2022 IEEE International Symposium on Electromagnetic Compatibility & Signal/Power Integrity (EMCSI 2022)

Spokane, Washington, USA
1 – 5 August 2022

IEEE Catalog Number: CFP22EMC-POD
ISBN: 978-1-6654-0930-8

****** This is a print representation of what appears in the IEEE Digital Library. Some format issues inherent in the e-media version may also appear in this print version.***

IEEE Catalog Number:	CFP22EMC-POD
ISBN (Print-On-Demand):	978-1-6654-0930-8
ISBN (Online):	978-1-6654-0929-2

Additional Copies of This Publication Are Available From:

Curran Associates, Inc
57 Morehouse Lane
Red Hook, NY 12571 USA
Phone: (845) 758-0400
Fax: (845) 758-2633
E-mail: curran@proceedings.com
Web: www.proceedings.com

TABLE OF CONTENTS

MONDAY – AUGUST 1, 2022

TU-MO-AM-1 Fundamentals of EMC
(Sponsored by Education Committee)

Tutorial **8:30am - 5:30pm**
Room: 401A+B
Chair: John C. McCloskey, NASA/Goddard Space Flight Center, College Park, MD, USA
Co-Chair: Jen Dimov, NASA, Bowie, MD, USA

Session Abstract: A mainstay of the symposium, sponsored by EdCom.

This tutorial is an overview of many of the major topics that need to be considered when designing an electronic product or system to meet signal and power integrity (SIPI) and electromagnetic compatibility (EMC) requirements. The tutorial will present the foundational ideas from physics and mathematics and will demonstrate the engineering approaches to help the attendees to successfully design, evaluate, diagnose, and/or solve EMI problems. The main objective of this tutorial is to provide a learning opportunity for those that are new to EMC as well as provide a review of the basics to those who already have some experience in this area.

Conducted Emissions...N/A
Lee Hill[1,2,3]
[1]SILENT Solutions LLC, USA; [2]SILENT Solutions GmbH, Germany; [3]Worcester Polytechnic Institute, USA

Radiated Emissions...N/A
Cheung-Wei Lam
Apple Inc., USA

Radiated Electric and Magnetic Field Emissions Shielding Mitigations...N/A
Pablo Narvaez
Jet Propulsion Laboratory, USA

The Yin/Yang Relationship between Conducted and Radiated Coupling...N/A
John C. McCloskey
NASA Goddard Space Flight Center, USA

TU-MO-AM-2 Automotive EMC Standards and Instrumentation Update (Sponsored by TC-2)

Tutorial **8:30am - 12:00pm**
Room: 401C
Co-Chair: Garth D'Abreu, ETS-Lindgren, Cedar Park, TX, USA
Co-Chair: Craig Fanning, Elite Electronic Engineering, Inc., Downers Grove, IL, USA

Session Abstract: This tutorial will provide key updates to the global Automotive EMC Standards as well as review proposed changes to address the rapidly developing automotive industry. Experts actively involved and leading the global automotive standards committees will share the trends affecting changes to the standards and reasoning behind these changes. Attendees will quickly learn what is new in these standards, what to expect in the new revisions, what to anticipate in future standards based on automotive technology trends, and how this may influence their current EMC test and measurement activity. Attendees will also have a chance to contribute directly to the new standards revisions.

Automotive Standards Development by CISPR/D: Review of CISPR 12, CISPR 36 and CISPR 25...N/A
Craig Fanning
Elite Electronic Engineering, Inc., USA

Automotive Standards Development by CISPR/D Review of CISPR 12, CISPR 36, and CISPR 25...N/A
Craig Fanning
Elite Electronic Engineering, Inc., USA

EMC for Integrated Circuits – Test Methods for Vehicular Applications...N/A
Bob Mitchell
TÜV Rheinland N.A., USA

Evaluating Measurement Repeatability in Reverb Chambers...N/A
Garth D'Abreu
ETS-Lindgren, USA

Efficient Measurements Using Receivers and Measurement Detectors for Current and Future Automotive Test Applications...N/A
Jeremy Cline
Rohde & Schwarz, USA

TU-MO-AM-3 Recent Advancements in HEMP, EMP, and IEMI Protection – A Global Perspective

Tutorial **8:30am - 12:00pm**
Room: 402A
Chair: Tara Kellogg, ETS-Lindgren, Cedar Park, TX, USA
Co-Chair: Frank Sabath, Bundeswehr Research Institute for Protective Technologies and NBC Protection, Garstedt, Germany

Session Abstract: Despite the threats posed by High-Altitude Electromagnetic Pulse (HEMP), Electromagnetic Pulse (EMP) and Intentional Electromagnetic Interference (IEMI), limited emphasis has been placed on the protection of "critical infrastructure". In recent years, protection of critical infrastructure from the effects of HEMP, EMP, and IEMI events has been increasing with governments and industries placing more urgency on the need for protection. With heightened emphasis on protecting critical infrastructure and limited direction from governments, industries are struggling to quantify the threat posed by HEMP, EMP, and IEMI and to identify cost effective yet viable protection solutions.

Speakers in this tutorial will address the challenges to those industries considered "critical infrastructure", such as utilities (power, water, gas) and services (data, financial, communication). The tutorial will begin with an overview of various technologies and the latest real-world solutions that have been deployed to harden facilities. An example will be shared of an EMP/IEMI hardening solution developed around the IEC-61850 standard - including the design, deployment, and cost benefit analysis. The tutorial will then provide a global review by experts from industry and government, who will discuss their respective R&D activity. Attendees will receive a global overview on HEMP/EMP/IEMI protection solutions currently being implemented in the United States, Europe, and the Middle East.

