigate the current density distribution and electric and magnetic fields. The validation of the modeling approach will be presented and discussed considering a 3-phase induction motor. Furthermore, CISPR 25 will be considered to evaluate the interactions between electric and magnetic fields, current density distribution, and skin effect on an increasing frequency.

11:50 **Micro-Grid Inrush Current Stability Analysis** 440
Alexander Matthee, Niek Moonen, Frank Leferink
University of Twente, The Netherlands

Abstract: Transient currents can severely impact the operation of weak or islanded grids. Inrush current electromagnetic compatibility challenges, due to their unpredictable and intermittent nature, are very difficult to identify. Using multi-point synchronised measurements, analysis is performed on an inverter. The supply powers various loads that are observed during cold start as well as under load switching conditions. Inrush event triggered failure probability is linked to non linear and average load levels.

12:15 **The Effect of Spread Spectrum Modulation for a Buck Converter Coupled with a Single Wired Communication Link** 445

A. Pena-Quintal, K. Niewiadomski, V. Muneeswaran, S. Greedy, M. Sumner, D.W.P. Thomas
University of Nottingham, United Kingdom

Abstract: This paper explores the effect of using a Spread Spectrum modulation technique with a Buck Converter on a communication cable coupled at the input voltage. The EMI created by the switching of the power converter generates damped oscillations on the data cable that can have great impact on the quality of the communication channel. Frequency domain analysis shows lower EMI levels in the power cable when compared to the standard deterministic modulation. However, there is no real improvement to the actual communications as there in an increase in the measured Bit Error Rate when evaluated experimentally.

TP-WED-1B Antennas and Analysis (Sponsored by TC-2) 13:30 - 15:30

Chair: Thomas J. Fagan, Aerospace Corporation, Vail, AZ, USA

13:30 **Localized Time Rotation of the Electric Field Near the Boundary of the Reactive Near Field of a Dipolar Antenna** 451

James McLean
TDK R&D Corp., USA

Abstract: It is well known that in the reactive near electromagnetic field of a dipolar antenna such as a 1.4-m biconical antenna the electromagnetic field is predominantly electric in nature and that in some immunity measurements such as MIL-461, RS 103, the DUT is located in this region. That the field is predominantly electric in nature is considered acceptable if the anticipated coupling mechanism into the DUT is electric. It is less widely noted that near the boundary of the reactive near field (the induction zone) and outside of the H-plane of the dipole, the near electric field vector undergoes time rotation. For the geometry of MIL-461 RS 103 with a DUT located 1 meter from a 1.4-m biconical dipole we show that in the vicinity of 100 MHz, in some portions of the uniform field area, the electric field appears to be pseudo-circularly polarized with two orthogonal equal-magnitude components in phase quadrature. A simple analytical model is used to confirm the electric field rotation for an isolated dipole. A numerical simulation is employed to compute the field of a more complex and practical 1.4-m biconical antenna and also to model the effects of ground. Preliminary experimental results confirm the simulation. Clearly, such a field would affect a DUT differently from the way a linearly-polarized electric field would and also very differently from the way a true circularly-polarized plane wave would.

13:55 **Assessment of the Antenna-Equivalence Approach to Common-Mode Input Impedance Modeling** 457

A. Hubrechsen, L.A. Bronckers, A. Roc'h
Eindhoven University of Technology, The Netherlands

Abstract: Analytical modeling of the common-mode input impedance of a motor along with its cable for various installation characteristics would allow designers to assess EMI levels and to evaluate in an early stage if adaptations are needed in their cable installation. Earlier work has shown that the input impedance over frequency of such a system is mostly dominated by the cable. A common assumption is that a cable can be approximated as a monopole antenna above a ground plane, which has an input impedance equivalent to that of a dipole with a correction factor. We compare the Hall´en and King & Middleton dipole models to a measurement setup which is designed to reproduce parastic effects from the installation, to assess the validity of the analytical model. We analyze these results for various distances between the cable and the groundplane. We show that large discrepancies occur due to paristics of the installation and the presence of the groundplane, but that for some applications such closed-form analytical models may suffice in assessing frequencies at which radiated emissions occur.

14:20 **Consistency Analysis of S-parameter Indirect Measurement for Improving Estimation Result** 462

Noboru Maeda[1], Kengo Fukunaga[1], Keishi Miwa[2], Soichiro Ota[2]
[1]Soken, Inc., Japan; [2]Toyota Motor Corporation, Japan

Abstract: A consistency analysis procedure for our previously proposed indirect measurement method for the S-parameters of a multiport reciprocal circuit (e.g. bundle of wires or PCB traces) is proposed. In the measurement method, half of the ports are connected with some known loads and the remaining ports are directly measured by changing the load values to estimate the whole S-matrix. Some linear relations in the transfer coefficient submatrices between the direct and indirect measured ports have been used in the method. Those relations are selected to analyze the consistencies of the method from the theoretical viewpoint. Then, the indirect measurement method is applied to an example target, fixtures to measure the characteristics of wireharness mounted in a vehicle, to evaluate the consistencies in the calculation process. Also, a method to obtain an improved estimation result using the consistency evaluation is provided. Index Terms—Circuit analysis, Measurement techniques, Estimation theory, Automotive electronics .

14:45 **Comparison of Extrapolation Methods for De-Embedding Truncated Measured Transfer Functions** 468

David Martinez, Fernando Albarracin-Vargas, Juan Galvis, Gideon N. Appiah, Felix Vega, Chaouki Kasmi, Nicolas Mora
Technology Innovation Institute, United Arab Emirates

Abstract: This paper presents a comparison of three extrapolation methods used to re-construct the missing parts of truncated transfer functions used to de-embed measured transient electromagnetic signals.

TP-WED-2B Chambers (Sponsored by TC-2) 13:30 - 15:30

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

13:30 **GTEM Cell – An Alternative Immunity Test Environment for Automotive Components** 469

Nitin Aggarwal[1], Moawia Al-Hamid[1], Ralf Vick[1], Steffen Schulze[2]
[1]Otto-von-Guericke-Universität Magdeburg, Germany; [2]Würth Elektronik eiSos GmbH, Germany

Abstract: ALSE (Absorber Lined Shielded Enclosure), BCI (Bulk Current Injection), TEM (Transverse Electromagnetic) cell and stripline are some of the methods described by the ISO 11452-x standard series to test vehicle sub-components. Till today, the GTEM (Gigahertz Transverse Electromagnetic) cell was not considered for vehicle sub-component immunity testing. In this paper, the GTEM cell is assessed, using a simple EUT (Equipment Under Test) with an attached cable. Different cable layouts were tested in order to find the one with the worst case coupling of the external noise. Additionally, the GTEM cell's measurement result is compared with the standard immunity methods, based on the measured RF current on the EUT cable harness and required forward power of the power amplifier.

13:55 **Statistical Approach to Verification of Field Uniformity and Dominance of the Primary Field Component in the GTEM Cell** 475

Yevhenii Hubariev, Jan Sroka
Warsaw University of Technology, Poland

Abstract: Software capable to set electrical field strength in any point under interest in the GTEM cell is developed for setting uniform field area in set of points and for verification of the dominance of the primary field component over secondary field components as demanded in the standard IEC 61000-4- 20. Microsoft.NET programming platform is used. Uniformity is checked with statistical criteria. In the standard 75 % confidence level is required. This level is suitable for N = 5 total number of points. 75 % means 4 points. However by N = 6 this level gives in some circumstances erroneous verdict. The Author propose other suitable confidence levels. The application is validated with the GTEM 5317 cell from EMCO.

Best EMC Paper Finalist

14:20 **Investigation of the Workbench Faraday Cage Method, IEC 61967-5** 480

Morten Sørensen[1], Søren Kjærulff Christensen[2], Claus Vittarp[3], Hans Ebert[4]
[1]University of Southern Denmark, Denmark; [2]Terma A/S, Denmark; [3]DEIF A/S, Denmark; [4]Aalborg University, Denmark

Abstract: The Workbench Faraday Cage Method (WBFC), IEC 61967 Part 5, is a method to estimate common mode current radiated emission caused by integrated circuits either applied on a standardized test-board or on a final printed circuit board. The presented work analyzes the method with the help of simulations of a simple microstrip board with two attached cables connected to ground. The analysis shows that the theoretical foundation of the method is weak and that the WBFC method gives a poor prediction of the radiated emission.

14:45 **Analysis of the Impact of the Monitoring Equipment on the Common-Mode to Differential-Mode Conversion in Bulk Current Injection Tests** 486

Pablo J. Gardella[1], Eduardo Mariani[2]
[1]Instituto Tecnológico de Buenos Aires, Argentina; [2]Allegro Microsystems Argentina, Argentina

Abstract: In this paper, the common-mode to differentialmode conversion in a Bulk Current Injection (BCI) test setup is analyzed in the presence of an optical fiber transmitter. A modular-basis analysis based on S-parameters measurements and Electromagnetic simulations has been performed. It is shown that the loading effects can change the insertion losses from the RF amplifier to the Devices Under Test, even at frequencies as low as 10MHz by 2dB and up to 23dB at worst cases. The study has been undertaken with the substitution and closed-loop methods. Quantification of this problem as well as mitigation strategies are proposed, analyzed and evaluated with the aim of improving the accuracy of BCI simulations at early-design stages. Considering the significant cost of redesigning at an advanced point in the product development cycle, the presented work expects to raise awareness about how even small changes in the BCI setup can remarkably compromise the outcome.

TP-WED-3B 2.5D/3D/Exotic ICs/Packing and Emerging Technologies (Sponsored by TC-10) 13:30 - 15:30

Chair: DongHyun Kim, Missouri University of Science and Technology, Rolla, MO, USA
Co-Chair: Bo Pu, Missouri University of Science and Technology, Rolla, MO, USA

13:30 **Signal Integrity Design Methodology for Package in Co-Packaged Optics based on Figure of Merit as Channel Operating Margin** 492

Bo Pu[1], Jiayi He[2], Aaron Harmon[3], Yuandong Guo[3], Yuanzhuo Liu[3], Qiangming Cai[4]
[1]DeTooLIC Technology Co. , Ltd., China; [2] Cisco Systems, Inc., USA; [3]Missouri University of Science and Technology, USA; [4]Southwest University of Science and Technology, China

Abstract: Optical engines co-packaged with switching Application-Specific Integrated Circuit (ASIC) can offer a solution for advancement in bandwidth requirement and are potentially the ultimate direction for the long-touted "optical integration" era. This paper prnposes a novel signal integrity (SI) design methodology for package of co-packaged optics (CPO) by using channel operating margin (COM) as a figure of merit (FOM) for the first time. The conventional design method of SI based on individual criteria, such as masks for loss, crnsstalk, jitter, eye width/height, impedance, etc., are no longer able to be satisfied at the same time for cul'l'ent high-speed signals up to S0Gbps and even over lO0Gbps. COM, combining most of the individual criteria into a single value of signal to noise ratio, prnvides the possibility to estimate the quality of the channel and achieve a balance between performance and design complexity in the early design stage. In this work, a design methodology in a format of a visible map using the most two significant factors, loss, and crnsstalk, to satisfy the required COM is discussed in detail. With this novel methodology, one can predict the SI performance of a package in the early design stage when the real layout has not generated yet for full-wave simulation and can avoid the costly iteration in the conventional design concept.

Best SIPI Paper Finalist

13:55 **Design and Analysis of On-Package Inductor of an Integrated Voltage Regulator for High-Q Factor and EMI Shielding in Active Interposer based 2.5D/3D ICs** 498
Subin Kim, Seungtaek Jeong, Boogyo Sim, Seongsoo Lee, Hyunwook Park, Haeyeon Kim, Joungho Kim
Korea Advanced Institute of Science and Technology, Korea

Abstract: On-package inductor, a promising type of filter inductor for integrated voltage regulator (IVR) requires low loss and shielding structure for high IVR efficiency and vertical noise coupling. In this paper, we proposed a novel on-package inductor of an integrated voltage regulator for high-Q factor and EMI shielding in active interposer based 2.5D/3D ICs. The proposed on-package inductor is composed of 4 parallel spiral loops and a shielding loop. The proposed inductor is verified with simulation and measurement in frequency domain. It achieves both high-Q factor and high shielding effectiveness using the package re-distribution layers only. With its shielding structure, vertical magnetic noise coupling to a noise sensitive circuit block on active interposer is successfully suppressed by 25.5 dB and normal operation of circuit is ensured.

Best SIPI Paper and Best Student Paper Finalist

14:20 **The Whole Solution Space based Pin Pattern Optimization in BGA Technology** 504
Tao Wang
Missouri University of Science and Technology, USA

Abstract: I/O pin counts have been able to increase significantly thanks to ball grid array (BGA) packages. The pogopin socket and elastomeric socket are developed to test BGA devices for quick device screening, device characterization and final production test. The cross talk issue introduced by using production test socket is inevitable due to the high density of speed I/Os. To mitigate the cross talk problem, this paper discusses the methodology to quickly generate pin patterns in a full solution space aiming to select the optimal pin patterns which will produce acceptable SI/PI performance in the chip design phase.

TP-WED-4B Cables and Connectors Considerations and Testing (Sponsored by TC-4) 13:30 - 15:30

Chair: William Wantz, IV, Spira Manufacturing, San Fernando, CA, USA

13:30 **Single Pair Ethernet for the Industrial Internet of Things: Accurate Line Measurements** 505
Matthias Hampe, Thomas Müller, Alexander Stieler
Ostfalia Hochschule für angewandte Wissenschaften, Germany

Abstract: In this work accurate measurement setups have been developed in order to determine the per-unit-length parameters of Single Pair Ethernet (SPE) transmission lines in the frequency range 0Hz − 1.0GHz. In particular, the frequency dependence of all per-unit-length parameters will be derived, which goes far beyond the information in conventional data sheets. Based on these measurement results, accurate simulations in the fields of Automotive Ethernet, Internet of Things (IOT) and Industrial Internet of Things (IIOT) can be performed in future.

13:55 **Investigation of an Iterative Method for Finding of Currents, Voltages and Termination Impedances of PCB Traces based on Phase-Less Near-Field Data** 509
Robert Nowak, Stephan Frei
Technische Universität Dortmund, Germany

Abstract: The evaluation of near-field data can be an effective way to analyze EMI sources. In contrast to antenna measurements, near-field techniques can determine the emitted field without special requirements on the measurement environment. Moreover, critical sources can be found when current distributions can be identified. Therefore, current reconstruction methods for PCB traces were developed. With additional voltage information the termination impedances of the traces can be found. The known phase-less approaches suffers from different limitations, e.g., non-unique reconstruction results. In this paper, the necessary conditions for a unique reconstruction are discussed by investigating simulated phase-less near-field data. Based on these findings, measured near-field data of a PCB trace is evaluated, and the successful retrieval of the phase information is shown. Additionally, reconstructed voltage distributions are presented and compared to measurement data.

14:20 **EMI Investigation and Mitigation of Flexible Flat Cables and Connectors** 515

Xin Yan[1], Chunyu Wu[1], Dave Zhang[2], Shuai Jin[2], Songping Wu[2], Jun Fan[1], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]Google Inc., USA

Abstract: In modern mobile devices, as a result of the increase in data rate, requirement for higher density signal and costeffective solution, the flexible flat cable (FFC) now plays an important role to connect separated printed circuit boards (PCBs). Due to the low-cost fabrication and varied shielding structure, FFC has been identified as a noise source for electromagnetic interference (EMI) and desense issues. In this paper, the common mode noise generated from FFC and related connectors is investigated. With the assistance of full wave and circuit simulation, main cause of the common mode noise has been identified as the ground discontinuity and the related voltage difference between the PCB ground and the FFC ground. By providing better shielding and improving ground continuity, 11 dB reduction of total radiation power (TRP) is observed at 5 GHz.

14:45 **Meta-Networks: Reconfigurable Cable Network Topologies for Interference Control** 520

Mubarack Ahmed, Gabriele Gradoni, Stephen Creagh, Gregor Tanner
University of Nottingham, United Kingdom

Abstract: The importance of filters in signal processing abound in real-life applications such as audio electronics and power distribution networks. We introduce an efficient concept of constructing reconfigurable cable networks for interference control. The method utilises quantum-graph formalisms on composite nodes to implement reconfigurable, compact, wideband filters. By using a cascade of loop networks as building blocks, we show that such meta-networks can provide a flexible way of suppressing unwanted signals thereby increasing the efficiency of the underlying networks. Numerical results show that microwave interference can be filtered to allow only specific narrow (or wide) band frequencies to be fully transmitted while suppressing the other frequency bands. For example, a wave of frequency 0 f 6 GHz can be filtered using a cascade of three-loop networks with cable lengths 0:0001 l 0:05 m. By tuning one of the constituent cables, we are able to achieve maximum power transmission on a specific set of frequencies while completely suppressing signals of unwanted frequencies. The present paper shows how to implement narrow-, medium- and wide-band bandpass filters by adopting a simple and easy-to-design cable topology for the reconfigurable filter. The proposed solution can be easily integrated with solutions, including varactor diode and phase-shifter based architectures, to achieve practical implementations.

TP-WED-5B Intentional EMI and HEMP (Sponsored by TC-5) 13:30 - 15:30

Chair: Frank Sabath, Bundeswehr Research Institute for Protective Technologies and NBC Protection, Garstedt, Germany
Co-Chair: Mike McInerney, Consultant, Champaign, IL, USA

13:30 **Investigation of Protection Effects using Transient Voltage Suppressor Diodes-Based Circuits under High Power Microwave Pulses** 524

Xun Zeng, Liang Zhou, Chengrui Zhang
Shanghai Jiao Tong University, China

Abstract: This study demonstrates the protection effects using transient voltage suppressor (TVS) diodes-based circuits under high power microwave (HPM) pulses. Two types of TVS diodes were studied, and their dynamic resistances versus the input power were obtained. Five types of topology using these two TVS diodes-based circuits were designed and compared with their voltage-ampere characteristics. The dynamic resistances of each branch of two typical circuits were simulated and compared. These TVS diodes-based protection circuits were measured under HPM pulses with their protection effects recorded. The highest protection ratio of these circuits is approximately 17 to 20 dB when the input power of HPM pulses ranges from 50 to 62.5 dBm. The simulated and measured results show close correlations. This analysis is useful for further electromagnetic protections under HPM pulses.