EMP and IEMI Mitigation Strategies...N/A
Tara Kellogg
ETS-Lindgren, USA

Recent Advancements in HEMP, EMP, and IEMI Protection – A Global Perspective...N/A
Eric Easton
CenterPoint Energy, USA

EMP Protection of Infrastructures with Alternative Shielding Strategies...N/A
Nicolas Mora
Technology Innovation Institute, United Arab Emirates

Tolerance Values and Confidence Level of HEMP System Tests...N/A
Frank Sabath
Bundeswehr Research Institute for Protective Technologies and CBRN Protection, Germany

WS-MO-AM-4 Low Frequency EMI and Modelling of Conducted Interference in Systems with Multiple Converters (Sponsored by TC-7)

Workshop **8:30am - 12:00pm**
Room: 402B
Chair: Denys Pokotilov, Universiteit Twente, Enschede, Netherlands
Co-Chair: Karol Niewiadomski, University of Nottingham, Nottinghamshire, United Kingdom

Session Abstract: With the increasing complexity of the main grids of electrical power generation and consumption, the investigation of the radiated and conducted EM emissions becomes the main research task. One of the main emission sources is power converters which have a high impact on the operation of all in-grid devices. Due to the different working frequencies, the spectrum of outgoing emissions could vary from several kHz to several tenth MHz and higher, while a lot of problems are reported for the low-frequency range (2-150 kHz). This leads to poor electromagnetic compatibility between the interconnected devices and the grid, resulting in extra costs to reduce the emissions. Manufacturers and engineers are required to consider the complex interactions between devices present in the grid. However, in order to predict such interactions, the behavior of the system, where multiple interference sources are present needs to be understood. This IEEE+SIPI 2022 workshop aims to discuss the existing problems and methodologies to model and predict the Conducted Interference caused by multiple converters present in the system, with particular attention to the low-frequency range.

Assessment of the Aggregation and Propagation of Conducted Emissions in Power System...N/A
Dave Thomas
University of Nottingham, United Kingdom

Pearson's Random Walk Approach to Evaluating Interference Generated by a Group of Converters...N/A
Robert Smolenski
Uniwersytet Zielonogórski, Poland

Modelling of Power Converters as Sources of EMI in Modern Power Networks...N/A
Antonella Ragusa
INM-National Council of Research (CNR), Italy

Common-Mode EMI Noise Analysis and Reduction for AC-DC-AC Traction Systems with Paralleled Power Modules...N/A
Shuo Wang
University of Florida, USA

TU-MO-AM-5 EMC Testing Basics (Sponsored by TC-2)

Tutorial **8:30am - 12:00pm**
Room: 402C
Chair: Doug Kramer, ETS-Lindgren Inc., Cedar Park, TX, USA
Co-Chair: Bob Mitchell, TÜV Rheinland North America, Townsend, MA, USA

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

What are EMC Tests Actually Measuring?...N/A
Todd Hubing
LearnEMC, USA

EMC Basics – Test Planning...N/A
Jack McFadden
ETS-Lindgren, USA

Antennas for EMC...N/A
Alistair Duffy
De Montfort University, United Kingdom

Calibration of EMC Test Equipment...N/A
Doug Kramer
ETS-Lindgren Inc., USA

EMC Lab Design: An Overview of the Process, Possibilities, and Issues...N/A
Bob Mitchell
TÜV Rheinland N.A., USA

TU-MO-PM-2 Automotive EMC – Advances in Design and Test Methodologies

Tutorial **1:30pm - 5:30pm**
Room: 401C
Co-Chair: Garth D'Abreu, ETS-Lindgren, Cedar Park, TX, USA
Co-Chair: Robert Kado, Stellantis US, Grosse Pointe, MI, USA

Session Abstract: The introduction of new international standards for EMC is a slow and laborious process that generally lags the introduction of new automotive technology. The trend toward higher levels of autonomy and electric vehicles is driving the need for more sophisticated automotive EMC design and test scenarios. Vehicle platforms continue to become increasingly more complex with different versions of electric propulsion, entertainment, and safety related systems all having to function reliably without affecting safety or the legacy communications infrastructure. The safety and reliability requirements for modern vehicles could rival the requirements for aerospace and military systems, but this must be accomplished without the levels of system redundancy and verification seen in these industries. New automotive safety standards are helping to redefine automotive design management; but fundamental changes will also be required to the way designs are engineered and tested. In this tutorial, experts from industry and academia will share the latest developments in automotive EMC and related standards to address these emerging automotive trends.

Evaluating the Test Environment Options Available for Todays Vehicles...N/A
Garth D'Abreu
ETS-Lindgren, USA

Some Automakers Need to Rethink the Way They're Grounding Components in Autonomous Vehicles!...N/A
Todd Hubing
LearnEMC, USA

Test Procedures to Assess the Immunity of Automotive Electronics by the Use of Near-Field Probes...N/A
F. Grassi[1], X. Wu[1], G. Spadacini[1], S.A. Pignari[1], U. Paoletti[2], I. Hoda[2]
[1]Politecnico di Milano, Italy; [2]Hitachi, Japan

Comparison of Automotive EMC Testing in Reverberation vs Anechoic Chambers...N/A
Andreas Lundberg
RISE Research Institutes of Sweden, Sweden

EMC Challenges and Design Considerations for Electric Vehicles (EVs)...N/A
Michelle Liu, Rodrigo Rodriguez
Tesla Inc., USA

TU-MO-PM-3 Model Based System Engineering, Mode Filtering, Robotics: Modern Antenna Measurement Techniques for EMC and RF Applications (Sponsored by TC-9)

Tutorial **1:30pm - 5:30pm**
Room: 402A
Co-Chair: Zhong Chen, ETS-Lindgren, Cedar Park, TX, USA
Co-Chair: Dennis Lewis, The Boeing Company, Seattle, WA, USA

Session Abstract: Antennas are used in diverse environments for radiated EMC as well as RF measurements. Accurate calibration and characterization have a direct impact on the uncertainties of radiated measurements. During calibrations, the antenna test environment can be well controlled, but it may not with the antennas, and how the overall measurement uncertainties are affected. While traditional antenna and EMC test facilities are designed with specific measurement applications in mind, modern test facilities employing multi-axis robotic positioners provide a near limitless degree of re-configurability in terms of measurement types and scan geometries. This new type of testing may be applied to EMC and 5G test applications as well.

One of the goals of the tutorial is to address antenna measurements in diverse and often complicated test environments. Advances in the latest research in antenna measurements, modeling, and robotics are presented.