13:55 **Non-Invasive Optimal Coupling upon Detection of a Local Change of Impedance in a Cable Network** 528

K. Brahima Yeo, Matthieu Davy, Philippe Besnier
Université de Rennes 1

Abstract: In this paper, we apply a novel wavefront shaping technique within a cable network. By manipulating an array of crosstalk sources at different locations of the network, we demonstrate experimentally a strong enhancement of the intensity at a specific wire end where an impedance change occurs. The optimal wavefront for maximal focusing is determined non-invasively using the generalized Wigner-Smith operator. Our approach relies on two successive measurements of the scattering matrix at the injection ports, before and after the change. The optimal wavefront then closely corresponds to the first eigenstate of the generalized Wigner-Smith operator. Thus, a maximum focused intensity is reached at a remote distance without cooperation of the target, opening up new perspectives in the context of electromagnetic aggressions or attacks (cybersecurity).

Best EMC Student Paper Finalist

14:20 **Susceptibility of Sensors to IEMI Attacks** 533

Louis Cesbron Lavau[1], Michael Suhrke[1], Peter Knott[2]
[1]Fraunhofer Institute for Technological Trend Analysis INT, Germany; [2]RWTH Aachen, Germany

Abstract: The use of sensors has grown dramatically in recent years and many devices rely on the information provided by them. The potential vulnerability of sensors to attacks that use Intentional Electromagnetic Interference (IEMI) needs to be investigated. These attacks can cause typical errors such as a forced restart of a system, capturing erroneous sensor data, data communication being impeded or even disrupted, as well as a complete freeze of all processes. In order to measure the susceptibility of sensors to IEMI, it is important to understand the internal mechanisms that lead to the undesired effect. This paper investigates the impact of IEMI on three separate sensors: a Barometer, a Magnetometer and Current Sense Sensor. Having full access to sensor ports and interface information may help to explain erroneous values and could lead to the development of protective measures in the future.

14:45 **Conducted Electromagnetic Pulse Testing of Digital Protective Relay Circuits** 538

Tyler Bowman[1], Ross Guttromson[1], Tim Minteer[2], Travis Mooney[2], Matt Halligan[3]
[1]Sandia National Laboratories, USA; [2]Schweitzer Engineering Laboratories Inc., USA;
[3]The Boeing Company, USA

Abstract: The electric power grid is one of the most critical national infrastructures, and determining the susceptibility of power grid elements to external factors is of significant importance for ensuring grid resilience. Reliable energy is vital to the safety and security of society. One potential threat to the power grid comes in the form of strong electromagnetic field transients arising from high-altitude nuclear weapon detonation. The radiated EM fields from these can affect the operation of electronic components via direct field exposure or from the conducted transients that arise from coupling onto long cables. Vulnerability to these pulses for many electrical components on the grid is unknown. This research focuses on conducted pulse testing of digital protective relays in a power substation and their associated high-voltage circuit breaker circuit and instrumentation transformer circuits. The relays, yard cables, power supplies, and components representing yard equipment were assembled in a manner consistent with installation in a substation to represent the pulse's propagation in the components and wiring. Equipment was tested using pulsed injection into the yard cable. The results showed no equipment damage or undesired operations for insult levels below 180 kV peak open circuit voltage, which is significantly higher than the anticipated coupling to substation yard cables.

Best EMC Paper Finalist

TP-WED-6B Power Integrity Analysis and Design 3 (Sponsored by TC-10) 13:30 - 15:30

Chair: Kinger Cai, Intel Corporation, Palo Alto, CA, USA
Co-Chair: Bumhee Bae, Samsung Electronics, Suwon-si, Korea (the Republic of)

13:30 **Reinforcement Learning for the Optimization of Decoupling Capacitors in Power Delivery Networks** 544
Seunghyup Han, Osama Waqar Bhatti, Madhavan Swaminathan
Georgia Institute of Technology, USA

Abstract: This paper proposes an advantage actor–critic (A2C) reinforcement learning (RL)–based method for the optimization of decoupling capacitor (decap) design. Unlike the previous RL-based methods used for the selection of decap types or decap placements, the proposed method enables placement and the simultaneous selection of both decap types and their placements, thereby simplifying the design process. The results show that the proposed method can provide a larger number of optimized decap design solutions compared with previous methods, and can yield decap solutions even for multi-port optimization.

13:55 **Impact of Accuracy of Capacitor ESL Values in High-Speed Power Delivery Network Design** 549
Mengxuan Li[1], Siqi Bai[2], Tamar Makharashvili[2], Albert E. Ruehli[2], James L. Drewniak[2], Daryl Beetner[2]
[1]Zhejiang University, China; [2]Missouri University of Science and Technology, USA

Abstract: While the equivalent series inductance (ESL) of multi-layer ceramic capacitors is widely used for power integrity analysis, the definition of ESL is ambiguous. Its value depends on how the capacitor is mounted on the PCB and on coupling to the nearby pads, traces, vias, and return plane. A single value for ESL is not sufficient to quantify the behavior of a capacitor in a broad number of power distribution network (PDN) designs and will lead to errors in the simulated PDN impedance. The impact of errors in ESL is analyzed in the following paper using measurements and simulations. The dependence of ESL on the layout is demonstrated using fullwave simulations. Measurements of 0402 and 0201 capacitors show that using the datasheet ESL can lead to up to 47% overestimation of the value of the total connection inductance, Labove. Test PDN structures with various stackups were analyzed to quatify the error in the total impedance due to errors in ESL. Results show that errors in ESL can lead to a 26% overestimation in the overall PDN impedance in the studied examples. Overestimation of ESL may cause more capacitors to be put on the board than needed.

14:20 **Metaheuristic Optimization of Decoupling Capacitors in a Power Delivery Network** 554
Surendra Hemaram, Jai Narayan Tripathi
Indian Institute of Technology Jodhpur, India

Abstract: In VLSI circuits and systems, it is a common practice to reduce power supply noise in power delivery networks by decoupling capacitors. The optimal selection and placement of decoupling capacitors is crucial for maintaining power integrity efficiently. This paper presents a metaheuristic technique based generic framework for decoupling capacitor optimization in a practical power delivery network. The cumulative impedance of a power delivery network is minimized below the target impedance by optimal selection and placement of decoupling capacitors using state-of-the-art metaheuristic algorithms. A comparative analysis of the performance of these algorithms is presented with the insights of practical implementation.

TP-WED-7B EMI Issues in Electric Vehicle Charging (Sponsored by SC-5) 13:30 - 15:30

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

13:30 **Interference Risks from Wireless Power Transfer for Electric Vehicles** 559
Karina Fors, Sara Linder, Peter Stenumgaard, Kia Wiklundh
Swedish Defence Research Agency, Sweden

Abstract: Wireless power transmission (WPT) for electrical vehicle (EV) charging is a relatively new application of wireless energy transfer and its potential electromagnetic (EM) interference impact on other systems has not been investigated in depth. The proposed frequencies for WPT-EV are also used by radio communication systems or services. WPT systems transfer high power and can cause out-of-band and spurious EM emissions. In the analysis, both current and proposed emission limits for WPT systems are considered.

13:55 **Susceptibility Analysis of Different Communication Technologies in Presence of High Power Charging Emissions** 564

S. Jeschke, M. Kleinen, M. Olbrich, J. Bärenfänger
EMC Test NRW GmbH, Germany

Abstract: In the context of the electrification of public and heavy duty transportation vehicles, large batteries are implemented providing driving distances of several hundred kilometers. With the increase of battery capacity also comes a significant increase of its recharge time. Thus, currently a working group deals with new specifications for Megawatt Charging Systems (MCS) to enable DC charging at power levels of a few megavolt-amperes. Apart from the intended energy flow, the power electronic systems generate unwanted broadband emissions due to switching operations of the converters. These, in return, are coupled onto the wired communication lines, routed in parallel to the DC lines inside the charging cable, causing a potential degradation of the system. Therefore, a communication technology providing a sufficient data rate while not being susceptible to the disturbances generated by the power electronics of the chargers, is mandatory. This work focusses on the comparison of Controller Area Network (CAN), 100Base-T1 and Power Line Communication (PLC) as wired communication systems regarding their suitability for this purpose. Initially, typical disturbances of DC charging stations are identified and an appropriate test setup is proposed to generate the typical disturbances. Subsequently, measurements are conducted and the impact on the communication systems at physical and transport layer are compared and evaluated, respectively.

14:20 **Methodology for Reduction of Noise Interference in Wireless Charging Implantable ECG Sensor** 569

Dawon Jeong[1], Jongwook Kim[1], Haerim Kim[1], Dongwook Kim[2], Jaehyoung Park[1], Seongho Woo[1], Sungmin Park[3], Seungyoung Ahn[1]
[1]Korea Advanced Institute of Science and Technology, Korea; [2]Yeungnam University, Korea; [3]Pohang University of Science and Technology, Korea

Abstract: According to commercialization of implantable medical devices (IMDs), wireless charging system is necessary to solve the problem of battery duration. However, magnetic field generated by the wireless charging system may cause magnetic interference to the IMDs, especially, implantable ECG sensor. Therefore, this paper proposes a methodology for reduction of the noise interference at the implantable ECG sensor with wireless charging system. The methodology is to design the pattern of the trace between the sensing electrodes of the sensor using the effect of canceling the magnetic vectors. By applying the methodology, reduction of the noise interference was verified through simulation and measurement.

TP-WED-8B Numerical Modeling and Simulation Techniques 1 (Sponsored by TC-10) 13:30 - 15:30

Chair: Bichen Chen, Facebook, Inc., Menlo park, CA, USA
Co-Chair: Qiaolei Huang, Amazon Lab126, Sunnyvale, CA, USA

13:30 **Simulation of Mode Division Multiplex Transmission Method in Shielded Four-Wire Cable** 570

Tohlu Matsushima, Takuya Sato, Yuki Fukumoto, Nobuo Kuwabara
Kyushu Institute of Technology, Japan

Abstract: A mode division multiplex transmission system that assigns signals to the eigenmodes of a transmission line was proposed for a cable that is uniform in the longitudinal direction. The transmission characteristics when the proposed method is used in a 1m long shielded untwisted 4-wire cable were verified by circuit simulation. It is shown that the proposed method enables four-channel simultaneous transmission. In addition, the proposed method significantly improves the crosstalk compared to the differential and single-ended transmission methods.

Best SIPI Paper Finalist

13:55 **Time Domain Modeling Method for the Crosstalk Analysis of Multiple Parallel Microstrip Lines** 575

Zhihong Ye, Mengzu Ru, Xiaolin Wu, Bei Tang, Yi Wang, Yifeng Yuan
Chongqing University of Posts and Telecommunications, China

Abstract: Based on a higher order finite-difference time-domain (FDTD(2,4)) method, and transmission line (TL) equations, an efficient time domain hybrid method is presented for the fast crosstalk analysis of multiple parallel microstrip lines. In this method, the per unit length (p.u.l) inductance and capacitance distribution parameters of multiple microstrip lines are solved by the empirical formulas firstly. Then, the crosstalk model of multiple parallel microstrip lines excited by lumped voltage source is established by the TL equations. Finally, the higher order FDTD (2,4) selecting large space step is utilized to discretize the TL equations to obtain the transient responses on these microstrip lines and terminal loads, which needs less mesh number and improves the computation efficiency without decreasing the calculation accuracy. A numerical example of three parallel microstrip lines excited by lumped voltage source is employed to verify the accuracy and efficiency of this presented method by comparing with the BLT equation and commercial software CST in terms of precision and time consumption. Moreover, the effects of length, height and thickness of microstrip lines on the crosstalk results are simulated and analyzed to master some valuable crosstalk principles.

14:20 **Modelling, Simulation and Optimization of High Density Capacitance Solutions for HPC Applications** 579

Sumant Srikant, Seungki Nam, Sungwook Moon
Samsung Electronics Co. Ltd., Korea

Abstract: Present day HPC (High Performance Computing) designs require a vast range of Power Integrity (PI) optimization techniques to help meet challenging specifications. In this work, we present the multiple high density capacitance options available to help achieve the target and go over the various aspects involved (modelling, system simulations and optimizations) to achieve a PI compliant HPC system PDN design

14:45 **Basic Study on a Novel FDTD Method Implemented Frequency Dispersion of PCB** 580

Taiki Kitazawa[1,2], Ren Kitahara[3], Taiki Yamagiwa[3], Jerdvisanop Chakarothai[4], Yuichi Hayashi[2], Takashi Kasuga[1]
[1]National Institute of Technology, Nagano College, Japan; [2]Nara Institute of Science and Technology, Japan; [3]The University of Electro-Communications, Japan; [4]National Institute of Information and Communications Technology, Japan

Abstract: Signal transmission degrades significantly in GHz band due to loss of substrates, which is generally frequency-dependent. In this paper, the purpose is to develop a novel FDTD algorithm which can incorporate frequency dispersion of FR-4 substrates. Complex relative permittivity is measured up to 26.5 GHz by balanced-type circular disk resonator and then used in the FDTD analyses. It is shown that numerical results are in a good agreement with measurement results using VNA over the broad frequency range, demonstrating validity of the method.

SS-WED-B Advanced Methods to Model, Evaluate, and Measure Electromagnetic Interference at Low Frequency in Transportation and Renewable Energy Systems 13:30 - 15:30

Chair: Abduselam Hamid Beshir, Politecnico di Milano, Milan, Italy
Co-Chair: Waseem Elsayed, Universiteit Twente Faculteit Elektrotechniek Wiskunde en Informatica, Zielona Góra, Lubuakie, Poland

13:30 **Assessment of Validity Conditions for Black-Box EMI Modelling of DC/DC Converters** 581
Lu Wan, Abduselam Beshir, Xinglong Wu, Xiaokang Liu, Flavia Grassi, Giordano Spadacini, Sergio Pignari
Politecnico di Milano, Italy

Abstract: Black-box modelling approaches, based on suitable sets of measurements at the output ports of the device, are often exploited for the modelling of power converters to predict their conducted emissions. However, these techniques can be effectively applied only if the device to be modelled can be approximately treated as a linear and time-invariant (LTI) system. This assumption is not necessarily satisfied by every power converter. In order to investigate suitable conditions assuring effectiveness of black-box modelling for a boost converter, this work investigates the role that the converter input capacitors and the functional inductor play in masking the inherent non-linear and time variant behavior of the switching modules, and their impact on the effectiveness of the proposed black-box model. It will be shown that preliminary measurements of the differential mode impedance of the converter can provide useful information on the feasibility of black-box modelling techniques, even in the absence of detailed information on the internal architecture of the converter.

13:55 **Behavior of COTS-Based Equipment under Ship Mains Supply Frequency Tolerance Requirements** 586
Muhammad Imam Sudrajat[1,2], Niek Moonen[1], Hans Bergsma[3], Frank Leferink[1,3]
[1]University of Twente, The Netherlands; [2]2Indonesian Institute of Sciences, Indonesia; [3]Thales Nederland B.V., The Netherlands

Abstract: The use of commercial off the shelf (COTS) devices have become a preferred strategy in ship system developments. In this work, we investigated the behavior of an uninterruptible power supply (UPS) using COTS-based equipment on a ship's power distribution system. It focuses on the implementation of IEC 60092-101 and STANAG 1008 Ed. 9 frequency tolerance requirements. One of the important benefits of this work is that it can be used as a consideration for the electromagnetic risk of integrating COTS-based equipment in an islanded power system like ships. The voltage and current behavior of the equipment under test were measured and recorded at four different points simultaneously using a multi-point measurement technique. From the analysis, it was found that when the frequency of the mains supply is deviated by 5 % the current at the UPS input is modulated and the maximum current is increased.

14:20 **Comparison of Selected Support Vector Machine Approaches for Stochastic Power Electronic Circuit Simulation with Parasitics** 591
Karol Niewiadomski, Sharmila Sumsurooah, David W.P. Thomas
University of Nottingham, United Kingdom

Abstract: This paper provides a comparison between optimization methods used for tuning the hyperparameters of Support Vector Machine model in a stochastic circuit simulation for conducted interference. The methodology is used to create a surrogate model of the frequency and amplitude of the dominant mode of the interference, which is a result of presence of parasitics in the considered switching circuit. Optimization algorithms are compared by obtaining the computational time and by computing a posteriori error of their predictions. The best optimization algorithm in the example provided here is found to be the quasi-Newton Broyden–Fletcher–Goldfarb–Shanno algorithm.

Best EMC Paper Finalist

14:45 **Using Time-Efficient Wavelet Packet Transform Decompositions to Analyze EMC Issues in Transportation Systems** 597

Ileana-Diana Nicolae, Kostic Dusan, Petre-Marian Nicolae, Radu-Florin Marinescu
University of Craiova, Romania

Abstract: The paper deals with the design, test and usability of an optimized time-efficient decomposition relying on the wavelet packet transform (WPT) when used to analyze EMC interferences. Firstly, one describes the mathematical support and implementation aspects relative to deducing cutoff frequencies from the harmonic range 40…100 that can be used to separate and analyze components of high frequencies (depending on different accepted accuracies), when using an original WPT tree, denoted by T7. An original technique was conceived in order to generate flags (0/1) associated with the terminal nodes of T7 such as to reduce the number of decompositions required for their computation. Based on them, labels with 4 values were deduced for the nodes in the upper levels of T7, in the same idea of runtime saving. Simulations on synthetic data proved runtime savings of around 67.5% for both decomposition and re-composition of T7. The technique accuracy was tested by comparing the results of „low-pass" filtering with those yielded by the Matlab toolkit used for denoising and respectively with those obtained without the labeling technique. The set of cut-off frequencies available for filtering with T7 proved to be significantly larger than that provided by the Matlab toolkit. After the successful validation stage, the method was applied on 2 real datasets acquired from the terminals of an auxiliary converter from a locomotive.

THURSDAY TECHNICAL PAPERS AND ABSTRACTS

Thursday, August 12, 2021

TP-THU-1A Power Systems (Sponsored by TC-2) 11:00 - 13:00

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

11:00 **Anticipating Common-Mode Conducted Emission of DC-DC Converter from Electric Near-Field Scan** 603

A. Boyer, N. Nolhier, F. Caignet, S. Ben Dhia
LAAS-CNRS, France

Abstract: This paper aims at proposing a method based on electric near-field measurement to estimate common-mode conducted emission produced by DC-DC converter along a cable harness. The method is evaluated on two case studies: an academic board with simple rectangular copper island and buck converter board.

11:25 **Practical Measurement of Aircraft Electrostatic Charging** 609

Per Thaastrup Jensen, Anders Struwe Mynster
Force Technology, Denmark

Abstract: As part of risk assessment for helicopter hoisting operations a measurement campaign for practical evaluation of charge voltage and energy of an aircraft was performed. An electrostatic field meter setup was developed and tested using a drone setup and a helicopter setup. The measurement capability of the setups was demonstrated as being useable. The conversion factor between static field meter reading and the helicopter to ground potential as function of distance (height above ground) for the test setup has been derived and showed an inverse square root proportionality. This allowed for a helicopter potential measurement system without conductive wires between the helicopter and ground. The generation of electrostatic charging for a helicopter was confirmed using the developed test setup although weather conditions only allowed retrieval of one data series.

11:50 **Voltage Distribution in Group-Grounded 8 x 2 Solar PV Panel Assembly during Lightning Strike** 615

Faisal Peer Mohamed[1], Wah Hoon Siew[2]
[1]Military Technological College, Oman; [2]University of Strathclyde, United Kingdom

Abstract: This paper is focused on the effect of group grounding of solar PV assemblies using both end-point and mid-point grounding on the potential rise across the solar PV panels during a lightning strike. This system consists of 16 assemblies forming an 8x2 array. Simulation has been carried out for various lightning attachment points in PSPICE using the lossy transmission line model. Voltage drop at various points in the assembly is determined for various soil resistivities. Based on the simulation results, group grounding of solar PV panels with middle grounding shows a lower voltage transient potential rise compared to end grounding.

TP-THU-2A Automotive (Sponsored by TC-2) 11:00 - 13:00

Chair: Ahalya Srikanth, Ford Motor Company, Lasalle, ON, Canada

11:00 **Forensic Analysis of Automotive Controller Area Network Emissions for Problem Resolution** 619

Yu Xian Teo, Jiaqi Chen, Neil Ash, Alastair R. Ruddle, Anthony J.M. Martin
HORIBA MIRA Ltd., United Kingdom

Abstract: Electromagnetic emissions associated with the transmission of automotive controller area network (CAN) messages within a passenger car have been analysed and used to reconstruct the original CAN messages. Concurrent monitoring of the CAN traffic via a wired connection to the vehicle OBD-II port was used to validate the effectiveness of the reconstruction process. These results confirm the feasibility of reconstructing in-vehicle network data for forensic purposes, without the need for wired access, at distances of up to 1 m from the vehicle by using magnetic field measurements, and up to 3 m using electric field measurements. This capability has applications in the identification and resolution of EMI issues in vehicle data network, as well as possible implications for automotive cybersecurity.

11:25 **Research on Non-Standard Transient Conduction Waveform Measurement of Automotive Low Voltage Electronic Components** 624

Dengyu Zhang, Shuai Hou, Yue Zhang, Li Jiang
China Automotive Technology and Research Center Co., Ltd., China

Abstract: ISO 7637-2:2011 is the main standard for electrical transient conducted immunity test of automotive lowvoltage electronic components. It provides signals of different strength and different parameters for manufacturers to verify product performance of their products. However, with the development of the automotive industry, more and more signals not included in ISO 7637-2:2011 have been found to affect automotive electrical and electronic components and threaten vehicle safety. Detailed analysis and elaboration of these nonstandard signals has been provided in this paper, which can explain many vehicle failure problems during start-up, driving and parking.

11:50 **Forensic Analysis of Automotive Data Network Traffic during Vehicle Radiated Immunity Tests** 628

Yu Xian Teo, Jiaqi Chen, Neil Ash, Alastair R. Ruddle, Anthony J.M. Martin
HORIBA MIRA Ltd., United Kingdom

Abstract: Radiated immunity testing of vehicles has the potential to cause changes in, or corruption of, in-vehicle network messages, which may not necessarily result in a directly observable effect on the vehicle. Nonetheless, such effects may have undesirable impacts that are not currently considered or are only identified if message logs are analysed post-test. Analysis of in-vehicle automotive controller area network (CAN) traffic recorded before and during radiated immunity tests has been used to identify changes in CAN messages to highlight the susceptibility of particular electronic modules or the direct corruption of CAN messages. This capability has applications in the identification and resolution of possible vehicle radiated immunity issues, as well as possible implications for automotive cybersecurity.

TP-THU-3A Advanced Methods to Model, Evaluate, and Measure Electromagnetic Interference at Low Frequency in Transportation and Renewable Energy Systems 11:00 - 13:00

Chair: Abduselam Hamid Beshir, Politecnico di Milano, Milan, Italy
Co-Chair: Waseem Wafik Elsayed, Universiteit Twente Faculteit Elektrotechniek Wiskunde en Informatica, Zielona Góra, Lubuakie, Poland

11:00 **The Influence of Commercial PC Switched Mode Power Supply Interference on the PRIME PLC Performance** 632
Waseem El Sayed[1,2], Paolo Crovetti[3], Piotr Lezynski[1], Robert Smolenski[1], Amr Madi[1,2], Flavia Grassi[4]
[1]University of Zielona Góra, Poland; [2]University of Twente, The Netherlands; [3]Politecnico di Torino, Italy; [4]Politecnico di Milano, Italy

Abstract: In the last few decades, the use of power converters has become essential in the smart grid environment. Consequently, this leads to the presence of a high-level of conducted electromagnetic interference between the smart grid elements. This paper studies the effect of two power converter modulation techniques: conventional fixed-frequency modulation and spread-spectrum modulation, on the performance of the Power Line Communication (PLC) signal. The paper presents a practical implementation of the system and discusses the results for different operating scenarios.

11:25 **Concept of Impedance Diversity for Conducted Interference Mitigation** 637
Muhammad Ammar Wibisono[1,2], Niek Moonen[1], Deny Hamdani[2], Frank Leferink[1,3]
[1]University of Twente, The Netherlands; [2]Institut Teknologi Bandung, Indonesia; [3]Thales Nederland B.V., The Netherlands

Abstract: This paper presents the concept of impedance diversity to mitigate the disturbance caused by varying impedances of non-linear loads in the time domain. Simulations were performed in LTSpice to show the concept of the impedance diversity, and measurements were performed using a speed-controlled water pump as the source of interference and PLC modems as the victim. The impact of the interference from the water pump on the PLC modem is quantifiedwith the Frame Error Rate (FER), which is calculated as the ratio between the erroneous frames and total frames sent by the PLC. The measurement result shows that the impedance mode of the PLC modem affects the frame errors caused by the interference from the water pump.

11:50 **Mode Decomposition in Multichannel Time-Domain Conducted Emission Measurements** 643
Daria Nemashkalo[1], Niek Moonen[1], Frank Leferink[1,2]
[1]University of Twente, The Netherlands; [2]Thales Nederland B.V., The Netherlands

Abstract: A conventional conducted emission test provides insufficient information in terms of differential and common mode interferences. Only the normal mode interference can be measured, which complicates the design or optimization process for a power line filter if needed. Moreover, measurements performed with conventional test receivers are time-consuming and only one measurement channel is available. In this paper, a measurement approach for digital mode decomposition is presented using multiple channels simultaneously. Results obtained with the proposed approach are compared with regular active and passive separation networks.

TP-THU-4A Transportation EMC (Sponsored by TC-7) 11:00 - 13:00

Chair: Sebastian Koj, IAV GmbH, Hannover, Germany
Co-Chair: Xinglong Wu, Politecnico di Milano, Milano, Italy

11:00 **Efficient Multichannel Time-Domain Multiaxis Loop Antenna Measurement for Frequencies below 30 MHz** 648
Denys Pokotilov[1], Robert Vogt-Ardatjew[1], Frank Leferink[1,2]
[1]University of Twente, The Netherlands; [2]Thales Nederland B.V., The Netherlands

Abstract: Conventional frequency-domain measurements are slow and are not able to grab time-varying effects, compared to time-domain measurements. Standard measurement procedures, for example CISPR 36 for electric vehicles, requires measurements at multiple positions around the equipment under test. Small resolution bandwidth in combination with long dwell time for every frequency step, results in a long measurement time. This is especially true in the lower frequency range as the bandwidths are small and thus need more measurement time. CISPR 36 requires also using only one antenna in parallel or perpendicular position to the equipment under test at once. Using time-domain measurements, the measurement speed can be already significantly improved. The effectiveness of measurements can be increased drastically if multiple antennas are positioned at several locations around the equipment under test, and multiple digitiser channels are used in parallel. A new antenna construction for multidirectional measurements in combination with a cost-efficient multichannel digitizer for time-domain measurements in the frequency range below 30 MHz is proposed in this paper. Simulation results, theoretical background and initial measurements are shown, proving that such a method is indeed viable.

11:25 **Overvoltages Induced in the Supplying Line by an Electric Railway Vehicle** 653
Petre-Marian Nicolae[1], Marian-Stefan Nicolae[1], Ileana-Diana Nicolae[1], Alexandru Netoiu[2]
[1]University of Craiova, Romania; [2]SC SOFTRONIC SA, Romania

Abstract: The paper focuses on a railway traction system. A railway vehicle, driven by a.c. three-phase asynchrnnous motors supplied thrnugh inverters from a single phase transformer, is connected to it. A brief description of the single phase a.c. (50 Hz, 25 kV) driving system is prnvided. The traction substation consists in down step voltage transformers supplied from the power system. The single phase traction system, when connected to the three-phase supplying system, intrnduces non-symmetries and cunent harmonics. A 50 km line segment from a simple supplying line was considered for simulation of overvoltages at cunent harmonics. A conect design of the rnilway vehicle driving system must meet the requirements imposed by the standard EN 50388 relative to its connection to the supplying line. Prnctical validation concerning overvoltages is discussed.

11:50 **Mathematic Modelling of Distribution of Traction Current Harmonics** 659
Tetiana Serdiuk, Kseniia Serdiuk
Dnipro National University of Railway Transport named after Academician V. Lazaryan, Ukraine

Abstract: The questions of propagation of traction current harmonics along the length on an homogeneous feeder zone at the one- and two-end power supply and the definition of their influence on code current flowing in rail lines were elaborated. The mathematic modelling of a traction supply net was carried out. The spectrum of traction current and the most dangerous harmonics influencing the track circuits were assessed for the application of electric locomotive with the PWM-invertors. To this end, the values of current and voltage on the primary winding of the traction transformer of the double-section electric locomotive were determined.

12:15 **Highly Compact Dual-Band Lumped Element Band-Pass Filters in LTCC for Avionic Systems** 663
S. Hassan Mousavi, Aref Pourzadi, Ammar Kouki
École de Technologie Supérieure, Canada

Abstract: The Dual Band Pass Filters (DBPF) with high stop band rejection at center frequencies of 122 and 330 MHz are designed. The DBPF filters are fabricated in low temperature co-fired ceramic (LTCC) technology using a lumped element approach. Measured results show close agreement with simulations with very small form factor. The overall size of the dual band-pass filter is 32 mm×18 mm×2.2 mm.

TP-THU-5A EM Information Leakage and Lightning (Sponsored by TC-5) 11:00 - 13:00

Chair: Yuichi Hayashi, Nara Institute of Science and Technology, Nara, Japan
Co-Chair: William A. Radasky, Metatech Corporation, Goleta, CA, USA

11:00 **Multiple and Reproducible Fault Models on Micro-Controller using Electromagnetic Fault Injection** 667

Vanthanh Khuat[1,2], Oualid Trabelsi[1], Laurent Sauvage[1], Jean-Luc Danger[1]
[1]Télécom Paris, France; [2]Le Quy Don Technical University, Vietnam

Abstract: In this paper, we present a method to obtain multiple and reproducible fault models on a 32-bit Micro-controller (MCU) using Electromagnetic Fault Injection (EMFI). By using different Pulse Width (PW), this method allows to obtain either a replay or skip of instructions fault model with a fault rate up to 100%. Specifically, a replay of an instruction block is obtained with the PW of 1.5 nano second (ns), whereas a skip of an instruction block is observed with the PW of 7.0 ns. With these types of fault model, an adversary may be able to retrieve secret information, as cryptographic key, by using efficient attacks. The study is carried out by enabling or disabling the cache. The only difference is that the resulting faulty block is either 32 bits when the cache is disabled or 64 bits when the cache is enabled. The impact of the Pulse Amplitude (PA) has been analyzed, and the fault model has been characterized at bit level. These results demonstrate the efficiency and the flexibility of the EMFI which should be considered for designing robust MCU.

11:25 **Machine Learning Voice Synthesis for Intention Electromagnetic Interference Injection in Smart Speaker Devices** 673

Tanner Fokkens, Zhifei Xu, Omid Hoseini Izadi, Chulsoon Hwang
Missouri University of Science and Technology, USA

Abstract: This work presents the effectiveness of using machine learning (ML) synthesized voice samples to control smart speaker devices through radiated intentional electromagnetic interference (I-EMI). In previous works, the feasibility of using IEMI to control smart speaker devices was shown. However, devices that are trained to only recognize a single person's voice or only execute certain commands from that person will not be as susceptible to this attack. By training a generative adversarial network (GAN) using samples of the target's voice, this security feature can be bypassed directly, increasing the feasibility of the attack.

11:50 **The Application of the Duffing Oscillator to Detect Electromagnetic Leakage Emitted by HDMI Cables** 678

Ye Li[1,2], Wei Fan[1], Weiqing Huang[1,2]
[1]Chinese Academy of Sciences, China; [2]University of Chinese Academy of Sciences, China

Abstract: HDMI (High Definition Multimedia Interface) cables could emit EM (Electromagnetic) leakage when transmitting video signals, such that it could cause sensitive information leakage, leading to a severe security threat. However, the radio signals are too weak to be detected due to the complex electromagnetic environment. Therefore, we propose a novel non-linear detection method based on the Duffing oscillator, which is immune to noises and sensitive to periodic signals, and can even detect signals with very low SNR (Signal-to-Noise Ratio). In this paper, we first verify this method through simulation. Then this method would be applied to real signal detection in a shielded room. Overall, we achieve detecting real signals and successfully verify this method.

12:15 **On the Calculation of Electrical Surges in Underground Cables due to a Direct Lightning Strike** 682

Susana Naranjo-Villamil[1], Christophe Guiffaut[2], Julien Gazave[1], Alain Reineix[2]
[1]EDF Group, France; [2]Institut de recherche XLIM, France

Abstract: When a building is struck by lightning, the lightning current travels through its reinforcement and along the lightning channel, generating a transient electromagnetic field. A part of the current reaches the ground termination system and the other part is distributed among the cable ducts and soil-containing conductors leading away from the building. Electrical surges can be induced by the transient fields, the coupling between the structures, and a partial lightning current entering the cables via its grounding. Since the Lightning Protection System (LPS) is generally designed based on the worst-case scenario, a parametric study is conducted using the FDTD method to identify the configurations in which the surges in the cables interconnecting two buildings are maximized. The results are compared to the case in which the cables are grounded at the entrance to the buildings. The direct connection to the reinforcement increases the currents and shifts the resonances towards higher frequencies.

TP-THU-6A Computational Electromagnetics II (Sponsored by TC-9) 11:00 - 13:00

Chair: Yansheng Wang, Google LLC, Santa Clara, CA, USA

11:00 **Nearfield to Farfield Transformation of a Small Patch Antenna by using Plane Wave Spectrum Method** 688

Tao Wang[1], Xinxin Tian[2], Wei Zhang[1], Xin Yan[1]
[1]Missouri University of Science and Technology, USA; [2]Guangdong University of Technology, China

Abstract: Modern planar scanning techniques in the near-field measurement of antennas and scatters are based on the planewave spectrum (PWS) representation of the field. The theoretical development of planar near-field antenna measurements is usually based on this plane wave spectrum representation of electromagnetic fields. This work provides a detailed derivation of the coordinate-free form of the near-field to far-field transform that is central to the planar near-field measurement methodology. A patch antenna that works at 10GHz is designed and used as the validation example. Results from 3D electromagnetic simulation and PWS method correlate well demonstrating that PWS can be used to predict the antenna's far-field once the nearfield measurement is completed. This PWS method is suitable for quickly characterizing antennas used in nowadays's mobile system without conducting antenna measurement in an anechoic chamber. In this paper, the PWS method is revisited and demonstrated that it can be used to analyze the miniaturized antenna used in mobile systems.

11:25 **Efficient Computation of Partial Elements for Non-Orthogonal PEEC Meshes** 692

Luca Di Angelo[1], Daniele Romano[1], Giulio Antonini[1], Ivana Kovačević-Badstübner[2], Ulrike Grossner[2]
[1]University of L'Aquila, Italy; [2]ETH Zurich, Switzerland

Abstract: The partial element equivalent circuit (PEEC) method has proven to be able to provide a valid solution method of the Maxwell's equations in the time as well as the frequency domain. The extension of the basic PEEC approach to non-orthogonal geometries has significantly expanded the applicability of the method. The computation of interaction integrals is typically performed numerically and it results to be time-consuming. This work presents a new flexible and accurate computational method for determining the partial inductances in the quasi-static limit. More specifically, an automatic decomposition of the non-orthogonal geometries into parallelepipeds is proposed so that analytical formulas which are available in this case can be used. The accuracy, and speed of the proposed method is compared with standard integration routines exhibiting a satisfactory accuracy and reduced computation time.

11:50 **Efficient and Flexible Huygens' Source Replacement of mm-Scale Human Brain Implants** 697

Cheng Yang, Morten Schierholz, Eileen Trunczik, Leon Maximilian Helmich, Heinz-D. Brüns, Christian Schuster
Technische Universität Hamburg, Germany

Abstract: Implants for monitoring or stimulation of nervous activity in the human brain offer multiple challenges for electromagnetic compatibility. Both the electromagnetic emission into the surrounding brain tissue and the electromagnetic interference with other implants have to be tightly controlled. From a computational perspective the hierarchical structure and the frequency dependence of the brain tissue as well as the high aspect ratio between implant features and the size of the brain offer multiple challenges. Here, we propose an approach based on the Huygens' principle in combination with a method of moments to overcome part of these challenges with respect to the computation of possible interference between implants. The approach makes use of the fact that due to high losses in the brain tissue at frequencies below 1 GHz the interaction between implants can be characterized as weak coupling. Apart from being computationally more efficient the proposed approach is also flexible in the sense that different victim implants can easily be computed. Results for a realistic head model show good agreement between this approach and a traditional full-wave simulation.