A New Concept to Enhance Site VSWR for Anechoic Chamber Performance Evaluation Using Mode Filtering Techniques
Zhong Chen
ETS-Lindgren, USA

Simulation of Antenna Measurements Using Model based System Engineering (MBSE)...N/A
Dennis Lewis
The Boeing Company, USA

Advances and Gain Extrapolation Measurements Using Robotic Measurements
Greg Masters
Next Phase Measurements, USA

TU-MO-PM-4 Introduction to Power Electronics Electromagnetic Interference Analysis and Suppression

Tutorial **1:30pm - 5:30pm**
Room: 402B
Chair: Shuo Wang, University of Florida, Gainesville, FL, USA
Co-Chair: Cong Li, GE Global Research, Niskayuna, NY, USA
Co-Chair: Chulsoon Hwang, Missouri University of Science and Technology, Rolla, MO, USA

Session Abstract: Nowadays, power electronics is widely implemented in almost all electronic and electrical products. Switching mode power conversion is employed to increase energy conversion efficiency and increase power densities. On the other hand, the switching voltages and currents lead to electromagnetic interference (EMI) which can compromise the normal operation of other circuits or equipment nearby. To help engineers to understand the power electronics EMI and solve EMI problems, we are organizing this tutorial to introduce the fundamentals of EMI analysis, simulation and suppression. The speakers are from both academia and industry companies.

EMI Issues and Solutions in PWM Power Converters...N/A
Rudy Wang
Delta Electronics, USA

Understand the EMI Using Circuit Simulation and Analysis Method...N/A
Zheng Luo
Monolithic Power Systems, USA

Systematic WBG EMC Solutions and Weight Impacts for Aviation Applications...N/A
Cong Li
GE Research, USA

Magnetic Component Characterization and Design to Suppress EMI in Power Electronics Systems...N/A
Shuo Wang
University of Florida, USA

TU-MO-PM-5 Introduction to 5G and Related Health Effects Issues (Sponsored by TC-3)

Tutorial **1:30pm - 5:30pm**
Room: 402C
Chair: Robert Olsen, Washington State University, Pullman, WA, USA

Session Abstract: In this session, an introduction to the unique characteristics of 5G communication systems will be given along with a discussion about measurement of 5G electromagnetic fields. Of special interest is the recent claim that there are issues about human exposure to 5G electromagnetic fields that are different from those relating to earlier versions of cellular communication systems. These will be discussed. Finally, recent experience with planning, permitting and siting of 5G systems will sumarized.

Introduction to 5G and RF Exposure Issues...N/A
Robert G. Olsen
Washington State University, USA

RF Exposure Limits...N/A
Kenneth R. Foster
University of Pennsylvania, USA

5G in Wireless...N/A
Jason Verduzco
Verizon Wireless, USA

5G Field Measurement Challenges...N/A
Steven D. Schennum
Gonzaga University, USA

TUESDAY – AUGUST 2, 2022

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

Room: Exhibit Hall
Chair: Robert G. Olsen, Washington State University, Pullman, WA, USA

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

Understanding the Havana Syndrome

PLANNED PANELISTS INCLUDE:

- Ken Foster (ret.), Department of Bioengineering, University of Pennsylvania, IEEE Fellow, who had studied the Microwave Auditory (Frey) Effect and is one of the authors of the recently published article, "Can the Microwave Auditory Effect be 'Weaponized'?"
- William Radasky of Metatech Corp., IEEE Fellow, who is well-known to the EMC community as an expert in the area of Intentional Electromagnetic Interference.

Abstract: According to a 2020 US National Academy report, "in late 2016, U.S. Embassy personnel in Havana, Cuba, began to report the development of an unusual set of symptoms and clinical signs." for some of these patients, their case began with the sudden onset of a loud noise, perceived to have directional features, and accompanied by pain in one or both ears or across a broad region of the head, and in some cases, a sensation of head pressure or vibration, dizziness, followed in some cases by tinnitus, visual problems, vertigo, and cognitive difficulties. One conclusion of the report was that, "Overall, directed pulsed RF energy, especially in those with the distinct early manifestations, appears to be the most plausible mechanism in explaining these cases among those that the committee considered." In this panel session, two experts, one in biophysical mechanisms and one in high power electromagnetics, will discuss whether this conclusion is or is not reasonable.

Experiments & Demonstrations 10:00am - 12:00pm

Room: Hall A Experiments and Demos
Co-Chair: Gabe Alcala, Advanced Test Equipment Corp. (ATEC), San Diego, CA, USA
Co-Chair: Jacob Dixon, IBM, Rochester, MN, USA

Session Abstract: As a result of the Call for Experiment and Demonstration Proposals, we are pleased to announce the accepted proposals below that will be presented at the 2022 IEEE International Symposium on Electromagnetic Compatibility, Signal and Power Integrity, August 1-5, in Spokane, Washington. You will not want to miss the popular Experiments and Demonstrations program that will be held in the Exhibition Hall on August 2-4. This hands-on activity provides a unique learning experience that complements the technical presentations at the symposium. It is traditionally one of the educational highlights of the annual symposium!

The Benefits of a Novel Wideband EMI Receiver Concept...N/A

Matthias Keller[1], Jeremy Cline[2]
[1]Rohde & Schwarz, Germany; [2]Rohde & Schwarz, USA

Abstract: Modern EMI test receivers use Fast Fourier Transformation (FFT) to speed up measurements by magnitudes. The vendors of FFT-based EMI test receivers have been working to increase the FFT bandwidth since these instruments were introduced more than 15 years ago. But a wider FFT bandwidth is posing a challenge to the dynamic range of the receiver. This demonstration introduces a novel receiver concept to achieve faster measurements and a wider real-time bandwidth without compromising dynamic range. In addition to explaining the motivation behind the new concept, this demonstration will use actual real-world examples to illustrate the advantages of the new technology in different EMI testing scenarios.

Shielded Cable Terminations' Impact to Shielding Effectiveness for Aviation Wide Band Gap Converter Applications...N/A

Cong Li, Xuan Yi
GE Global Research, Niskayuna, New York, USA

Abstract: This work demonstrates shielded cable terminations' impacts to shielding effectiveness for Aviation Wide Band Gap (WBG) Converter applications.

A modified cable Shielding Effectiveness (SE) test setup Based upon SAE ARP5416A Figure 34 will be presented. This test setup will be firstly used to compare the impacts of cable termination to the cable's individual SE performance. Different cable terminations' SE performance will be experimentally shown.

This setup will also be used to demonstrate the cable's systematic SE performance when it is integrated in a representative aviation motor drive system, which include power converter, shielded cable and motor. This cable's systematic SE performance will also be experimentally shown and compared against individual SE.