Best EMC Paper Finalist

12:15 **The Impact of Shimming Strategies and Scan Regions on RF-Induced Heating near a Bone Screw under 3T MRI** 703

Xiaolin Yang, Jianfeng Zheng, Ji Chen
University of Houston, USA

Abstract: This paper investigates the impact of shimming strategies and scan regions on the radiofrequency (RF) induced heating near a bone screw in the ASTM phantom under 3T magnetic resonance imaging (MRI). Three shimming strategies, i.e. B1 homogeneity, focusing performance, and power efficiency, and two scan regions, head and chest, were studied. The peak RF-induced heating in terms of local specific absorption rate (SAR) is compared among quadrature source excitation and the three shimmed source excitations obtained by using a particle swarm optimization method. For the scan region of the head, all three shimming strategies can reduce the RF-induced heating. For the scan region of the chest, the shimming strategies of B1 homogeneity and focusing performance can reduce the peak SAR while the shimming strategy of power efficiency increases the peak SAR.

TP-THU-7A Machine Learning/Cloud Computing 2
(Sponsored by TC-9 and TC-10) 11:00 - 13:00

Chair: Tianjian Lu, Google, Mountain View, CA, USA
Co-Chair: Hanfeng Wang, Google Inc, Mountain View, CA, USA

11:00 **Accelerating the Simulation of Finite Difference Time Domain (FDTD) with GPU** 707
Yongjun Liu, Jing Wang, Jian Liu
Cadence Design Systems Inc., USA

Abstract: In this paper, we discuss the implementation of three dimensional FDTD method to Nvidia's CUDA architecture. Finite-difference time-domain is a numerical analysis technique used for modeling computational electrodynamics. Since it is a time-domain method, FDTD solutions can cover a wide frequency range with a single simulation run, and treat nonlinear material properties in a natural way. Because FDTD requires the grid must be sufficiently fine to resolve both the smallest electromagnetic wavelength and the smallest geometrical feature in the model, it may result in very long simulation time. OpenMP, MPI, SIMD technique can be used to speed up the simulation. Another technology, Nvidia's CUDA, allows the time to be reduced a lot.

11:25 **A Modified Genetic Algorithm for the Selection of Decoupling Capacitors in PDN Design** 712
Jack Juang[1], Ling Zhang[1], Zurab Kiguradze[1], Bo Pu[1], Shuai Jin[2], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]Google Inc., USA

Abstract: Decoupling capacitors are used to provide adequate and stable power for integrated circuits in printed circuit boards (PCB). For complicated and large designs, it is difficult to select capacitors to meet voltage ripple limits while also minimizing cost because the search space is too large. In this work, a new genetic algorithm (GA) is proposed for the selection and placement of capacitors to meet a target impedance using as few capacitors as possible. The GA is centered around controlling the number of unused port locations in the GA population solutions, with the result of smoothing out the GA convergence and speeding up the convergence rate. A result comparison is made of the proposed GA against other algorithms and found the GA competitive if not better for the select test cases.

Best SIPI Student Paper Finalist

11:50 **Reinforcement Learning-Based Decap Optimization Method for High-Performance Solid-State Drive** 718
Jaeyoung Shin, Soomin Kim, Kihyun Sung, Hyunwoo Jung, Jinwook Song, Wooshin Choi, Hyungjong Ko, Junghwan Choi, Sanghyun Lee
Samsung Electronics Co., Ltd., Korea

Abstract: In this paper, we propose an improved optimal decoupling capacitor (decap) design method based on Qlearning algorithm for high-performance solid-state drive (SSD). The proposed method selects optimal decap combinations that satisfies target impedance with minimum decap number. Based on Q-learning algorithm combined with transmission line theory, optimal decap combinations of power distribution network (PDN) can be provided. The proposed method was verified with voltage ripple measurement and PDN impedance simulation using SSD for high-performance server application. Conventional decap optimization method are using complex and time-consuming analytical tool with power integrity (PI) domain expertise. However, the proposed method requires only the PDN and decap information along with a simple Q-learning model without PI knowledge, providing faster and accurate results than full search optimization method. For example, in 21 decaps combination problem, the proposed method's computing time consumes only few minutes, 89.09 sec, which is significantly reduced result compared with the conventional full search simulation. Therefore, we expected the proposed method can be widely used to solve for decap optimization problem with complex PDN.

TP-THU-8A Evaluation and Simulation of EMI in Wireless Systems (Sponsored by TC-12) 11:00 - 13:00

Chair: Karen Burnham, Electro Magnetic Applications, Inc., Lakewood, CO, USA
Co-Chair: Gang Feng, General Test System, Inc., Waterloo, Ontario, Canada

11:00 **Estimating Regions of Wireless Coexistence with Gaussian Process Surrogate Models** 722
Jacob D. Rezac[1], Noel C. Hess[2], Jason B. Coder[1]
[1]National Institute of Standards and Technology, USA; [2]Univeristy of Colorado-Denver, USA

Abstract: Simultaneous coexistence of multiple wireless communications systems sharing the same spectrum is critical for the success of modern and future communications. We develop a technique for estimating regions of wireless coexistence (RWC) – the transmission configurations of each of the wireless systems which permit coexistence – based on measurements of key performance indicators (KPIs) of those systems. In this article we focus on two-way coexistence tests, which aim to determine the impact each of the communications systems have on each other. The new technique is based on a Gaussian process surrogate model of the unknown transmission-configuration-to- KPI functions. We introduce a sequential design of experiments based on this surrogate model which is designed to reduce the number of measurements necessary to reach a highly-accurate estimate of a RWC. On an illustrative example, this technique reduces the average number of required measurements by over 40% compared to a baseline experimental design. Similar results are achieved for a measurement-informed simulation based on a coexistence test between an Bluetooth Low Energy device and an IEEE 802.11n Wi-Fi devices.

11:25 **Simulation based EMI Prediction for High Speed Differential Signals** 728
Qiaolei Huang, Jaswanth Vutukury, Deepak Pai, Gary Rara, Akshay Mohan, Jagan Rajagopalan
Amazon Lab126, USA

Abstract: Electromagnetic Interference (EMI) failure is a common occurrence in electronic devices. Failing to comply with FCC/CE requirements set by government agencies delays the product time to market. Besides following proper design guidelines of layout, grounding, shielding, filtering, etc., using simulation to predict EMI failures during early design stage will greatly save time and cost. In this paper, EMI from a practical product with multiple pairs of high speed differential signals are studied. The power spectrum density of both common mode and differential mode on those differential pairs are measured. By combining with noise source information and simulated far field transfer functions, the simulated EMI can be obtained. The simulation results are later compared with measured results to show the accuracy of simulations.

11:50 **DoE-Based Evaluation of the Impact of the Twisted-Pair-Cable Parameters on the Wireless Communication Performance** 733
Oussama Sassi[1], Pascal Hervé[2], Moncef Kadi[3]
[1]Volkswagen AG, Germany; [2]CSA Group Bayern GmbH, Germany; [3]ESIGELEC, France

Abstract: In the automobile industry world, connectivity and autonomous driving have become a new trend. The next generation of vehicles should support the new communication technologies for infotainment systems and streaming services. In addition, for the autonomous deriving, the vehicles should be equipped with advanced driving assistance device and highspeed network. That is why the requirements for ensuring high performance and robustness especially of the wireless communications systems in modern connected vehicles are significantly greater compared to systems from even a couple of years ago. The electronic devices and the data network in the vehicle emit electromagnetic interference and can disturb the communication systems. This paper presents a calculation approach to evaluate the electromagnetic field radiated from a twisted pair cable. Based on an equivalent wire model, we calculate wire currents to perform the radiated electromagnetic field. Application of the Design of Experiment DoE approach can be used to analyze the influence of wire parameters and the results help to characterize the cable impedance. This enables the estimation of the Over-the-Air packet error rate obtained in a typical radiated test setup. The results can be used to evaluate the performance of the communication system in the early phase of vehicle project.

Best EMC Paper Finalist

12:15 **Intelligent Energy Saving Solution of 5G Base Station based on Artificial Intelligence Technologies** 739

Rumeng Tan[1], Tong Wu[2], Ying Shi[1], Yanpu Hu[3]
[1]China Telecom Corp Ltd., China; [2]National Institute of Metrology, China; [3]China Academy of Information and Communications Technology, China

Abstract: This paper introduces the basic energy-saving technology of 5G base station, and puts forward the intelligent energy-saving solutions based on artificial intelligence (AI) and big data technologies to forecast and optimize the management of 5G wireless network energy consumption. With the continuous innovation and evolution of 5G energy-saving technology based on AI and other emerging technologies, the operating expense (OPEX) of mobile network operators will be effectively reduced.

SS-THU-A Risk-Based EMC 11:00 - 13:00

Chair: Tim Claeys, Katholieke Universiteit Leuven, Brugge, Belgium
Co-Chair: Vasiliki Gkatsi, Universiteit Twente, Enschede, Netherlands

11:00 **A Methodology for Estimating the Criticality of Energy Infrastructures in the Context of IEMI** 743

Fernando R. Arduini[1,2], Marian Lanzrath[1], Thorsten Pusch[1], Michael Suhrke[1], Heyno Garbe[2]
[1]Fraunhofer Institute for Technological Trend Analysis INT, Germany;
[2]Leibniz Universität Hannover, Germany

Abstract: The power system has been undergoing a modernization process due to the insertion of Smart Electronic Devices (SEDs) and advanced communication systems. However, along with the advances allowed by such modernization, new security threats to the electricity sector have emerged. One of these threats is known as Intentional Electromagnetic Interference (IEMI), where criminals misuse high power electromagnetic sources aiming to interfere with and disrupt critical devices belonging to energy infrastructures. In this perspective, the development and enhancement of IEMI threat analysis strategies oriented to the electricity sector are relevant to guarantee the security and reliability of the power system. Therefore, this paper proposes a user-friendly methodology to classify energy infrastructures' criticality with respect to IEMI targeting grid operators willing to address security issues in their energy facilities. The application of the methodology is exemplified with a typical transmission substation part of the power system.

11:25 **Risk-Based EMC System Analysis Platform of Automotive Environments** 749

Vasiliki Gkatsi[1], Robert Vogt-Ardatjew[1], Frank Leferink[1,2]
[1]University of Twente, The Netherlands; [2]Thales Nederland B.V., The Netherlands

Abstract: Constantly on-going changes in new technologies applied in modern vehicles introduce many challenges in the automotive electromagnetic compatibility engineering. So far, the currently implemented EMC requirements and methods present sufficient performance. However, they do not illustrate thoroughly an actual automotive environment. They tend to focus on the EMC validation of each system individually without always considering other possible influential factors and coexisting systems. Aim of this paper is to introduce an EMC system investigation platform using a simplified model that demonstrates an automotive environment in order to point out the importance and scale of significance of various parameters. In this paper, the structure of the introduced three-point model is first described and explained. Then, experiments are presented in order to point out the influence of selected macroparameters. Finally, suggestions for further extension of the model through Monte Carlo simulations are proposed with a brief presentation of a modelling procedure.

11:50 **Vulnerability of Wireless Smart Meter to Electromagnetic Interference Sweep Frequency Jamming Signals** 755

Arash Nateghi, Martin Schaarschmidt, Sven Fisahn, Heyno Garbe
Leibniz Universität Hannover, Germany

Abstract: The installation and use of smart home technology that uses wireless communication channels, according to the 802.11 standard series, is rapidly increasing. This article discusses the effect of Electromagnetic Interference Sweep Frequency Jamming Signal applied to a wireless smart meter installed in a three-phase domestic and light commercial electricity distribution board. More specifically, a method of frequency jamming signal generation technique, jamming signal radiation and its interference measurements method are explained in this paper. Then, the impact of disturbances are discussed and mitigation mechanisms such as construction material shielding, digital filtering and a systematic approach of electromagnetic risk assessment are given.

12:15 **Risk Assessment Approach for EM Resilience in Complex Systems using Bayesian Networks** 760

Lokesh Devaraj[1], Alastair R. Ruddle[1], Alistair P. Duffy[2], Anthony J.M. Martin[1]
[1]HORIBA MIRA Ltd., United Kingdom; [2]De Montfort University, United Kingdom

Abstract: Current trends in the automotive industry are reshaping the architectures and electromagnetic characteristics of road vehicles. Increasing electrification and connectivity are enabling considerable packaging flexibility and leading to radically different electromagnetic environments. At the same time, increasing automation of driving functions will require unprecedented levels of system dependability. However, existing EMC engineering processes were developed in a very different world of low system complexity and incremental technological development. In order to adapt to rising system complexity and the increasingly rapid pace of technological change, it is considered that a more agile risk-based approach is better suited to ensure the electromagnetic resilience of future vehicles and other complex systems. This paper outlines a Bayesian network approach that allows the combination of both technical and nontechnical aspects in assessing the likelihood of issues that could lead to system-level risks. This approach could be used to help achieve EM resilience from the earliest stages of product development, where the detailed information required to undertake detailed risk assessment is generally unavailable.

TP-THU-1B Immunity (Sponsored by TC-2) 13:30 - 15:30

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

13:30 **Examination of the RF Output Power on Electromagnetic Susceptibility Tests of the Radio Equipment** 765

Umut Doğan, Ugur Sukru Ceran, Kadir Arslan
Vestel, Turkey

Abstract: In recent years, wireless smart devices which use radio frequencies are emerging increasingly in all areas of our life. This article presents the influences of radio frequency (RF) output power level on RF electromagnetic field and RF common mode immunity tests of wireless radio equipment. According to the ETSI EN 301 489-17, the RF output power level should be adjusted to the maximum level during the tests. However, the use of RF output power level in daily life may not work at the maximum or fixed level in a wireless device. In order to observe the effects on test results, RF common mode and RF electromagnetic field immunity tests are performed at the maximum RF output power level as stated in the standard and at different RF output power levels as independent from the standard. The results of the measurements are compared with each other at the certain frequencies.

13:55 **Design of a Reference Device for Burst Immunity Interlaboratory Comparison** 771

Emrah Tas, Frédéric Pythoud
Swiss Federal Institute of Metrology, Switzerland

Abstract: In order to improve and to standardize the quality in EMC testing services, increasing efforts have been given in the organisation of interlaboratory comparisons and proficiency testing. Several devices have been designed and realized for this purpose for various emission and immunity tests. In this publication, we pursue this development and propose a new reference device for interlaboratory comparisons and proficiency testing services in electrical fast transients/burst immunity testing according to IEC 61000-4-4. The device is equipped with adapted detecting circuitry to measure and record the burst pulses and relevant parameters for offline evaluation. The concept and the architecture of the device and its operation principles are explained in detail. The preliminary evaluation of its stability and linearity is performed and its capabilities to detect errors in a typical testing scenario is explained.

14:20 **Study on Noise Distribution Generated from Multiple LED Lights Installed on Duct Rail** 777

Ifong Wu, Kaoru Gotoh
National Institute of Information and Communications Technology, Japan

Abstract: The radiation noise from LED lights in the simultaneous use of multiple LED lights is not a simple linear increase with respect to the number of LED lights. The amount of increase in radiation noise becomes more complex with frequency as the number of LED lights increases. To clarify the radiation noise characteristics from multiple LED lights, a radiation model was simulated when multiple LED lights were connected to the same power line. In this study, the change in noise distribution on the power line depending on the installation position of multiple LED lights was investigated to clarify the relationship between the radiation noise and LED lights on the power line.

TP-THU-3B Low-Frequency EMC Issues (Sponsored by TC-7) 13:30 - 15:30

Chair: Petre-Marian Nicolae, University of Craiova, Craiova, Romania
Co-Chair: Douglas Aguiar do Nascimento, University of Zielona Góra & University of Twente, Zielona Góra, Poland

13:30 **Performance of Representative Transformer-Less Topologies for Photovoltaic Applications** 778
Duc-Thanh Do, Holger Hirsch
University of Duisburg-Essen, Germany

Abstract: This paper faces the effectiveness of transformerless topologies for small-scale photovoltaic (PV) applications. The main issues of leakage current and common-mode (CM) voltage are adapted by some representative proposed topologies as full-bridge, H5, H6, HERIC. Due to the lack of knowledge, the CM noise source should be internally reduced. Meanwhile, the performance of advanced transformer-less topologies have been reproduced analytically and analyzed for common-mode and differential-mode components. Similarly, the reduction of the harmonic emission can be clarified by considering different control strategies of pulse width modulation (PWM) as random PWM schemes. Based on simulation results, the deduced conclusions are produced to recommend the disturbance properties of single-phase PV applications.

13:55 **Square Wave Shaper with Filter Characteristics to Reduce EMI and Passive Component Count** 783
Rahul Nadgouda[1], Herbert Hackl[1,2], Bernd Deutschmann[1,2]
[1]Technische Universität Graz, Austria; [2]Silicon Austria Labs GmbH, Austria

Abstract: Filters and pulse shapers are widely used to reduce Electromagnetic Interference (EMI) by shaping the signal waveform. As the order of filter increases so does the silicon area requirement, which becomes an issue specially for low frequency applications. This paper outlines a methodology to implement a square wave shaper which approximates low-pass filter (LPF) characteristics using squaring circuits, with the aim of reducing component count for significant gain in silicon area. The shaper is analyzed in comparison to an ideal Bessel LPF and resulting differences are presented. Lastly, area savings are estimated and an outline of possible implementation of the shaper on schematic is presented.

14:20 **Magnetic Field Produced by Current in Typical Planar and Three-Dimensional Elements of Metal Structures** 787
Melania Pavlova, Petr Vorshevskii, Alexander Worshevsky
Saint-Petersburg Marine Technical University, Russian Federation

Abstract: Results of low frequency modeling for some shapes of metal structures with current make it possible to predict the magnetic strength around the structure. The obtained graphs and calculation model are useful for EMC evaluation and education.

14:45 **How to Earn Money with an EMI Problem: Static Energy Meters Running Backwards** 788
Tom Hartman[1], Bas ten Have[1], Niek Moonen[1], Frank Leferink[1,2]
[1]University of Twente, The Netherlands; [2]Thales Nederland B.V., The Netherlands

Abstract: The increased use of non-linear appliances in households has resulted in several conducted electromagnetic interference issues, such as misreadings of static energy meters used for billing purposes of the households' energy consumption. In this paper a case is presented where a static energy meter indicates a power generation, while power is actually being consumed. A perceived power generation of more than 430W is measured by a static energy meter installed in a household when a television with a commercial off the shelf remote controlled switch with dimming functionalities consumed 21W. The same situation is reproduced in a controlled lab environment, to eliminate possible influences of other appliances in the grid, which confirmed the on-site results. The current waveforms causing this supposed generation of power are investigated and it is observed that the phase firing angle of the current pulse drawn by the load in combination with the commercial off the shelf remote controlled switch affects the metering errors and determines whether the errors indicate a false generation, a too high consumption of power, or no error at all. A combination of the household equipment and a basic unloaded switched mode power supply in conjunction with two remote controlled switches resulted in a perceived power generation of more than 600W. Having these loads connected for the entire day would counteract the total consumption of an average household and could even ”generate” energy, and thus generate money for the consumer.

TP-THU-5B ESD and Smart Grid IEMI (Sponsored by TC-5) 13:30 - 15:30

Chair: Joost Willemen, Infineon Technologies, Munich, Germany
Co-Chair: Mike McInerney, Consultant, Champaign, IL, USA

13:30 **Two Algorithms Analyzing Discharge Parameters based on Neural Network and Wavelet Transformer** 794

Fangming Ruan[1], Sheng Guan[1], Yang Meng[2], Lan Yin[1], Yanli Chen[1], Kui Zhou[1]
[1]Guizhou Normal University, China; [2]Qilu University of Technology, China

Abstract: Special relationship exists between environmental conditions and discharge characteristic parameters in electrostatic discharge (ESD) events. The neural network can explore the potential law between input and output if taken discharge condition parameters as a neural network input. Characteristics of discharge results are affected by environmental conditions, and hence discharge parameters can be described with the output of a neural network. Two algorithms of artificial intelligence were used to analyzing discharge results in electrostatic discharge. The nonlinear relationship between discharge conditions and discharge effect may be a new potential discharge feature. Noise in discharge current can be suppressed with wavelet and Kalman filter method. The characteristics measured in the real experiment were compared with the prediction parameters from the neuronetwork calculation result. According to the prediction data, the discussion was conducted on correctness accuracy and the discharge process trend analysis.

TP-THU-6B Aerospace/Automotive Computational Electromagnetics (Sponsored by TC-9) 13:30 - 15:30

Chair: Scott Piper, General Motors Corp, Canton, MI, USA

13:30 **Estimating Fields in Spacecraft Cavities: Experimental Validation of Finite-Difference Time-Domain and Power Balance Computational Tools** 798

Javier J. Pazos[1], Jeff Phillips[2], Eric Miller[1], Timothy McDonald[1], Jennifer Kitaygorsky[1]
[1]Electro Magnetic Applications, Inc., USA[2]Jeff Phillips Consulting, USA

Abstract: Electromagnetic fields in representative spacecraft cavities were successfully predicted using finite-difference time-domain and power balance computational tools. Results were validated with measurements of two test articles, showing excellent correlation in shielding effectiveness from 300 MHz to 18 GHz. The tools and methods presented here can serve as part of a toolkit to rapidly estimate shielding effectiveness, the impact of payloads, and overall fields in spacecraft cavities.

13:55 **The Impacts of Solar Cell Size, the Spacing between Current-Collecting Fingers, and Switched Strings, on the Electromagnetic Radiation from Solar Panels for Satellite Applications** 804

David Norte
Ball Aerospace, USA

Abstract: Conventional solar panels are comprised of a given number of rows and columns of solar cells such that the overall array of solar cells forms a rectangular pattern. In applications of solar panels, it is sometimes necessary to regulate the current extracted from a solar panel by switching the strings of solar cells within the panel. This switching action can also extend the life of the solar cells by preventing a given cell from being actuated 100% of the time.

14:20 **Black-Box DC-DC Integrated Circuit Modeling towards Design for EMC in Automotive Electronics** 810

N. Ishibashi[1], L.K. Manepalli[2], D. Nath[2], B.P. Nayak[2], S. Kadam[2], D. Gope[2,3]
[1]Indian Institute of Science, India; [2]Panasonic Corporation, Japan; [3]Simyog Technology Pvt. Ltd., India

Abstract: Recently, IoT and sensor networks have developed rapidly and design for EMC has become challenging. In automotive electronics, V2X technology that enables Advanced Driver Assistance Systems (ADAS) has led to stringent EMC requirements for in-vehicle equipment. Therefore, in addition to noise countermeasure technology, it is becoming important to predict EMC risk. Simulation is an effective method to analyze and monitor EMI/EMC performance right from the early design stage, such that possible upstream problems can be addressed in a cost-effective manner. A primary challenge towards such a simulation methodology is the non-availability of models for Integrated Circuits which are the sources of noise. In this work, by measuring the EMC characteristics of the DC-DC converter IC from outside, a macro-model is created without including any proprietary information of the IC interior. This is combined with an electromagnetic simulation framework to generate system-level EMC results. The proposed model-based simulation methodology is validated with measurements for a DC-DC converter system.

14:45 **Extraction of Single Cell Impedance from within a Battery Pack by Virtual De-Embedding: A Proof of Concept** 815

Herbert Hackl[1,2], Martin Ibel[1,2], Juliano Mologni[3], David J. Pommerenke[1,3], Bernhard Auinger[1,2]
[1]Silicon Austria Labs GmbH, Austria; [2]Technische Universität Graz, Austria; [3]ANSYS Inc., USA

Abstract: Models for the simulation of battery pack impedance are usually composed of models for the individual cells which the pack is made of, linked with a description of cell-to-cell and cellto- housing coupling. Thus, conventional battery pack modeling requires knowledge of the cell first, which is usually obtained by measurement on single cells. In this work, a solution to the inverse problem is described, i.e. measurement of the pack is available and impedance of the cells within shall be derived. Therefore, the pack's impedance needs to be partitioned into the cells' 'internal' impedances and exterior coupling effects, like mutual inductance. Proposed method employs 3D simulation of the battery pack with surrogate cell models. Measurement data and simulation model are then combined to find individual cell impedances by fitting the simulated pack impedance to the measured. For validation of the approach, single cell impedances obtained by virtual deembedding from different measurement setups are compared and related to reference results from literature. Considered frequencies range from 9 kHz to 1 GHz. This paper proves usability of the concept by using two 18650 Lithium-ion cells connected in series.

TP-THU-7B High-Speed Link/Bus Design 1 (Sponsored by TC-10) 13:30 - 15:30

Chair: Bo Pu, Missouri University of Science and Technology, Rolla, MO, USA
Co-Chair: DongHyun Kim, Missouri University of Science and Technology, Rolla, MO, USA

13:30 **Far-End Crosstalk Control Strategy for High-Volume High-Speed PCB Manufacturing: The Concept of Critical Resin Content Percent** 820

Yuandong Guo[1], Shaohui Yong[1], Yuanzhuo Liu[1], Jiayi He[1], Bo Pu[1], Xiaoning Ye[2], Albert Sutono[2], Vijay Kunda[2], Amy Luoh[2], DongHyun Kim[1], Jun Fan[1]
[1]Missouri University of Science and Technology, USA; [2]Intel Corporation, USA

Abstract: Far-end crosstalk (FEXT) can reduce the eye opening and eventually decrease the maximum data rate that can be transmitted through the high-speed interconnections. Therefore, FEXT is an important concern in high-speed digital design. The contributors of stripline FEXT include the dielectric inhomogeneity and the proximity effect. In addition, a characterization technique for the effective relative dielectric constant (Dk) of both core and prepreg has been proposed recently for the analysis of the inhomogeneous medium and induced FEXT. In our study, the FEXT levels of the striplines on various printed circuit boards (PCBs) are measured and compared. It is brought to our attention that for some PCB striplines sharing the same stack-up, same PCB material, and manufactured by the same vendor, the corresponding measured FEXT magnitudes of these coupled single-ended traces could vary drastically, which may bring great challenges to the hardware engineers about FEXT level control during the highvolume PCB production phase. In this paper, the root cause of this issue is investigated and analyzed. The "critical resin content percent" concept is proposed to explain the variations in the Dk values of prepreg that result in the FEXT level variance. The full wave simulations are conducted to identify the "critical glass weave". A measurement-based statistical analysis is performed to verify the "critical resin content percent" concept. A design guideline for FEXT control strategy in the high-volume PCB manufacturing is presented based upon this investigation.

13:55 **Far-End Crosstalk Analysis for Stripline with Inhomogeneous Dielectric Layers (IDL)** 825

Yuanzhuo Liu[1], Shaohui Yong[1], Yuandong Guo[1], Jiayi He[1], Liang Liu[1], Nick Kutheis[1], Albert Sutono[2], Vijay Kunda[2], Amy Luoh[2], Yunhui Chu[2], Xiaoning Ye[2], DongHyun Kim[1], Jun Fan[1]
[1]Missouri University of Science and Technology, USA; [2]Intel Corporation, USA

Abstract: Far-end crosstalk (FEXT) noise is a critical factor that affects signal integrity performance in high-speed systems. The FEXT level is sensitive to the dielectric inhomogeneity of the stripline in fabricated printed circuit boards (PCB). Stripline is typically modeled as a 2-layer model with core and prepreg layers. However, in reality, the stripline is laminated by multiple inhomogeneous dielectric layers (IDL). The dielectric layers of the stripline are laminated with epoxy resin and glass bundles. The dielectric permittivity ( ) of the epoxy resin and glass bundles are different, which causes the inhomogeneity of the dielectric layers while also increasing the FEXT magnitude. Therefore, a typical 2- layer structure is inaccurate to model the FEXT. In this paper, the stripline model is constructed with the core, prepreg, and resin pocket layers. To analyze the stripline with three IDL, a practical superposition method is proposed. A design guideline to mitigate the FEXT level in the stripline design is proposed based on the method.

Best SIPI Student Paper Finalist

14:20 **The Simulated TDR Impedance in PCB Material Characterization** 831

Yuandong Guo[1], DongHyun Kim[1], Jiayi He[1], Shaohui Yong[1], Yuanzhuo Liu[1], Bo Pu[1], Xiaoning Ye[2], Jun Fan[1]

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

Abstract: High-speed PCB design for signal integrity (SI) is about feasible material selection, trace geometry determination and optimization of discontinuities, where the accurate PCB material characterization is essential since incorrect material properties may lead to misleading results and wrong design descisions. The previous studies have revealed that the simulated time-domain reflectometry (TDR) impedance in material characterization, which is based upon the transmission-line-based methods, is erroneous when compared to the measured value, although a good agreement between simulation and measurement in the frequency domain can always be reached. In addition, it is also shown that achieving a satisfactory correlation in both transmission phase and trace impedance is a challenge for SI engineers. This implies that the transmission-line-based approaches, which are widely used in industries, are not perfect and that the extracted PCB material properties are not accurate enough. In this paper, a step-by-step investigation is performed and demonstrated to disclose the root causes of the TDR impedance discrepancy. It is found that the disagreement in TDR impedance is contributed by multiple factors which need to be taken into consideration during material characterization. The improved simulation result exhibits excellent consistency with the measured trace impedance. The suggestions to hardware designers on how more accurate PCB dielectric properties can be obtained are given by addressing the TDR impedance discrepancy issue.

14:45 **Application of IEEE-370 for PCIe Interconnect Test with 2X-Thru De-Embedding** 835

Se-Jung Moon, Xiaoning Ye, Kai A. Wang, Umair I. Khan, Timothy Wig

Intel Corporation, USA

Abstract: When PCIe 5.0 CEM connector testing result came out differently depending on the 2X-Thru de-embedding tools, we performed the tool accuracy test adopting the IEEE 370 specification and the framework. The key to success in this test was to ensure that the actual values of DUT (Device Under Test) were known and the qualities of data in use were good. Hence, we utilized PCIe 5.0 CEM connector and fixture model data for the direct comprehension in the compliance test and 370 plugand-play module data which provided the DUT direct measurement data. Best utilizing the metrics and criteria defined in 370 specification, four different states of art 2X-Thru de-embedding tools were tested, and the test results are summarized.

TP-THU-8B Aeronautics and Space EMC (Sponsored by TC-8) 13:30 - 15:30

Chair: Jim Lukash, Lockheed Martin Space Systems, Palo Alto, CA, USA
Co-Chair: Jen Dimov, NASA, Bowie, MD, USA

13:30 **RF Field and ESD Immunity Test on Cable Assembly Type AL SpaceWire Link** 840

Christos D. Nikolopoulos[1], Anargyros T. Baklezos[2], Panagiotis K. Papastamatis[2], Theodoros N. Kapetanakis[1], Ioannis O. Vardiambasis[1], Ioannis F. Gonos[2]

[1]Hellenic Mediterranean University, Greece; [2]National Technical University of Athens, Greece

Abstract: Many past, current, and future ESA's, NASA's and JAXA's science missions are using extensively SpaceWire (SpW) links, implementing LVDS for the physical layer, in order to transmit science data. Electrostatic discharge (ESD) events in wires and cables used on spacecraft, can damage electronics or affect data integrity and ultimately compromise the mission objectives. Consequently, it is imperative to determine the levels of susceptibility to electromagnetic effects of electrostatic discharges. In this work, indicative RF field and ESD immunity tests are performed on a cable assembly type AL SpaceWire link based on common EMC standards in order to evaluate SpW link performance under harsh conditions.

13:55 **The Changing Electromagnetic Environment Onboard All-Electric Aircraft, an EMC Perspective** 845

Leonardo C. Malburg[1], Niek Moonen[1], Frank Leferink[1,2]

[1]University of Twente, The Netherlands; [2]Thales Nederland B.V., The Netherlands

Abstract: All-electric aircraft (AEA) is an emerging subject, due to its environmental contributions and economical appeal, thus, such technology is progressing at a fast pace towards commercial applications. The changing electromagnetic environment (EME) which such aircraft will endure, encompass not only current technologies, but will experience new EMI effects, originating from future mobile communication, power conversion, and increase in air-traffic. As a consequence of an operation relying solely on electric and electrical systems (avionics), together with the implementation of a high-power electric powertrain, AEA will experience increased levels of EMI. Therefore, to regulate the EMI changes onboard AEA, current aerospace standards must be assessed in order to identify possible limitations and bottlenecks. This paper presents an insight into the future EME, its EMC issues, and the intricacies towards the implementation of AEA for regional commercial flights.

SS-THU-B Risk-Based EMC 13:30 - 15:30

Chair: Fernando Ribeiro Arduini, Fraunhofer, Euskirchen, Germany
Co-Chair: Davy Pissoort, Katholieke Universiteit Leuven, Bruges, Belgium

13:30 **EMI Risk Estimation for System-Level Functions using Probabilistic Graphical Models** 851
Lokesh Devaraj[1], Alastair R. Ruddle[1], Alistair P. Duffy[2]
[1]Horiba Mira Ltd., United Kingdom; [2]De Montfort University, United Kingdom

Abstract: In general, the functions provided by complex systems often involve multiple sub-systems and components that are functionally dependent on each other. The dependency could be to receive power, control signals, input data, memory storage, feedback etc. With the increasing use of electronic systems to perform critical functions, the potential for malfunctions due to electromagnetic interference need to be identified and mitigated. Hence, a risk analysis, estimating the likelihood and severity of electromagnetic interference effects, is desirable from the very early stages of system development. In this paper, the use of probabilistic graphical models for estimating the likelihood of electromagnetic disturbances causing system malfunctions with various degrees of severity is demonstrated using a very simple case study. Statistical data are synthesised to illustrate the construction of conditional probability distribution tables for a Bayesian Network system model. Factorization and inference techniques are then applied to demonstrate the formulation and answer of queries that could be of value during system risk assessment.

13:55 **Time-Efficient EMI Risk Evaluation Method in a Hospital Environment** 857
Mumpy Das[1], Robert Vogt-Ardatjew[1], Bärbel van den Berg[2], Frank Leferink[1,3]
[1]University of Twente, The Netherlands; [2]Medisch Spectrum Twente Hospital, The Netherlands; [3]Thales Nederland B.V., The Netherlands

Abstract: Hospitals are one of the most critical and sensitive environments where possible EMI issue may have life-threatening effects. Although the electronic equipment placed within satisfies various EMC standards, a risk of EMI still exists. Due to the high complexity and dynamics of this system, the electromagnetic environment substantially differs from the one of an EMC laboratory. A full risk-based EMC analysis can significantly help mitigate this problem but requires plenty of effort, time, and careful management. In this paper, we present a simplified but robust, time efficient method of evaluating the electromagnetic risks, as an intermediate step before implementing a full riskanalysis campaign. Such an analysis allows to get the first impression about the environment and its influence on the medical device within.

14:20 **Analysis and Estimation of Electromagnetic Energy Coupled into IC packages** 862
Hui Tang[1], Arunkumar H. Venkateshaiah[2], John F. Dawson[2], Andrew C. Marvin[2],
Martin P. Robinson[2], Jie Ge[3]
[1]Nantong University, China; [2]University of York, United Kingdom; [3]Nantong Vocational University, China

Abstract: Interference analysis and prediction in integrated circuits (ICs) is of significant interest to the Electromagnetic Compatibility (EMC) community. In this paper, an easy method is introduced to estimate the level of RF interference coupled into ICs through the package. Although IC packages are in different forms with large number of pins, the presented analysis method provides a general solution and greatly shortens the computation time by creating a simplified model with consideration of the cross coupling between pins. The expected voltage range at the outer ends and inner ends of the pins are also investigated for resistive loads. The levels of energy coupled into PCB traces and packages are also compared for immunity analysis.

14:45 **Resilience of Reed-Solomon Codes against Harsh Electromagnetic Disturbances: Influence of Over-Voltage Detection** 868
Pejman Memar, Jens Vankeirsblick, Dries Vanoost, Tom Holvoet, Jeroen Boydens
Katholieke Universiteit Leuven, Belgium

Abstract: Communication networks are the backbone of the modern safety-critical systems. Thus, it is crucial to protect these error-prone networks against electromagnetic disturbances in ever more polluted electromagnetic environments. One major vulnerability in communication networks, even the networks which are armed with Error Detection and Correction Codes, is undetected incorrect data, also known as false negatives. From the safety viewpoint, false negatives must be mitigated to an as low as reasonably practicable level. This paper presents the influence of over-voltage detection on the behavior of primitive Reed- Solomon Codes under harsh single-frequency electromagnetic disturbances. In this regards, three different threshold pairs are employed. Our simulations show that by choosing an appropriate range, over-voltage detection could substantially decrease the number of false negatives. Furthermore, it is found that this improvement in the electromagnetic resiliency of Reed-Solomon Codes has been obtained at a cost: decreasing the availability. Nevertheless, this study takes advantage of this trade-off to provide a more resilient system in a safety-critical environment, as is the aim of this paper.