Common Mode Conducted Susceptibility Testing – A Simplified Method...N/A

John McCloskey, Jen Dimov
NASA/Goddard Space Flight Center, College Park, Maryland, USA

Abstract: Discussion of alternate and simplified method of performing common mode conducted susceptibility (CMCS), also known as bulk cable injection (BCI) on power and signal cables in order to assess a test article's susceptibility to common mode currents induced on its interconnecting cables. Suggestions are provided to perform the test in a more time-efficient manner while still meeting all objectives.

Assessment of a test article's susceptibility to common mode currents induced on its interconnecting cables can be a very powerful tool in an EMC engineer's toolkit. It can facilitate early diagnosis of potential crosstalk and radiated susceptibility problems, and they may be performed right in the hardware developer's laboratory before the equipment is ever brought to an EMI test chamber.

This demonstration shows how the complex procedure defined by the MIL-STD-461G CS114 test method may be drastically simplified to require only the signal source, measurement receiver/analyzer, injection clamp, and monitor probe. No directional couplers or software control is needed, which facilitates its use outside of a formal qualification venue.

This demonstration shows techniques that limit the available power that may be injected into any test cable, thus simplifying the setup and eliminating the need for a complex control loop that unnecessarily increases the test time. When properly implemented, these techniques can significantly reduce the test time per cable while still meeting all test objectives.

Using this approach, even a test article with a large number of cables can complete CMCS testing in a few hours, thus making it a much more attractive option than the full method specified in MIL-STD-461G.

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

Technical Papers **10:20am - 11:10am**
Room: 401B
Chair: Emmanuel Decrossas, NASA Jet Propulsion Laboratory, Pasadena, CA, USA
Co-Chair: Marina Koledintseva, Boeing Defense Space and Security, St. Charles, MO, USA

10:20am **High Permittivity Anisotropic 3D Printed Material** 1
Aaron Harmon, Victor Khilkevich, Kristen M. Donnell
Missouri University of Science and Technology, USA

Abstract: In this work, the diagonal elements of the permittivity matrix for dielectric samples, 3D printed with a carbon fiber-loaded material (XT-CF20), are measured for frequencies within the range of 1 MHz to 18 GHz. These permittivity measurements demonstrated a strong anisotropy, indicating that the electromagnetic properties of the CF20 material depend on the infill method used to print. The importance of understanding the anisotropy for microwave device design is demonstrated via a dielectric-loaded cavity resonator application.

10:45am **Graphene-Based Electromagnetic Absorbing Textiles for 5G Frequency Bands** 7
A.G. D'Aloia, H.C. Bidsorkhi, A. Tamburrano, M.S. Sarto
Sapienza University of Rome, Italy

Abstract: The feasibility of graphene Based absorbing textiles for electromagnetic absorption at 5G frequency bands is investigated. With this aim, a novel manufacturing method for the production of polyvinylidene fluoride (PVDF) coatings filled with graphene nanoplatelets is investigated. The produced samples are morphologically characterized and the electrical and electromagnetic properties are assessed. In particular, the effective complex dielectric permittivity is measured in the Ku-band and the results are used to predict by simulations electromagnetic properties of the graphene Based coatings for frequencies up to 40 GHz. Finally, the radar absorption properties are measured for frequencies up to 40 GHz.

TP-TU-AM-TC12 EMC for Emerging Wireless Technologies (Sponsored by TC-12)

Technical Papers **10:20am - 12:00pm**

Room: 401C

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

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

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

10:20am **Passive Intermodulation under Different Spring Contact Conditions** 12

Shengxuan Xia[1], Emmanuel Olugbade[1], Yuchu He[2], Yansheng Wang[2], Hanfeng Wang[2], Krishna Rao[2], Marco Poort[2], Haicheng Zhou[2], Warren Lee[2], Nicholas McDonnell[2], Jonghyun Park[1], Chulsoon Hwang[1]

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

Abstract: Modularized designs have been widely used in today's consumer electronic devices and flexible RF springs are used for electrical connections between the modules. In the meantime, aluminum alloy material becomes a common chassis option. It is well known that the oxidized chassis surface introduces a certain level of nonlinearity when contacted by the springs, as known as passive intermodulation (PIM). PIM is one of the well-known root causes of the RF desensitization (desense). This paper is focused on investigating the relationship between PIM and contact conditions of the springs, especially contact area. The PIM level behavior is explained mathematically by the regrowth rate and the RF power distributions on the contacts. Full-wave simulations and mechanical simulations were conducted to further support the hypothesis.

10:45am **Practical Fixture Design for Passive Intermodulation Tests for Flexible Metallic Contacts** 17

Shengxuan Xia[1], Yuchu He[2], Yansheng Wang[2], Hanfeng Wang[2], George Mankaruse[2], Danny Chan[2], Haicheng Zhou[2], Warren Lee[2], Nicholas McDonnell[2], Chulsoon Hwang[1]

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

BEST EMC STUDENT PAPER FINALIST

Abstract: Passive intermodulation (PIM) commonly exists in non-ideal metallic contacts. Since PIM typically represents an extremely low level of nonlinearity, it has not drawn enough attention over the years except for extremely high-power applications such as base stations. However, in recent years, the study on PIM has become essential in universally used consumer electronics design because of the higher requirement on the radio frequency (RF) sensitivity of wireless communications. The metal contacts caused PIM can create the sideband spectrum to interfere with the receiving band in the frequency divide duplex (FDD) mode. Therefore, the study on PIM for the frequently used flexible metallic components is important in the industry. The PIM characterizations for the flexible components at least demand the compression variability and the capability to inject high-power signals while monitoring the sideband spectrum. It is preferred to have the access to measuring more relevant quantities. This paper aims to summarize the practical experience in designing a high-dynamic range and multi-purpose applicable test setup for characterizing PIM in the flexible components. Capabilities to precisely measure/control PIM, gap variability, tilted angle variability, and DC resistance (DCR) are presented with measurement examples.