FRIDAY TECHNICAL PAPERS AND ABSTRACTS

Friday, August 13, 2021

TP-FRI-1A Noise, Jitter and Communications (Sponsored by TC-2) 11:00 - 13:00

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

11:00 **Jitter-Based Reconstruction of Transmission Line Pulse using On-Chip Sensor** 874

Bhuvnesh Narayanan[1], Bernhard Weiss[1], Tvrtko Mandić[2], Adrijan Barić[3]
[1]ams AG, Austria; [2]Innovation Centre Nikola Tesla, Zagreb, Croatia; [3]University of Zagreb, Croatia

Abstract: A technique for reconstruction of on-chip high frequency signals is demonstrated. The majority of the on-chip reconstruction methods based on subsampling technique are applicable to synchronized systems. This paper demonstrates a jitter-based subsampling technique for non-intrusive reconstruction of on-chip high frequency signals in nonsynchronized systems. The proposed technique is demonstrated on a custom designed IC in 180 nm technology. The on-chip sensors are used for acquisition of high frequency signals as a response to the transmission line pulses (TLP) applied to the IC. The presented technique is also used to investigate the influence of the TLP on the internal nodes of the IC.

11:25 **Design of Common Mode and Differential Mode Separator for Electromagnetic Noise based on Autotransformer** 878

Guo Jiandong, Zhang Yue, Li Xiaoguang, Sun Kaiyi, Zhang Haoseng, Ma Mingyu
China Automotive Technology and Research Center Co., Ltd., China

Abstract: The application of common mode and differential mode separators for electromagnetic noise is of great significance for improving the efficiency of electromagnetic compatibility trouble-shooting. By analyzing the characteristics of different electromagnetic noise separators, a common mode and differential mode separator network model for electromagnetic noise based on autotransformers is proposed. Through parameter extraction and simulation analysis, a common mode and differential mode separator for electromagnetic noise is designed. After comparing the actual measurement and simulation results of the separator parameters, the effectiveness of the separator design is verified.

11:50 **Deferred Time-Frequency Cross-Correlation for EM Source Determination with One-Port Measurements** 882

Umberto Paoletti
Hitachi, Ltd., Japan

Abstract: Time cross-correlation between near and far field is useful for electromagnetic noise source determination, but it requires synchronous two-port measurements. This is a problem when near field measurements may affect far-field. In this work it is shown that the deferred cross-correlation between frequency modulation and time domain signal can be used for source determination using only one-port measurements.

TP-FRI-2A Shielding (Sponsored by TC-2) 11:00 - 13:00

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

11:00 **Experimental Verification of Board Level Shielding Variability at Microwave Frequencies** 883

Andrew Marvin, John Dawson, Martin Robinson
University of York, United Kingdom

Abstract: This paper shows that the Shielding Effectiveness of a printed circuit board shield (PCBS) varies depending on the shield's external environment when the circuit board level shield is installed within a larger external enclosure. A reverberation chamber based technique is demonstrated that allows the underlying Shielding Effectiveness of the circuit board level shield to be evaluated along with an estimate of its expected variability due to the external enclosure.

Best EMC Paper Finalist

11:25 **Limitations of Shielding Effectiveness Measurements of Planar Materials using a DTEM Cell** 889

Vasiliki Gkatsi[1], Evangelia Tourounoglou[2], Robert Vogt-Ardatjew[1], Hans Schipper[2], Frank Leferink[1,2]
[1]University of Twente, The Netherlands; [2]Thales Nederland B.V., The Netherlands

Abstract: This paper addresses issues encountered in a method for measuring the shielding effectiveness of planar materials using a dual transverse electromagnetic cell. The aim of this work is to evaluate the performance of the setup and to point out its strengths and weaknesses. The effect of placement of several materials varying in size and texture is examined. Additionally, techniques for improving the setup and therefore the measurement accuracy and sensitivity are presented. The size of the aperture is investigated by applying two different methods in order to observe its effect on the shielding effectiveness results. Restrictions and limitations of the measurement method are discussed and supported by experimental results.

11:50 **Shielding Effectiveness Controlling of Coated Glass Assembly in Mobile and Positioning GPS Frequency Bands** 894

Xavier Radu[1], Michael Bruscaglia[1], Davide Micheli[2], Luca Bastianelli[3], Franco Moglie[3], Valter Mariani Primiani[3]
[1]AGC Glass Europe SA, Belgium; [2]CT.NEO.A.M–TIM S.p.A., Italy; [3]Università Politecnica delle Marche, Italy

Abstract: The increasing of frequencies for the bands assigned to mobile services has threatened the indoor coverage performances. The present paper is giving a solution to this issue introducing a technology able to mitigate glass metallic coating attenuation effects.

12:15 **Material Investigation on Radio Frequency Transparency and Thermal Stress Relaxation** 900

Nika Amralah
Raymond EMC Enclosures Ltd., Canada

Abstract: An investigation on thermally resistant and radio frequency (RF) transparent materials was performed. Thermal stress relaxation tests from 20°C to 150°C showed that polystyrene foam board and polycarbonate demonstrate signs of creep deformation over time. Polyurethane foam demonstrated no thermal stress relaxation. For RF penetrability testing, the 100 MHz to 40 GHz range was studied using an outdoor test setup. Open air measurements of two collinearly faced antennas were compared to measurements taken when material samples were placed between the two antennas. This demonstrated that rigid polyurethane foam, Teflon polytetrafluoroethylene (PTFE) and borosilicate glass are RF penetrable.

TP-FRI-3A Risk-Based EMC (Sponsored by TC-1) 11:00 - 13:00

Chair: Frank Leferink, University of Twente, Enschede and THALES, Hengelo, Netherlands
Co-Chair: Vasiliki Gkatsi, Universiteit Twente, Enschede, Netherlands

11:00 **A System's Perspective on the use of EMI Detection and Correction Methods in Safety Critical Systems** 905

Tim Claeys, Hassan Tirmizi, Hasan Habib, Dries Vanoost, Guy A.E. Vandenbosch, Davy Pissoort
Katholieke Universiteit Leuven, Belgium

Abstract: In this paper we discuss the condition assessment definitions previously used to analyse the effectiveness of ElectroMagnetic Interference (EMI) detectors/correctors. It is shown that those definitions do not resemble the correct condition and an expansion is needed. New expanded condition assessment definitions are presented and evaluated in comparison with the old ones for a two out of three majority voter system used in an Electro Magnetic (EM) diverse system. The new definitions provide a better insight into the effectiveness of EMI detectors on its own or in correctors. We also discuss the use of the new definitions in a multi-layer error detection and correction system.

11:25 **A Comparative Study of On-Chip CMOS S&H Voltage Sensors for Power Integrity: SOI vs. Bulk** 911

Qazi Mashaal Khan[1,2], Richard Perdriau[1,3], Mohammed Ramdani[1,3], Mohsen Koohestani[1,3]
[1]ESEO, France; [2]INSA Rennes, France; [3] IETR, France

Abstract: This paper evaluates the performance of two onchip sample & hold (S&H) voltage sensors, usable for power integrity measurements, with the aim to compare silicon-oninsulator (SOI) & bulk CMOS technologies. Both sensors were designed and simulated in 180 nm 5 V AMS-bulk and XFAB-SOI processes, using optimized parameters and compatible devices. The fundamental variables analyzed were power consumption, leakage current, slew rate (SR), and transient output voltage, under process, voltage and temperature variations. Compared to bulk technology, SOI was found to have lower power consumption (by 2.2 mW in average) and leakage supply current (by 9.5 pA at 27○C), higher sensitivity to process variations (up to 88% additional slew rate versus 39% at 80○C), higher resilience to temperature changes (6% in output voltage), and a larger occupied area. The SOI sensor is intended to be fabricated and used to evaluate injected continuous wave and transient disturbances as well as voltage fluctuations due to internal activity on power distribution networks.

11:50 **Sensitivity of Shielded Cable Transfer Impedance Measurement to Triaxial Cell Diameter** 917

Oskari Leppäaho[1], Frédéric Lafon[1], Priscila Fernandez-Lopez[1], Marine Stojanovic[1],
Richard Perdriau[2], Mohammed Ramdani[2]
[1]Valeo, France; [2]ESEO, France

Abstract: Triaxial measurement is an effective means to determine the transfer impedance of a shielded cable. It is based on coupled transmission line principle. In an ideal case, both transmission lines in the setup would be matched to guarantee the high frequency performance. In practice, matching is hard to achieve without compromising on usability and generality of the measurement setup. This paper discusses how triaxial cell diameter and the resulting impedance mismatch affects transfer impedance measurement results. In addition, the paper shows how impedance mismatches can be modeled, presents a simplified model to quickly understand the effects of impedance mismatch, and compares the model to results measured with different triaxial cell sizes. The simple model presented achieved similar accuracy to a more complex model defined in IEC 62153.

12:15 **Mutual Influence of Cavity Resonances of a Shielding Enclosure on the Resonance of a Dipole inside that Enclosure** 922

Zhao Chen[1], Tim Claeys[2], Ronny Deseine[1], Davy Pissoort[2]
[1]Barco NV, Belgium; [2]Katholieke Universiteit Leuven, Belgium

Abstract: In recent years, a risk-based approach has been proposed to better manage EM-related risks of electronic systems. Within this approach it is critical to detect potential risks as much and as early as possible. Unfortunately, many hazards (potential contributors to risks) are “hiding” deep in the system and/or can only appear when “excited” under certain conditions. One such example is electromagnetic (EM) resonance of components and structures (e.g., traces, heatsinks, PCBs, enclosures) within electronic systems. These resonances can further lead to unintended and increased coupling effects which may result in seriously hazardous situations. In this paper, we consider the relatively simple but basic case of a trace (modelled as a dipole) within a closed metallic enclosure. Both quantitative calculations and full-wave EM-simulation results reveal the complexity of the possible resonance mechanisms and interactions.

Best EMC Paper Finalist

TP-FRI-5A PIM Evaluation and Characterization (Sponsored by TC-12) 11:00 - 13:00

Chair: Valter Mariani Primiani, Università Politecnica delle Marche, Ancona, Italy
Co-Chair: Ross Carlton, ETS-Lindgren, Cedar Park, TX, USA

11:00 **A Recommended Practice for PIM Test of Antennas in Wireless Communication Systems** 928

Z.H. Cai, L. Liu, Y. Qi
General Test Systems Inc., China

Abstract: A test method is proposed to IEEE Standard Association recently for testing of passive intermodulation of base station or satellite antennas. PIM product may deteriorate the performance of sensitive communication systems. An innovative test system and calibration method have been proposed to remedy the defects in the current standards. The proposed anechoic chamber and method are suitable for testing antennas with PIM residual below -150dBc which cannot be measured accurately according to the method defined by the current standards.

11:25 **Self-Contact Introduced Passive Intermodulation Characterizations for Captured Springs** 929

Jiangshuai Li[1], Shengxuan Xia[1], Zhifei Xu[1], Yang Xu[1], Yansheng Wang[2], Yuchu He[2], Ken Wu[2], Nicholas McDonnell[2], Warren Lee[2], Haicheng Zhou[2], Jun Fan[1], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]Google LLC, USA

Abstract: Passive intermodulation (PIM) is one of the most common nonlinear behavior that exists in a variety of applications. Nowadays, consumer electronics designs use a variety of mechanical features for radio-frequency (RF) antenna feeds and grounding, such as springs, gaskets, screws, etc. When these components are placed in the path or nearby the RF antennas, the unsatisfying connection such as loose contact will generate PIM and create noise in the receiving frequency range. This can potentially cause RF desense issues. In product design, the most intrinsic method to improve the electrical connection is applying more compression between the spring tip and the landing substrate, but seldom will the engineers notice the spring structure itself can also introduce a lot of PIM. This paper concentrates on characterizing and validating the captured RF springs that can introduce noticeable PIM due to its structural self-contact phenomenon. An integrated camera recorded the spring side-view under compression. The measured information indicates that high PIM tends to occur when the spring contacts itself unintentionally

11:50 **Gaussian Process Regression Analysis of Passive Intermodulation Level and DCR for Spring Contacts** 935

Shengxuan Xia, Jiangshuai Li, Yang Xu, Ze Sun, Zhifei Xu, Yansheng Wang, Yuchu He, Nick McDonnell, Haicheng Zhou, Ken Wu, Jun Fan, Chulsoon Hwang
Missouri University of Science and Technology, USA

Abstract: In modern consumer electronic devices, for the purpose of having easier access for assembly and repair in a compact designed product, metallic connection components such as springs are universally used for metallic connections between modules or chassis. However, the non-ideal metallic connections tend to have a certain level of non-linearity. Therefore, significant attention has been aroused recently because the passive-intermodulation (PIM) can degrade the radio-frequency (RF) antennas' receiving quality especially when the unsatisfying spring connections are placed near the RF antenna. Typically, advanced and expensive instruments and components are required to estimate the non-linearity levels of the springs. However, those instruments are usually not available for the manufacturing factories for massive tests. This paper is focused on investigating the feasibility of estimating the nonlinearity level of spring contacts using DC resistance (DCR), which has easier access to be tested with much lower cost. Study showed that the DCR, when under certain conditions, can serve as the alternative figure of merit for PIM prediction. Then, the Gaussian process regression (GPR) analysis based on measured data can provide a statistical estimation to the generated PIM from the DCR values.

Best EMC Student Paper Finalist

TP-FRI-6A Computational Electromagnetics III (Sponsored by TC-9) 11:00 - 13:00

Chair: Shaowu Huang, Marvell Technology Group Ltd, Santa Clara, CA, USA

11:00 **Time Domain Computation of Full-Wave Partial Inductances based on the Numerical Inversion of Laplace Transform Method** 940

Fabrizio Loreto[1], Daniele Romano[1], Giulio Antonini[1], Martin Stumpf[2], Albert E. Ruehli[3]
[1]University of L'Aquila, Italy; [2]Brno University of Technology, Czechia; [3]Missouri University of Science and Technology, USA

Abstract: This paper presents the computation of time-domain partial inductances. The numerical inversion of the Laplace transform (NILT) is adopted to compute the time samples of the partial inductance. Furthermore, the causality can be strictly guaranteed by using a delayed implementation of the NILT method making use of the minimum distance between the spatial supports of the basis functions. The proposed method is tested by comparing the results with analytical ones existing for coplanar zero-thickness regions and with inverse Fourier transform techniques for non-orthogonal volumes.

11:25 **EMC Results Analysis using Statistical Comparison Criteria** 946

Samuel Leman[1], Sébastien Serpaud[1], Philippe Besnier[2]
[1]IRT Saint Exupéry, France; [2]INSA Rennes, France

Abstract: This paper presents an evaluation of statistical comparison criteria applied to analyze and to interpret EMC data results with their uncertainties characterizing an electronic system. Based on EMC simulated and/or measured results of shielded harness test case, five comparison criteria are used firstly to validate a data with a referent EMC results, secondly to identify sensitive parameters, and thirdly to estimate input parameters uncertainties.

11:50 **System Identification of Electromagnetic Devices based on Full-Wave Computations** 952

Carl Holmberg[1,2], Thomas Rylander[1], Jan Carlsson[1,3], Tomas McKelvey[1]
[1]Chalmers University of Technology, Sweden; [2]Volvo Car Corporation, Sweden; [3]Provinn AB, Sweden

Abstract: We present a framework that allows for the estimation of port-to-port characteristics of electromagnetic devices, which are linear and passive. Our approach is based on system identification (SI) techniques applied to the numerically computed admittance or impedance matrices of the electromagnetic device. The SI procedure yields a low-order model expressed in terms of a Pad´e approximant, which is represented as the ratio of two polynomials with respect to frequency. In this article, we demonstrate that the admittance and impedance matrices computed at a rather small number of frequency points can yield a highly accurate low-order model that describes the system response as a continuous function throughout the frequency band used for estimation of the model. The computational cost to store and evaluate the low-order model is basically negligible in comparison to the computational cost required by the numerical full-wave solver. The derived port-to-port model allows for the individual and independent analysis of subsystems that do not couple electromagnetically, where such subsystems can be combined later to form a complete system and this allows for great flexibility in a virtual design-process. We test our approach on two different crosstalk problems.

12:15 **A Simulation approach to Predict the Radiated EMI from a TV Panel** 958

Taeshin Kang[1], Matt Commens[1], Jihyun Lee[2], Jinho Kim[2], Seonha Lee[3], Sungwook Moon[3]
[1]Ansys Inc., USA; [2]Samsung Electronics Co. Ltd., Korea

Abstract: EMI (Electrical Magnetic Interference) regulation is strictly applied to display panel products, and it needs to be considered from IC design stage. In this work, we propose a virtual EMI simulation technique for TV products to simulate the EMI test of the CISPR 16 standard. The virtual EMI simulation implements both display panel and EMI measurement environment by Ansys HFSS simulation software, which enable to predict the EMI problem of the display panel products in IC design stage. The proposed simulation technique showed a good correlation with the EMI measurement results of the 55-inch 4K display model.

TP-FRI-7A Power Integrity Analysis and Design 1 (Sponsored by TC-10) 11:00 - 13:00

Chair: Kinger Cai, Intel Corporation, Palo Alto, CA, USA
Co-Chair: Bumhee Bae, Samsung Electronics, Suwon-si, Korea (the Republic of)

11:00 **Design of Power Delivery Network Droops** 959

Long Yang
Cisco Systems Inc., USA

Abstract: Based on a simple and typical power delivery network structure, the impedance profile is expressed in a novel form through a complicated derivation and then the Fourier transform is used to calculate the time-domain impedance response. After that, an exactly analytical formula of the load voltage droop induced by an ideal current step is derived. The analytical results are exactly matched with the commercial simulation tool. The resonant frequency is derived, and its damped property is discussed. Through the properties derived from the simple structure, a more complicated power delivery network is designed in control. The step current response in timedomain is also simulated to show the voltage droops, as the design expected.

11:25 **Achieving a Sub Miliohm Load Line on a Discrete Graphics Product** 963

Umesh HM[1], Kinger Xingjian Cai[2], Ashwini Anil Kumar[1], Pete Tirkas[2]
[1]Intel Corporation, India; [2]Intel Corporation, USA

Abstract: The Direct Current Load Line (DCLL) and the Alternating Current Load Line 3 (ACLL3) target of 0.5mOhm has been defined for a graphics core power delivery network in order to achieve the preferred peak performance on the next generation discrete graphics product. The pathfinding effort led to explore various innovative solutions to have a line of sight for achieving this challenging impedance target, which includes A. Study of various stack up and routing strategies to achieve the lower Resistance path (Rpath) B. Novel idea of bulk capacitors provision beneath System on Chip (SoC) cavity to lower Load Line (LL) around the Voltage Regulator Module (VRM) bandwidth C. Improved Power Integrity (PI) design methodology for an accurate ACLL and reasonable DCLL estimation D. Enhancement in Package Design for Manufacturing (DFM) rules to gain extra margins

11:50 **Decoupling Capacitor Optimization to Achieve Target Impedance in PCB PDN Design** 967

Shuang Liang[1], Biyao Zhao[1], Siqi Bai[1], Samuel Connor[2], Matteo Cocchini[2], Stephen Scearce[3], Dale Becker[2], Michael Cracraft[2], Matthew S. Doyle[2], Albert Ruehli[1], James Drewniak[1]
[1]Missouri University of Science and Technology, USA; [2]IBM Corporation, USA; [3]Cisco Systems Inc., USA

Abstract: With increasingly stringent requirements for lower voltage supply, and higher density in PCB (Printed Circuit) PDN (Power Distribution Network) design, power integrity has an increasingly important role in PCB design. The PI performance of the PCB design must meet requirements, or modification and trial-and-error are necessary to ensure the target impedance is satisfied. Lots of design practices and commercial tools are utilized to aid PI designers, e.g., developing a suitable stack-up, saving cost while placing enough decoupling capacitors, best layout for IC pins and so on. It is essential in the PCB PDN design to place as fewer decoupling capacitors as possible to achieve target impedance and voltage ripple goals while saving cost. In this paper, the influence from the types of decoupling capacitor and stack-up is considered. The variety of decoupling capacitors contributes to the objective of reaching the target with minimum number of decoupling capacitors.

Best SIPI Student Paper Finalist

12:15 **Cloud based FastPI Streamlining Platform Power Integrity Design** 973

Angela Chen[1], Kinger Xingjian Cai[1], Chi-te Chen[1], Chaitra Kotehal[2], Morgan Tseng[3], Joseph Chen[1]
[1]Intel Corporation, USA; [2]Intel Corporation, India; [3]Intel Corporation, Taiwan

Abstract: Cloud based FastPI, using Intel's first developed platform design automation methodology, facilitates Intel customers' board level PI design. For every power rail of the SoC, it provides quick design review, PDN optimization and sign-off to expedite Time-to- Market (TTM). Flexibility feature of the trade-offs among performance, cost, and form factors including stack-up and Zheight greatly helps customers' platform differentiation and product innovation.

TP-FRI-8A Printed Circuit Board Technology and SI Design 1 (Sponsored by TC-10) 11:00 - 13:00

Chair: Francesco de Paulis, University of L'Aquila, L'Aquila, L'Aquila, Italy
Co-Chair: Zhifei Xu, Kandou Bus, Lausanne, Switzerland

11:00 **Automated 3D Discontinuity Optimization with Speed Sensitivity for High Speed Serdes Channels** 977

Qian Dong[1], Kevin Cai[2], Anna Gao[2], Bidyut Sen[2]
[1]Stanford University, USA; [2]Cisco Systems, Inc., USA

Abstract: With the data rate increasing to 112 Gb/s, optimization of differential vias becomes critical for high-speed designs, as discontinuity of differential vias can severely impact signal qualities. Achieving a good differential via design for higher frequencies is becoming more and more challenging. In this paper, we present an unconventional way to optimize the differential vias, which is using different antipad sizes for input/output antipads and middle anipads. We then perform sweeping with different parameters and analyze the S-parameters by examining their impact on TDR, TDT, Group Delay, and eye diagrams. Our Python coding helps identify the optimization trend and make the complete sweeping fully automated with designated signal speed as a sensitive target.

11:25 **Dielectric Constant Extraction for Microstrip Transmission Lines based on S-Parameter Measurements and Cross-Section** 982

Yuanzhuo Liu, Shaohui Yong, Jiangshuai Li, Victor Khilkevich
Missouri University of Science and Technology, USA

Abstract: In this paper, a new dielectric constant extraction method for the microstrip substrate material is proposed, which is based on measured S-parameter and cross-section analysis of the transmission lines. The calculation process is detailed and application examples are given. The phase constant is calculated from the measured S-parameters. By analyzing the cross-section geometry using a 2D solver, the per-unit-length inductance and capacitance of the air-filled line are obtained. Then using analytical expressions, the dielectric constant of the substrate is extracted from the effective dielectric constant. Comparing to the published method that requires knowing the characteristic impedance of the line, the new method will introduce less error to the extraction procedure and will provide more accurate results.

11:50 **Signal Integrity and Crosstalk Analysis of PCBs within a PEC-PMC Bandgap Metallic Cavity** 988

Francesco de Paulis[1], Muhammet Hilmi Nisanci[2]
[1]University of L'Aquila, Italy; [2]Sakarya University, Turkey

Abstract: The PEC-PMC type of metallic cavities has been shown to be effective to inhibit cavity resonances within welldefined bandgap limits. Such cavities are realized by appropriately placing metallic pins on the cavity lid. However, the presence of such pins, may affect the signal transmission over interconnects routed in close proximity, or right underneath the pins. The systematic analysis carried out in this paper demonstrates the feasibility of such cavities from a signal integrity and crosstalk point of view. Different distances between the pin and the traces are analyzed, such that the pinned lid is demonstrated to have not detrimental impact on the traces insertion loss. Moreover, since cavity resonances cannot occur within the bandgap, the crosstalk among traces is not affected by the cavity, thus typical PCB design and layout rules can be simply applied for the design of digital and RF interconnects.

12:15 **Analysis on Unintentional Resonances in High-Speed Signals from Non-Ideal Routing Stub** 994

Yuanzhuo Liu, Siqi Bai, Bo Pu, JongJoo Lee, DongHyun Kim
Missouri University of Science and Technology, USA

Abstract: As more components are integrated into a denser area in electronic devices, the complexity of routing increases. A routing design resulting from routing tools may pass all design rule checks, but it can also result in signal integrity problems, which affect the performance of the entire link path, often not realized until the layout stage. In this paper, such designs are analyzed for their unintentional resonances in the insertion loss and the crosstalk of the signals. As an example, an unintentional power plane stub created by trace routing revisions adjacent to the signal trace behaves as a quarter-wavelength resonant structure. To avoid such unintentional resonances in high-speed signals, trace routing should be carefully designed and design rule checks must be improved to detect and warn the users of such potential signal integrity hazards.

SS-FRI-A Robust Design for System Level ESD: Device, PCB and System Level — 11:00 - 13:00

Chair: David Pommerenke, Technische Universitat Graz, Graz, Austria
Co-Chair: Mike McInerney, Consultant, Champaign, IL, USA

11:00 **Generic ESD Generator Model using Artificial Neural Network** 1000

Jawad Yousaf[1], Kamran Javed[2,3], Mohammed Ghazal[1]
[1]Abu Dhabi University, United Arab Emirates; [2]Saudi Data and Artificial Intelligence Authority, Saudi Arabia;[3]Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Pakistan

Abstract: Different commercial ESD gun models, although complying with the standard ESD waveform requirements in terms of rise time and current values for standard Pellegrini target, produce different ESD waveforms. The variations of the ESD source and target impedance in real-time with the change in the gun model affects the ESD susceptibility compliance testing results and immunity analysis for the estimation of possible ESD failure in a product. This study presents, for the first time, a novel generic ESD generator model using artificial neural network (ANN) based deep learning techniques. The developed deep learning model incorporates the characteristics of the real-time generated ESD waveforms by various commonly used commercial ESD gun models with different target load impedances. The presented model could be used as a generic ESD source for fast ESD susceptibility and immunity testing's at the design stage of a product using numerical or circuit-analysis-based tools.

11:25 **Improvement of SPICE based ESD Protection Models for IO Protection Modeling** 1006

Amin Pak[1,2], Seyed Mostafa Mousavi[1], David Pommerenke[1,2], Giorgi Maghlakelidze[3], Yang Xu[3]
[1]Technische Universität Graz, Austria; [2]Silicon Austria Labs GmbH, Austria; [3]Missouri University of Science and Technology, USA

Abstract: Modeling ESD protection using the System Efficient ESD Design (SEED) methodology enables optimal protection of an IO using TVS and external components. The success of modeling depends on the accuracy of the models. This work shows improvements to SPICE models used to characterize TVS diodes and IC I/O. The improvement is twofold. The transition phases between snapback and main current flow have been adjusted to achieve realistic waveforms for the rise times from 500 ps to 5 ns in a voltage range from Vt1 to the high current region, and complex curvatures of the IV curve are included. The model is capable of operating in generic SPICE and being tested in ADS and LT-SPICE. The paper explains this in detail to enable the reader to apply this modeling principle.

11:50 **IC-based Antenna Switch Modeling and Robustness Evaluation for SEED Applications** 1012

Seyed Mostafa Mousavi[1], Gabriel Fellner[1], David Pommerenke[1,2], Sandeep Chandra[3],
Ketan Shringapure[3], Warwick Ka Kui Wong[3]
[1]Technische Universität Graz, Austria; [2]Silicon Austria Labs GmbH, Austria; [3]Google, Inc., USA

Abstract: ESD discharges to antennas can damage the RF front end. In particular, antennas with highly inductive ground connections allow large ESD-induced voltages at their RF terminals. This work investigates the ESD properties of an RF switch used as an antenna tuner by measuring the voltages and currents at its terminals and building a SPICE model. The goal is to predict the damage threshold when the switch is used in an RF front end.

12:15 **ESD Susceptibility Analysis: Coupling to Traces and Interconnect** 1018

Mehdi Gholizadeh[1,2], Seyed Mostafa Mousavi[1], David Pommerenke[1,2], Amin Pak[1,2],
Gabriel Fellner[1], Jin Min[3]
[1]Technische Universität Graz, Austria; [2]Silicon Austria Labs GmbH, Austria;
[3]Amber Precision Instruments, USA

Abstract: ESD susceptibility scanning is an effective method to find the causes of ESD soft failures in electronic systems. A local probe is used to scan the system for sensitive areas. However, the voltages induced by the probe are often unknown. This paper quantifies the induced voltages from different probes when injected into traces and flex cables, and compares the values to the induced voltages caused by an IEC 61000-4-2 ESD gun in contact mode. The goal is to guide the reader to select voltage levels and probes during susceptibility scans in a way that avoids levels that may be associated with ESD gun injection and cause failure.

TP-FRI-1B Near Field Measurements (Sponsored by TC-2) 13:30 - 15:30

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

13:55 **Using the ANOVA F-Statistic to Isolate Information-Revealing Near-Field Measurement Configurations for Embedded Systems** 1024

Vishnuvardhan V. Iyer, Ali E. Yilmaz
The University of Texas System, USA

Abstract: The analysis of variance (ANOVA) F-statistic is proposed as a tool to isolate near-field measurement configurations that are sensitive to targeted chip processes in embedded systems. It is hypothesized that the desired measurement configurations have high F-values, i.e., the variation in a target process is a major contributor whereas obfuscating background processes and measurement uncertainty are minor contributors to the variance of measured signals. The concept is demonstrated by isolating data-dependent measurement configurations for a commercially available variant of the 8051 microcontroller: First, a multi-stage measurement protocol using Fvalues is developed to rapidly isolate optimal measurement configurations within the 4-D search space of 2-D probe location over chip area, probe orientation, and time. Then, signals captured using configurations with high F-values are analyzed to identify the Hamming weights of the output data computed by a randomized test code running on the 8051. It is shown that configurations with higher F-values generally result in more accurate classification of the output data; the configuration with the highest F-value results in 100% accuracy.

TP-FRI-3B Risk-Based EMC (Sponsored by TC-1) 13:30 - 15:30

Chair: Heyno Garbe, Leibniz Universitat Hannover, Hannover, Germany
Co-Chair: Fernando Ribeiro Arduini, Fraunhofer, Euskirchen, Germany

13:30 **The 4+1 Principles for EM Risk Management** 1030

D. Pissoort[1], M. Nicholson[2]
[1]Katholieke Universiteit Leuven, Belgium; [2]University of York, United Kingdom

Abstract: In this contribution, we translate the existing 4+1 principles for the safety assurance of software, as enshrined in standards such as Def-Stan 00-055, to 4+1 principles for electromagnetic risk management. These principles can be used as a guidance for a proper risk-based approach to manage (functional) safety risks or other risks due to electromagnetic disturbances.

13:55 **Characterizing the Robustness of Wi-Fi and Bluetooth against Continuous Wave EM Disturbances inside a Reverberation Chamber** 1031

Aleksandr Ovechkin[1], Tim Claeys[1], Dries Vanoost[1], John F. Dawson[2], Guy A.E. Vandenbosch[1], Davy Pissoort[1]
[1]Katholieke Universiteit Leuven, Belgium; [2]University of York, United Kingdom

Abstract: This paper describes a detailed test setup and procedure to characterize the robustness of Wi-Fi3 and Bluetooth 4.2 against continuous wave electromagnetic disturbances inside a reverberation chamber. Bluetooth 4.2 robustness was also characterized by continuous broadband noise. These experiments aim to reveal the susceptibility of commonly used wireless communication protocols against continuous wave noise. Results show that Wi-Fi3 has an abrupt rise in the packet error rate (up to 100%) when the continuous wave noise overlaps with the Wi- Fi3 working frequency. Bluetooth 4.2 is robust against continuous wave noise, thanks to the frequency hopping technique, but fails against broadband noise.

14:20 **Effects of the 3rd Harmonic Component on False Negatives in a Time Diverse Triple Modular Redundant System Under Reverberation Conditions** 1037

Hassan Tirmizi, Jonas Lannoo, Dries Vanoost, Guy A.E. Vandenbosch, Davy Pissoort
Katholieke Universiteit Leuven, Belgium

Abstract: In this paper, time diversity is used as an EM resilience technique in a Triple Modular Redundant (TMR) communication channel that is subjected to a multi-harmonic electromagnetic disturbance under reverberation conditions. The study shows that time diversity proves to be quite an effective measure in order to incorporate fault tolerance in the system. However, when compared to the single frequency case for which time diversity eliminates all potential false negatives, the multi-harmonic disturbance tends to have a slight percentage of false negatives, especially at high field strengths. Together with reverberation simulation results, a theoretical explanation is also presented that explains this phenomenon of multi-harmonic Electromagnetic Interference (EMI) induced false negatives.

TP-FRI-4B Circuit EMC Analysis, Testing and Considerations (Sponsored by TC-4) 13:30 - 15:30

Chair: William Wantz, IV, Spira Manufacturing, San Fernando, CA, USA

13:30 **Analytical Method to estimate Magnetic Fields from a 2D Scalar Potential for a Normative Setup** 1043

Guido A. Rasek, Madhavi Dhara
Valeo Siemens eAutomotive Germany GmbH, Germany

Abstract: Components in the electric drive train of vehicles must meet strict requirements from standards with regard to magnetic field emissions. High voltage cables play an important role in the distribution of intended functional and unintended parasitic currents. These currents result in radiated magnetic field emissions that are influenced by geometric configurations. A 2D approach with simplifications to calculate current to field transfer functions is presented to estimate the effect of the geometric configurations of the current loops on the resulting magnetic fields. Furthermore for analytical calculations, they are decomposed into geometric subareas based on the distribution of functional and parasitic currents. As a result transfer functions are presented for practical application in typical automotive laboratory setups from an analytical method without exaggerated complexity.

13:55 **Radio Frequency Interference Due to Power Plane Radiation and Mitigation using RFI and PI Co-Optimized Design in Mobile Platforms** 1049

Farnaz Foroughian, Jaejin Lee, Christian Chaves Bejarano, Pujitha Davuluri, Steven G. Gaskill
Intel Corporation, USA

Abstract: This paper's main focus is to study the noise radiation risk from motherboard power planes, including the mechanism of power plane radiation. A design for a power plane that is optimized for radio frequency interference (RFI) and power integrity (PI) is studied and simulation and measurement results are presented. This design has been proposed to reduce the level of RFI radiated from the power plane to the nearby antennas.

14:20 **Permittivity Measurement System using Stripline Method for the Europa Clipper Mission** 1054
Rohit Gawande, Alina Moussessian, Emmanuel Decrossas
NASA Jet Propulsion Laboratory, USA

Abstract: High radiation Jovian environment can deposit electrons in highly resistive dielectric materials, which could result in internal electrostatic discharge (IESD) causing damage to sensitive electronics such as the radar for Europa Assessment and Sounding: Ocean to Near-Surface (REASON) instrument on NASA's Europa Clipper mission. Special dielectric materials like static dissipative Polyetheretherketone (PEEK) ESD are under consideration for the Europa Clipper mission. PEEK loaded with carbon nanofibers improves the ESD performance for this material but the RF characteristics are unknown. We have developed a method to characterize the dielectric constant of a material as a function of frequency and temperature down to 30K. We present the measurement results of four samples of ESD. The measured data shows the permittivity of TECAPEEK ESD 11 is in the range of 7.16 to 9.87 at HF and in the range of 6.8 to 8.55 for VHF frequencies. The change in permittivity of ESD 11 down to 30 K is less than 7% at HF and less than 3% at VHF frequency. The sample to sample variability can be attributed to the inhomogeneity of the material.

14:45 **Estimating Electromagnetic Emissions from a Site Installation with Multiple Racks of Server Equipment** 1058
Ze Sun[1], Xu Wang[1], Chunyu Wu[1], Ben Kim[2], DongHyun Kim[1], Jun Fan[1]
[1]Missouri University of Science and Technology, USA; [2]Facebook Inc., USA

Abstract: More than hundreds, sometimes even thousands, of servers operate simultaneously inside a data center. Their radiation can be a problem and cause electromagnetic interference (EMI) issues. However, it is not feasible to perform full-wave 3D simulation of these racks because of the large electrical size of the model. In this paper, an algorithm is proposed to predict the emission from rack arrays. The equivalent dipole source is extracted from EMI measurement data of a single rack and reconstructed as a radiation source in a multiple rack model. The racks in an array can be divided into a few categories and the racks in each category have similar radiation patterns. Thus only one modeling of a representative rack is needed for each category. In order to take rack to rack scattering into consideration, a simplified model for each category is developed and method of moments is used to describe the radiation of representative racks. After the radiation calculations from a representative rack in all the categories are completed, the total radiation from the data center is predicted based on these representative-rack calculations. This method is much faster than the brute-force simulation of the entire data center, and is highly scalable to handle arbitrary number of racks in the data center.