11:10am **Clock Duty Cycle Tuning for Desense Mitigation in Modulation – Involved Cases** 23

Shengxuan Xia, Jun Fan, Chulsoon Hwang

Missouri University of Science and Technology, USA

BEST EMC PAPER FINALIST

Abstract: Nowadays consumers' electronic devices are highly integrated, and modules and integrated circuits (ICs) are usually placed close to each other due to the compact size. The modules and ICs may interfere with the radio frequency (RF) antennas and cause desense issues. In recent years, desense caused by direct coupling from the noise sources to the victim RF antennas has been well studied. However, more complicated mechanisms such as modulations between transmitting signals and low-frequency clock or data signals can also result in desense problems, especially in frequency divide duplex (FDD) applications. Typical solutions to desense problems will focus on suppressing the noise sources and/or the coupling paths, and little studies have shown the feasibility that desense in FDD applications can also be mitigated by engineering the spectral power distribution over the frequency range. This paper provides a comprehensive study on how to mitigate desense with the change in the spectrum distribution by tuning the duty cycle of the interfering clock. Measurements conducted on a real cellphone showed a 10 dB suppression of desense for certain TX bandwidth condition.

11:35am **SOC Level mitigations of RFI to Wi-Fi Bands from GDDR6 Clocks** ..... N/A
Siva Krishna Singamsetty, Suresh Krishnasamy, Kinger Cai
Intel Technology India Pvt Ltd, India

Abstract: In modern electronics, RFI (Radio Frequency Interference) caused to the WI-FI bands is a major concern because of the degradation in the Wi-Fi throughput performance. In this paper, the RFI caused to the WI-FI 5G band from GDDR6 Clock harmonics is illustrated with an actual design case. At the system level, the conventional RFI mitigation solutions include a metal case EMI Shielding. With the expansion of WI-FI bands, the conventional EMI shields in metal cases are obsoleting at the 5G frequencies and above. Therefore, the SOC level mitigations such as transition time control and duty cycle correction methods are analyzed to reduce the RFI at the source itself, which helps throughput performance in Wi-Fi bands.

SS-TU-AM-TC10 Solving Complicated SIPI/EMI/Thermal Engineering Issues in Mobile Systems by Using Multiphysics Simulations (Sponsored by TC-10)

Special Session **10:20am - 12:00pm**
Room: 402A
Chair: Jianmin Zhang, Google Inc., Mountain View, CA, USA
Co-Chair: Mingfeng Xue, Google Inc., Mountain View, CA, USA
Co-Chair: Songping Wu, Rivos Inc., Mountain View, CA, USA

10:20am **A Practical Simulation Flow for Singing Capacitor based Acoustic Noise Analysis** 29
Xin Yan[1], Songping Wu[2], Mingfeng Xue[2], Chi Kin Benjamin Leung[2],
Daryl Beetner[1], Jianmin Zhang[2]
[1]Missouri University of Science and Technology, USA; [2]Google LLC, USA

Abstract: Multilayer ceramic capacitors (MLCCs) are widely used in modern electronics. Due to the piezoelectric effect of the ceramic material, however, MLCCs subjected to electrical noise may vibrate and generate acoustic noise, as 'singing'. Acoustic noise can be annoying for users, especially within mobile devices, so it becomes important to perform acoustic noise analysis before a product is released. In this paper, a practical simulation flow for singing capacitor Based acoustic noise is presented. The simulation flow and analysis method are developed on Ansys Sherlock and Mechanical. In Ansys Sherlock, local library and Approved Vendor List (AVL) files were used to build the model efficiently. After the PCB and all parts were set correctly, the model was imported to Ansys Mechanical for further modal analysis and harmonic analysis. Using the proposed simulation flow the simulation model could be easily created, and the inherent vibration properties and frequency response of the structure could be estimated.

10:45am **Investigation of PCB Generated Magnetic Field as an Acoustic Noise Source on Wearable Devices** 34
Yuchu He, Neil Harris, Hanfeng Wang
Google LLC, USA

Abstract: Wireless earbud is the most sold wearable type in the consumer electronics market. As wireless earbuds offer more functionalities, the increased complexity and integration may introduce undesirable coupling between different components. One of the undesirable coupling is the magnetic coupling between the earbud main logic board (MLB) and the speaker coil. The low frequency current ripples on the MLB power rail may induce current with acoustic frequency components on the speak coil and lead to unpleasant audible noise. In this paper, the magnetic field generated by an earbud MLB is investigated through simulation with 3D FEM solvers and measurement with a low frequency H-field probe.

11:10am **Simulation and Analysis to Minimize Audio Noise in System Design** 38
Mingfeng Xue, Yao Ding, Benjamin Leung, Gemin Li, Jianmin Zhang
Google LLC, USA

Abstract: This paper presents a flow of modeling and simulating acoustic noise in a typical earbud design. The noise source investigated is the multi-layer ceramic capacitor, known as singing capacitor, which is widely used on the power delivery network of electronic circuit boards. Good correlation between simulated and measured audio noise spectra is achieved. The developed modeling methodology helps to understand the key factors impacting on audio noise, and to provide a way to identify potential acoustic noise risk at the early design stage. Possible mitigation solutions are also investigated to demonstrate the model flexibility in what-if analysis.

11:35am **Multiphysics Analysis of Induced Acoustic Noise in an Earbud Speaker** 43
Pavani Gottipati[1], Krishna Mellachervu[1], Mingfeng Xue[2], Jingchen Liang[1],
Benjamin Leung[2], Jianmin Zhang[2]
[1]Ansys, Inc., USA; [2]Google LLC, USA

Abstract: Speakers can be sensitive to nearby electronics. Electrical traces carrying high frequency electrical currents can induce electromagnetic current in the voice coil of a speaker. The induced current can cause vibration of the voice coil thereby resulting in audible acoustic noise. This paper provides a Multiphysics simulation workflow to compute the force on voice coil due to the induced electromagnetic field from an aggressor coil placed in the vicinity of the earbud module.

TP-TU-AM-TC4 Electromagnetic Interference – I (Sponsored by TC-4)

Technical Papers **10:20am - 12:00pm**
Room: 402B
Chair: Todd Hubing, LearnEMC, Stoughton, WI, USA
Co-Chair: Wei Zhang, Missouri University of Science and Technology, Rolla, MO, USA

10:20am **The Prospects of Replacing Chattering Relay Susceptibility Test with MIL-STD-461G CS115** 48
John G. Kraemer
Collins Aerospace, USA

Abstract: This paper examines the possibility of replacing the DO-160 chattering relay susceptibility test with MIL-STD-461G CS115. The background of both tests is presented along with the results of a comprehensive test campaign involving 12 different aerospace representative cables. Conclusions and recommendations centered on Using CS115 as a replacement for the chattering relay test are presented.

10:45am **Performances of Multilayer Composite Materials for Broadband Shielding** 54
P. Clerico[1,2], L. Pichon[1,2], O. Dubrunfaut[1,2], X. Mininger[1,2], C. Gannouni[1,2], Y. Liu[1],
D. He[1], J. Bai[1], L. Prévond[1]
[1]Paris-Saclay University, France; [2]Sorbonne Université, France

Abstract: The paper investigates the shielding effectiveness (SE) of multilayers composite materials over a wide frequency band. First, several nanocomposite materials are characterized, and behavior laws are deduced up to several GHz. Then different arrangements involving conductive layers and composite layers are compared. Finally, a three-layer arrangement combining a magnetic material and a conductive sheet is shown to provide a high shielding effectiveness from DC to 10 GHz.

11:10am **3D Printed Multilayer Microwave Absorber** 59
Wei Zhang, Rui Mi, Victor Khilkevich
Missouri University of Science and Technology, USA

BEST EMC PAPER AND BEST STUDENT PAPER FINALIST

Abstract: This paper explores the possibility to create 3D printed multilayer electromagnetic absorbers. The proposed design is similar to the thin-film filters used in optics and consists of interleaving high and low permittivity layers. Based on transmission line theory, the multilayer absorber can be designed in a circuit simulator. Analytical equations, circuit simulations, and measurements are used to analyze and validate the designed absorber. Multilayer absorbers based on 3D printed material can be an inexpensive option for engineering usage with great design flexibility and fast fabrication.

11:35am **A Low EMI Characteristic of LPDDR5 SDRAM with Edge-Placed PADs and Short Re-Distribution Lines** 64

Jun-Bae Kim[1], Chang Ki Kwon[1], Sangwook Park[1], Yoo-Chang Sung[1], Jeong Don Ihm[1], Wooil Kim[1], Jungho Jin[1], Sangjoon Hwang[1], Changsik Yoo[1], Jung-Hwan Choi[1], Jingook Kim[2]
[1]Samsung Electronics Co., Ltd., Korea; [2]Ulsan National Institute of Science and Technology, Korea

Abstract: For mobile DRAM, low EMI (Electro-Magnetic Interference) chip architecture is highly required. So, mobile DRAM's EMI characteristic Using center-placed pads and edge- placed pads has been investigated. Our near-field scan measurement results show that the peak H-field magnitude of LPDDR5 Using edge-placed pads is lower by 11.5 dB than that of the other one Using center-placed pads. Furthermore, when comparing our measurement results to our simulation results showing that the power plane resonance of PoP (Package-on-Package) affects low frequency EMI radiation significantly, we have also noticed reasonable agreement on the peak H-field magnitude trend.

TP-TU-AM-TC10 Passive Component Modeling and Measurement Techniques (Sponsored by TC-10)

Technical Papers **10:20am - 12:00pm**

Room: 402C

Co-Chair: Mingfeng Xue, Google Inc., Mountain View, CA, USA

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

10:20am **Capacitor Model Details Key to Measurement Correlation** 69

Steve Sandler
Picotest, USA

Abstract: Power integrity and system engineers have the task of designing, optimizing, and assessing the power distribution network impedance. EM simulators are used to model these networks to optimize the decoupling capacitors and to perform worst case assessments, Using simulated dynamic chip currents and applying worst case tolerances. Once the hardware is constructed, measurements are performed for correlation, so that the model can be validated. Many engineers struggle to achieve reasonable part model and circuit model correlation. This paper explores two prevalent reasons for this shortfall and provides a methodology for performing accurate capacitor measurements to achieve these correlations.

10:45am **A Deep Neural Network Modeling Methodology for Extraction of RLGC Parameters in µ-Wave and mm-Wave Transmission Lines** 74

Stephen Newberry, Ata Zadehgol
University of Idaho, USA

BEST SIPI PAPER FINALIST

Abstract: Transmission line geometry is one of the most critical aspects of high-speed digital and radio frequency (RF) printed circuit board (PCB) design. While relatively simple equation-based methods exist to estimate transmission line parameters such as characteristic impedance, they do not hold accuracy beyond certain structural limitations such as track width to dielectric thickness ratios. Electromagnetic field solvers have become far more common in recent times and can deliver exceptional accuracy with relatively low computational cost. This paper describes a proof-of-concept neural net which utilizes five input parameters of an uncoated microstrip transmission line and is able to output the per-unit-length equivalent resistance, inductance, conductance, and capacitance (RLGC) parameters. The goal of a deep-learning Based transmission line tool is to enable accurate microstrip and stripline PCB trace design with computation speeds which allow the engineer to compute hundreds or thousands of iterations in a short period of time with commodity hardware. The final model calculates characteristic impedance with less than ±1.33 Ω error for 100,000 swept samples when the samples are within the middle 90% range of the training data and with a computation speed increase of 14.5 times faster than the benchmark field solver.

11:10am **Extraction of Stripline Surface Roughness Using Cross-Section Information and S-Parameter Measurements** 80

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

BEST SIPI STUDENT PAPER FINALIST

Abstract: To characterize additional conductor loss introduced by conductor surface roughness, various models have been proposed to describe the relationship between foil roughness levels and surface roughness correction factor. However, all these empirical or physical models require a PCB sample to be manufactured and analyzed in advance. The procedure requires dissecting the PCB and is time and labor-consuming. To avoid such a process, a new surface roughness extraction process is proposed here. Only the measured S-parameter and nominal cross-sectional information of the board are needed to extract the roughness level of conductor foils. Besides, this method can also deal with boards having non-equal roughness on different conductor surfaces, which is common in the manufactured printed circuit boards (PCB). The roughness level on each surface can be extracted separately to accurately model their contribution to the total conductor loss. The presented method is validated by both simulation and measurement. A good correlation is achieved between extracted roughness level and the measured value from the microscope.