TP-FRI-5B Radiated EMI Modeling and Reduction for Power Conversion Systems (Sponsored by SC-5) 13:30 - 15:30

Chair: Shuo Wang, University of Florida, Gainesville, FL, USA

13:30 **Radiated EMI Reduction with Double Shielding Techniques in Active-Clamp Flyback Converters** 1064
Zhedong Ma[1], Juntao Yao[1], Shuo Wang[1], Honggang Sheng[2], Srikanth Lakshmikanthan[2], Doug Osterhout[2]
[1]University of Florida, USA; [2]Google Inc., USA

Abstract: Electromagnetic interference (EMI) issue becomes a headache problem when the switching frequency has been pushed higher and higher for the smaller size and higher power density. Up to now, the conducted EMI can be controlled very well with decades of exploration and research. However, the radiated EMI is still hard to be understood and controlled, the techniques to reduce the radiated EMI are limited. In this paper, active-clamp flyback converters are taken as the example, the radiation model is developed, the double shielding technique is proposed to mitigate the radiated EMI effectively no matter the EMI filters are placed on the AC line or DC bus. The concept of this technique is explained in detail, the experiments are conducted to verify the analysis. The guideline to choose the appropriate connection method of the double shielding technique is given for both the AC line and DC bus EMI filters.

13:55 **Radiated Electromagnetic Interference Source Modeling for a Three Phase Motor Drive System with a SiC Power Module** 1070
Boyi Zhang, Shuo Wang
University of Florida, USA

Abstract: SiC power modules have become the most promising candidates to replace the Si power modules in threephase motor drive systems. However, the fast switching speed and switching frequency of SiC power modules raise the concern of radiated electromagnetic interference (EMI). In this paper, an analytical time-domain model is firstly proposed for the EMI noise sources of SiC power modules. The influence of the non-linear junction capacitance, power loop parasitic inductance, and the operation conditions on the radiated EMI are then investigated in depth. Simulation and experimental results show a good agreement between the proposed analytical model and the measured radiated EMI.

14:20 **Impact for Radiated Noise by Current Smoothness with Bare SiC MOSFET and Si RC-IGBT Chips** 1075

Toshiya Tadakuma[1], Michael Rogers[2], Koichi Nishi[1], Motonobu Joko[1], Masahito Shoyama[3]
[1]Mitsubishi Electric Corporation, Japan; [2]Mitsubishi Electric US Inc., USA; [3]Kyushu University, Japan

Abstract: Power device structures have been improved to shrink area of chip and to reduce power loss. The switching speed has continued increasing to reduce switching loss, and electromagnetic noise also has been increasing and shifting to higher frequency. It is important to reduce generation of noise for establishing proper operation of power converters or inverters for motor control, thus simple switching behavior should be reconsidered anew. This report describes the relationship between switching behavior and intensity of the electric field at an antenna using electromagnetic potential and wavelet transform with switching data measured by extended double pulse test for bare SiC MOSFETs and Si RC-IGBTs.

14:45 **A Survey of Modeling and Reduction Techniques of Radiated EMI in Power Electronics** 1081

Juntao Yao, Zhedong Ma, Yanwen Lai, Shuo Wang
University of Florida, USA

Abstract: Radiated electromagnetic interference (EMI) is an important and challenging topic in modern power electronics. To analyze radiated EMI, modeling research is the foundation. Modeling research can reveal fundamental mechanisms including switching noise generation, noise conversion into the radiation excitation, antenna characteristics, and near field couplings' impact. Radiated EMI models are developed. Based on radiated EMI modeling research, noise reduction techniques are developed, including component improvement, printed circuit board (PCB) layout improvement, high-frequency EMI filters, and shielding. This paper summarizes recent research advances and discusses future radiated EMI challenges and research topics.

TP-FRI-6B Transmission Line Computational Electromagnetics (Sponsored by TC-9) 13:30 - 15:30

Chair: Scott Piper, General Motors Corp, Canton, MI, USA

13:30 **Calculation of Radiated Emission from STP Cable by Chain-Parameter-Matrix** 1087

Nobuo Kuwabara, Tohlu Matsushima, Yuki Fukumoto
Kyushu Institute of Technology, Japan

Abstract: Radiated emission from shielded twisted pair (STP) cable was calculated using a chain-parameter-matrix. The series connection of the matrix represented the transmission line inside the shield, and the common-mode (CM) cunent was obtained by solving the matrix equation. The induction voltage on the outside of the shield was determined from the CM cunent using the shield's transfer impedance. The cunent on the outside of the shield was calculated from this induction voltage. And then, the radiated electric field was calculated from this cunent. The matrix elements representing the transmission line between conductors and shield were determined from the measurement, and the transfer impedance was also determined from the measurement. The line constants between shield and grnund were determined from the theory by assuming the shield as a copper rnd. The maximum cunent on the outside of the shield and the maximum radiated electric field were measured in the frequency range from 30 MHz to 300 MHz, and these were compared to the calculated value. The calculation results of the maximum cunent intensity were well agreed with the measured value, and the calculation results of the maximum radiated electric-field strength were almost agreed with the measured value.

Best EMC Paper Finalist

13:55 **Multi-Output Variable-Fidelity Bayesian Optimization of a Common Mode Choke** 1093

Rodrigo Silva Rezende[1], Mirsad Hadžiefendić[1], Jan Hansen[2], Rolf Schuhmann[1]
[1]Technische Universitat Berlin, Germany; [2]Robert Bosch GmbH, Germany

Abstract: In this paper, we propose a modification of the wellknown kriging modeling technique and its multi-fidelity variant in order to generate a surrogate model of a vector-valued output of a common mode choke. Combined with Bayesian optimization, we solve a multi-objective optimization problem to find the tradeoff between inductance, total volume, and resonance frequency. With the proposed method, we calculate a Pareto front of the objective functions more than 200 times faster compared to the solution without the surrogate.

Best EMC Student Paper Finalist

14:20 **Network Model of a Transmission Line with a Cable Ferrite for Simulation in LTspice** 1099
Steffen Schulze[1], Moawia Al-Hamid[2], Marco Leone[2]
[1]Würth Elektronik eiSos GmbH, Germany; [2]Otto-von-Guericke University, Germany

Abstract: Cable ferrite sleeves are common suppression components for reducing common-mode noise on wires and cables. This paper continues previous work on the characterization of those components regarding their electrical parameters. In this paper the parameters of a low-permeability nickel-zinc ferrite sleeve are extracted using the core geometry and measured permittivity and permeability data up to 5 GHz. Then a lumped element transmission line model, including the ferrite, is set up as a netlist for numerical circuit simulation in LTspice®. From the results the current distribution along the transmission line is extracted at different frequencies and compared with the analytical solution. In the second part a 3D full-wave model of the transmission line, created and simulated in CONCEPT-II, is presented. The results of this approach are compared with the analytical solution for the current distribution, showing a perfect match.

14:45 **Data-Driven Discovery of the Governing Equation for the Transmission Lines System** 1105
Yanming Zhang, Lijun Jiang
The University of Hong Kong, Hong Kong

Abstract: Sophisticated structures in the transmission line system introduce the nonuniformity and nonlinearity, which brings the challenge for its characterization and modeling. In this work, a novel data-driven method is proposed to derive the governing partial differential equations of the transmission line. Based on the polynomial interpolation of the spatialtemporal samples of current and voltage, the time and spatial derivatives can be obtained. Then, the ridge regression algorithm is adopted to determine the active spatial differential terms from the candidate functions. Three benchmarks, the uniform and nonuniform transmission line, and a soliton generation system, are provided to demonstrate the validity of the newly proposed approach.

TP-FRI-7B High-Speed Link/Bus Design 3 (Sponsored by TC-10) 13:30 - 15:30

Chair: Bo Pu, Missouri University of Science and Technology, Rolla, MO, USA
Co-Chair: DongHyun Kim, Missouri University of Science and Technology, Rolla, MO, USA

13:30 **A Review of Kramers-Kronig Integral Relations for Signal Integrity Applications** 1110
Ravi Shaw[1], Gerardo Romo Luevano[2], Timothy Michalka[2]
[1]Qualcomm India Private Limited, India; [2]Qualcomm Technologies, Inc., USA

Abstract: This paper presents an overview and applications of the Kramers-Kronig (K-K) integral equations which are used to characterize a causal system. The conventional form of the KK integral is discussed which involves a singularity in the integrand. A modified form of the K-K integral is presented which removes the singularity in theory. The causal dielectric permittivity model proposed by Djordjevic-Sarkar is used to demonstrate the evaluation of K-K integral using standard numerical integration techniques. Also, examples of passive impedance network and causal transmission line models are considered. Three different implementation methods of the K-K integral are shown, and their errors are compared. The results show a good match between the original data and K-K integral retrieved data.

13:55 **The Sensitivity of ENRZ to Crosstalk – In Comparison to NRZ, PAM3, and PAM4** 1116
Sherman S. Chen, Zhifei Xu, Brian Holden, Armin Tajalli
Kandou Bus, United Kingdom

Abstract: In this article the performances of ENRZ (Ensemble NRZ) under the interferences of crosstalk, in conjunction with NRZ (Non-Return-to-Zero), PAM4 (Pulse Amplitude Modulation of 4-level), and PAM3 are investigated. Two typical crosstalk patterns with varying levels of crosstalk are studied. The simulation results and the underlying causes are analyzed. Overall, ENRZ shows more robustness than NRZ, PAM3, and PAM4 in terms of crosstalk.

14:20 **LPDDR5 (6.4 Gbps) 1-tap DFE Optimal Weight Determination** 1122

Sunil Gupta
Qualcomm Technologies, Inc., USA

Abstract: SI (Signal Integrity) analysis of a LPDDR5 SoCDRAM PoP (Package-on-Package) system using 1-tap DFE (Decision Feedback Equalization) is presented. The system was running at 6.4 Gbps with 0.47V VDDQ at SS corner. The DFE mitigates the reflection based ISI and results in improved eyeaperture. DFE has been extensively used in serial differential interfaces such as USBSS and PCIe but their use in LPDDR5 parallel single-ended interface is new and presents unique challenges as the JEDEC standard hexagonal eye-mask defines two timing specifications, namely @Vref+/-0mV and @Vref+/- 50mV. Vref being the reference voltage in the eye center used for measuring the eye-opening. Based on the channel analyzed, during Writes, the optimal 1-tap DFE feedback-weight was ~5mV which improved eye-aperture @Vref+/-50mV without degrading the eyeaperture @Vref+/-0mV. Further increasing the feedback-weight resulted in over-equalization causing the eye-aperture @Vref+/- 0mV to decrease even though the eye-aperture @Vref+/-50mV kept increasing.

TP-FRI-8B IBIS based Power Integrity Modeling (Sponsored by TC-10 and SC-5) 13:30 - 15:30

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

13:30 **Improving Power Supply Induced Jitter Simulation Accuracy for IBIS Model** 1127

Yin Sun[1], Chulsoon Hwang[2]
[1]Zhejiang Lab, China; [2]Missouri University of Science and Technology, USA

Abstract: This work presents a new algorithm for improving the simulation accuracy of power supply induced jitter (PSIJ) in input/output buffer specification (IBIS) model. The improvement is realized by modifying the switching coefficient Ku and Kd as a function of both time and power rail voltage. The incorporation of time averaged effect of the power rail noise on buffer output switching edge during the time range of buffer propagation delay is the key element for the enhanced accuracy. In addition, implementation of the proposed algorithm in an open source spice simulator Ngspice is demonstrated. The accuracy of the proposed new algorithm is validated through transistor level circuit simulations.

13:55 **Time Domain Continuous-Time Model of Current Mode Buck Converter for Power Delivery Network Design**..... 1133

Anfeng Huang[1], Jingdong Sun[1], Hongseok Kim[1], Jun Fan[1], Zhenxue Xu[2], Shuai Jin[2], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]Google Inc., USA

Abstract: Proper power integrity (Pl) analysis is essential for modern electronics devices to minimize voltage noise. The lowfrequency response of a power distribution network (PDN) is determined by the voltage regulator modules (VRMs) installed on the board. However, the conventional VRM model is either represented by an over-simplified passive circuit or an encrypted model provided by then vendor. These models can only work for limited operating conditions. In this paper, a generic average model for up-to-date DC converter is proposed. Both time and frequency domain responses of a current-mode buck converter with adaptive on-time control (AOT) method are captured by the proposed model. This cycle-by-cycle averaged model can be extended for converters with other control methods.

Best SIPI Student Paper Finalist

14:20 **A Behavior Model of Voltage Regulator Module with Adaptive Voltage Positioning and PCB Parasitics for Power Distribution Network Design** 1139

Junho Joo[1], Anfeng Huang[1], Runbing Hua[1], Bin-Chyi Tseng[2], Hank Lin[2], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]ASUSTek Computer Inc., Taiwan

Abstract: In this paper, a behavior modeling method of a buck converter with adaptive voltage positioning (AVP) and PCB parasitics for power distribution network design (PDN) is introduced. The behavior model of voltage regulator module (VRM) is previously proposed for the power integrity modeling and analysis. The proposed behavior model is applied to the buck VRM in a practical high-speed digital board. For the completeness of the behavior model, an AVP design and PCB parasitics are applied to reproduce the power supply rail noise in the practical design. To validate the behavior model, the design parameters of voltage and current controllers of buck VRM in the board are extracted based on the measurement. The proposed model shows a good correlation with the measurement under various loading conditions.

SS-FRI-B Robust Design for System Level ESD: Device, PCB and System Level 13:30 - 15:30

Chair: David Pommerenke, Technische Universitat Graz, Graz, Austria
Co-Chair: Mike McInerney, Consultant, Champaign, IL, USA

13:30 **A Portable Test Platform for Capturing ESD Induced Fields** 1144
Nikola Becanovic, Seyed Mostafa Mousavi, Gabriel Fellner, David Pommerenke
Technische Universität Graz, Austria

Abstract: As a first step in a survey of the ESD risk to mobile devices, a small, battery powered portable system that emulates a mobile device for the purpose of capturing its electrostatic discharge environment is described. The system contains multiple electric, magnetic field sensors as well as a current sensor to capture ESD events and their associated transient fields. Bandwidths of > 2 GHz are achieved. The system is connected via an analog optical fiber. It is intended to provide reference data of fields captured in controlled conditions in order to determine the type and voltage of ESD discharges with these data in the second step. This will provide a data base of the occurrence rate and severity of ESD discharges at customer side. Goal is to better base the selection of ESD test levels on actual ESD levels.

13:55 **New Implicit ESD Test Methodology and Simple Simulation Method for ESD Risk Evaluation** 1149
Scott Lee[1], Leo Wu[2], Kyle Chang[2], Ray Huang[2], Joseph Lin[2]
[1]Ring, Taiwan; [2]Quanta Computer Inc., Taiwan

Abstract: ESD test [1] is essential for IT product certification. While, usual test methodology requires complex system setup and have device damage risk. And, it is time consuming to evaluate ESD risk by current simulation method. Hence, this paper introduces new implicit ESD test methodology by using thermocouple to visualize discharging path and avoid complex process for system setup and device damage risk. Then, a simple simulation method to use s-parameter to check ESD risk by energy leakage examination are introduced as well to shorten simulation time required for ESD risk evaluation of board design.

14:20 **Effect of Approach Speed on Spark Length determining Air Discharge Current from ESD Generator in Environment with Different Temperature and Humidity** 1153
Takeshi Ishida[1], Yukihiro Tozawa[1], Osamu Fujiwara[2]
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Abstract: An air discharge current waveform for immunity testing is largely affected by various factors such as test voltage, approach speed, ambient temperature (T) and relative humidity (RH). For investigating the combined effect of the approach speed and climatic conditions on the air discharge current, we previously measured air discharge currents from an electrostatic discharge (ESD) generator with test voltages from 2 kV to 15kV at two approach speeds of 80 mm/s and 20 mm/s under 6 combinations of T and RH in the IEC specified and non-specified climate range. The result showed that the effect of the approach speed on air discharges significantly differ depending on whether the climate condition is within the IEC specified range or the IEC non-specified range. Under the IEC specified climate conditions, at a test voltage of 15 kV, the 80 mm/s causes the discharge current peak that decreases as the absolute humidity (AH) increases, whereas the 20 mm/s gives the peak less affected by the AH. Under the IEC non-specified climate conditions, the current peak decreases regardless of the approach speed when the AH increases. In this study, to examine why the above findings occurred at different approach speeds in particular, we estimate the spark lengths for air discharges of the ESD generator from our previously measured air discharge currents. As a result, under the IEC specified climate conditions, at a test voltage of 15 kV, the 80 mm/s gives the spark length that increases as the AH increases, whereas the 20 mm/s causes the longer spark length than the 80 mm/s, which is almost unaffected by the AH. Under the IEC nonspecified climate conditions, the spark length increases regardless of the approach speed when the AH increases. A spark length dependence on the current peak is exhibited to be on a specific curve according to the test voltages from 2 kV to 15 kV regardless of the approach speeds and climatic conditions. This property is quantitatively analyzed by using a simplified equivalent circuit of ESD generator based on the IEC standard.

14:45 **SEED Modeling of an ESD Gun Discharge to a USB Cable Surrogate** 1159

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Abstract: An IC protected by a transient voltage suppression (TVS) diode may fail if the TVS device does not turn on or does not turn on quickly enough, causing the IC to take the full brunt of the ESD event. System Efficient ESD Design (SEED) simulation can help predict when the TVS will turn on and the level of ESD stress seen by the IC. In the following paper, models are developed to predict the voltage and current through a TVS and on-chip protection diodes connected to a USB cable when an ESD gun discharges to a pin at the end of the cable. A hybrid simulation methodology is proposed, which uses a full-wave model of the ESD gun, cable, and enclosure combined with the ESD protection devices and test board's circuit-level models. The response of the ESD protection is studied in simulation and measurement for a variety of cable configurations. Simulations of the voltage and current waveforms match measurements 24-35%. The total charge delivered to the on-chip diode as a function of ESD gun voltage was predicted within 21%.

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