11:35am **Dielectric Loss Tangent Extraction Using Two Single-Ended Striplines of Different Width** 86

Jiangshuai Li[1], Yuanzhuo Liu[1], Liang Liu[1], Shengxuan Xia[1], Scott Hinaga[2], Victor Khilkevich[1]
[1]Missouri University of Science and Technology, USA; [2]Cisco Systems, Inc., USA

BEST SIPI PAPER AND BEST STUDENT PAPER FINALIST

Abstract: Frequency-dependent electrical properties of dielectric materials are one of the most important factors for high-speed signal integrity design. Recently a method of accurately measuring the dielectric loss tangent (tan δ) of differential lines was proposed. By taking into account the ratio between the differential and common mode per-unit-length resistances, the surface roughness contribution to the total loss is eliminated and dielectric parameters can be determined. In this article, a similar method is applied to a combination of two single-ended lines. To evaluate the accuracy of the extraction, the impact of the de-embedding errors was investigated, which allows to optimize the test PCB design. The extraction method was validated in measurement Using a PCB with several two-width pairs of striplines. The extracted loss tangent of several optimal two width pairs of single-ended lines is validated by the SPDR measurements.

POSTER Poster Sessions

Poster Session **1:00pm - 3:40pm**
Room: Hall A
Chair: Dave Arnett, Garmin International Inc., Olathe, KS, USA

Session Abstract: Browse posters and discover the scientific research and findings of your peers

Impact of Antenna Tilt on Measurements below 1 GHz in Anechoic Chamber ..... N/A

Krzysztof Sieczkarek, Adam Maćkowiak
Poznań Institute of Technology, Poland

Abstract: Article shows how the antenna tilt reveals the true nature of radiated emission phenomenon up to 1 GHz

PCB Parameter Extraction for Signal Integrity Modeling 93

Kaisheng Hu
Ciena, Canada

Abstract: PCB material parameters (Dk, Df and surface roughness) are key factors for signal integrity analysis. By Using the parameters within vendor's datasheets directly, simulation result always have big offset compared with lab measurement result due to different production variations. To improve the accuracy of simulation and guarantee a design to be successful for the first-time, one test coupon board is designed, fabricated, and measured. PCB laminate parameters are extracted Based on lab measurements instead of datasheet values. With the extracted parameters and same stack up under same factory production process, high-speed channel simulation can predict transmission line & RF transition's performance on real PCB products with reliable simulation accuracy up to 50 GHz.

Abstract: The wide-scale adoption of electric vehicles may have the capability of efficient and fast charging while the car is in motion or dynamic wireless power transfer (DWPT) technology. Magnetic pad and compensation topology are two major factors affecting the amount of power transfer and efficiency of dynamic wireless power transfer. This article presents an iterative approach to designing magnetic pads and optimization of a double-side LLC compensation network. The optimization of coil pad was performed Using a parametric sweep. Finite-element modeling in ANSYS Maxwell 3D was developed to achieve a desired value of self and mutual inductance of the coils. The effect of coil misalignment was also analyzed. A case study of a 3-kW dynamic wireless power transfer system was simulated under different loads Using MATLAB/Simulink to verify the features of the proposed system. The system showed DC-DC efficiency as high as 97.80% with constant voltage output

Abstract: Development of a portable system to measure broadband electromagnetic emissions in underground mines poses many challenges, the most significant being mitigating the contribution of spectrum analyzer electric field emissions to the composite electromagnetic environment of a survey area. This paper presents a novel method to mitigate a spectrum analyzer's electric field emissions.

WITHDRAWN

Abstract: As a method for shortening vehicle development times, Model Based Development (MBD) is attracting attention. In automotive co[illegible] analyzes the ability to establish Electronic Control Unit (ECU) - harness - ECU communications and reflects this in product design. With the increasing speed of communications in recent years, precisely estimating the amount of attenuation in harnesses is becoming more necessary and how to reduce error in high frequency bands has become an issue. This paper proposes a technique for measuring surface roughness with laser microscopes and modeling it in order to improve the precision of harness models.

Abstract: This work presents a possibility of in-situ characterization of RF gaskets Based on the occurrence of nonlinear transitions resulting from aging and corrosion of used gaskets over time due to, e.g., thermal stress or moisture.

Abstract: This paper proposes a methodology to evaluate the signal integrity of PCB's signal waveforms Using deep learning. The presented method includes the convolutional neural network (CNN) model which can classify automatically the result utilizing images of the high-speed signal waveform measured in the memory circuit. The conventional method is necessary to understand the standard and make an effort to define it to make sure the resulting waveform is evaluated, however, this method can judge pass/fail only with the images of the signal, so it has the advantage to reduce the time (20%) of data processing. In this paper, high-speed signal waveform data of the LPDDR bus were analyzed Using the Altair PollEx simulation tool, and the resulting waveform was processed in Python language for the training. The result showed that compliant waveforms satisfying the signal integrity criteria were found within Epoch4 with high accuracy, which validates the effectiveness of the proposed methodology.

Passive Cross Talk Cancellation (XTC) Techniques to Enable System Miniaturization ..... N/A

Stephen Christianson[1], John Drew[1], Ranjul Balakrishnan[2], Rebecca Castro Artavia[3], Esteban Torres Pineda[3]
[1]Intel Corporation, USA; [2]Intel Corporation, India; [3]Intel Corporation, Costa Rica

Abstract: The accelerating demands of end-users and competing requirements of higher-bandwidth, smaller form-factor memory bus solutions require nonlinear design implementation to continue meeting the requirements of silicon architecture. Passive crosstalk and ISI compensation techniques provide a compelling means for enabling next-generation memory solutions as they are free or low-cost, no- or low-power, and consume minimal real estate. This document details several of the most effective techniques that can be applied on high speed memory buses, each of which yields performance improvements of one or more speed bins and can be placed modularly alongside modern equalization and active crosstalk cancellation schemes.

A Full-Wave FDTD-Circuit Solver for Transient Analysis of Interconnects and Circuit Components ..... N/A

Xuezhe Tian, Yongjun Liu, Yingxin Sun, Mingjin Zhang, Jian Liu
Cadence Design Systems Inc., USA

Abstract: A full-wave 3D FDTD-circuit hybrid method is proposed and applied for transient analysis of systems with interconnects and circuit components. The co-simulation of field and circuit solvers is fulfilled through the internal ports defined between the circuit reference patch and its field connections. The hybrid solver retains the 3D FDTD modeling of distributed interconnects and incorporates lumped circuit physics including active gains and nonlinearity. The behavioral modeling of circuits described by the IBIS (I/O Buffer Information Specification) is also supported in the proposed procedure.

TU-TU-PM-1 Introduction to EMI Modeling Techniques

Tutorial **1:30pm - 5:30pm**
Room: 401B
Chair: Karen Burnham, Electro Magnetic Applications, Inc., Lakewood, CO, USA
Co-Chair: Scott Piper, General Motors Corp., Canton, MI, USA

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

Introduction to the Finite-Difference Time-Domain Modeling Technique...N/A

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

Hybrid Modeling Approaches...N/A

Karen Burnham
Electro Magnetic Applications, Inc., USA

Modeling with the Method of Moments...N/A

J. Drewniak[1], T. Makharashvili[1], X. Tian[1], R. Jobava[2], G. Gabriadze[2], A. Demurov[2],
A. Gheonjian[2], Z. Legenzoff[1], S. Connor[3], B. Archambeault[3]
[1]Missouri University of Science and Technology, USA; [2]EMCoS, Georgia; [3]IBM Corporation, USA

Introduction to the Partial Element Equivalent Circuit (PEEC) Approach Applied to EMC+SIPI...N/A

Giulio Antonini[1], Albert E. Ruehli[2], Lijun Jiang[3]
*[1]University of L'Aquila, Italy; [2]Missouri University of Science & Technology, USA;
[3]Univeristy of Hong Kong, China*

Introduction to the Finite Element Method...N/A

Chuck Bunting
Oklahoma State University, USA

The Importance of Validation for All Simulations...N/A
Scott Piper
General Motors Company, USA

WS-TU-PM-2 Application of Reverb Chambers

Workshop **1:30pm - 5:30pm**
Room: 401C
Chair: Vignesh Rajamani, Exponent Inc., Phoenix, AZ, USA

Session Abstract: This tutorial will provide an introduction to recent applications of reverberation chambers. It is intended to provide EMC engineers who are interested in applying reverberation chambers to various measurement issues and the extension of reverberation chambers to solve a variety of EMC problems.

This half-day tutorial provides a brief overview of Reverb Chamber (RC) theory, followed by recent applications of RCs. The tutorial material will be updated to reflect recent research results and implications. The format will be a conference presentation style (lecture) followed by questions moderated by the chairman. It is designed for both academics and people from industry who will be involved in radiated emission or immunity testing of commercial or military systems using reverberation chambers and will be valuable to personnel evaluating the use of reverberation chambers as a complement to or replacement for other types of radiated test facilities and for personnel who are trying to use statistical methods to characterize the electromagnetic environments.

Introduction – Rationale for RC Testing Overview of Reverberation Chamber Theory...N/A
Vignesh Rajamani
Exponent Inc., USA

Absorbing Materials – Reverberation Chamber Assessments...N/A
Chuck Bunting
Oklahoma State University, USA

Flexible Testing: Shaken, Not Stirred...N/A
Frank Leferink[1,2,3]
[1]*Thales Nederland B.V., The Netherlands;* [2]*University of Twente, The Netherlands;*
[3]*University of Nottingham, United Kingdom*

Reverb Chamber Challenges...N/A
Garth D'Abreu
ETS-Lindgren, USA

SS-TU-PM1-TC6 Critical Challenges and Solutions in Spectrum Engineering (Sponsored by TC-6)

Special Session **1:30pm - 2:45pm**
Room: 402A
Co-Chair: Robert Johnk, Institute for Telecommunication Sciences (NTIA/ITS), Arvada, CO, USA
Co-Chair: Sarah Seguin, Resonant Frequency, Maple Grove, MN, USA

1:30pm **Improving Spectrum Sharing Interference Criteria: A Survey of a Critical Need for Measurements** 125
Andrew W. Clegg, Sarah A. Seguin, Charles Baylis, Austin Egbert, Robert J. Marks II
Baylor University, USA

Abstract: As radio spectrum becomes more congested and more valuable, an increasing number of potential conflicts is occurring between or among disparate systems and services. Such potential conflicts can be related to systems sharing the same band or even the same channel. Because of unwanted emissions (which include out-of-band emissions and spurious emissions), potential conflicts can arise in immediately adjacent bands, and even bands that are far removed from the operating frequencies of the potentially interfering system. We refer to these issues as potential conflicts, because whether a conflict does or does not exist in reality is often far from clear. Such claims are typically Based on paper studies that combine interference criteria for a particular service, propagation models, deployment models, usage assumptions, and other factors. The inputs, assumptions, and even the applicability of any or all of these specific factors are debatable, with the potential interferer relying on liberal interpretations, and the potential victim assuming conservative parameters. In the end, often the potential interfering operator concludes with certainty that no harmful interference will occur, and the potential victim operator concludes with certainty that harmful interference will occur. The regulator, which is often understaffed with appropriate resources to perform its own detailed technical analyses, must make a judgment call, which is usually Based on a combination of policy goals, politics, and the "loudest voice." Sometimes that judgment call results in overly restrictive requirements that causes inefficient spectrum use, or policies that may in fact lead to harmful interference in actual deployments. In this paper, we make an argument that the current situation could be significantly improved if one or more independent third-party "co-existence labs" were established that can help provide neutral input to regulators on the compatibility between various systems and services in the radio spectrum.

1:55pm **Spectrum Sharing Brokers for Active and Passive Devices** 131
Sarah A. Seguin, Adam Goad, Charles Baylis, Robert J. Marks II
Baylor University, USA

Abstract: Acute spectral crowding has necessitated the launch of multiple efforts centered on both the better use of electromag- netic spectrum and expanding spectrum use into increasingly higher frequencies. With the imminent proliferation of Fifth Generation (5G) systems in the 24 GHz band, these devices can present interference from out-of-band emissions to space-based weather radiometers conducting passive measurements of water vapor thermal emissions in the neighboring 23.6 – 24 GHz band. There is a critical need to accommodate both passive devices and active device transmitters, such as 5G systems, and allow for these active systems to adjust their transmissions to avoid critical weather radiometer systems in the nearby band. A survey of brokering systems is discussed and how they have the potential to protect crucial passive devices from unwanted interference by accounting for all spectrum users that could potentially interfere.

2:20pm **Understanding Spectrum Sharing and Coexistence: Field to Lab Methodology and Case Study** 135
Darren McCarthy
Rohde & Schwarz USA, Inc., USA

Abstract: The FCC and NTIA continue to refarm spectrum for commercial use with the potential for new problems to arise without proper impact assessment. Most recently, the impact of 5G C-Band systems on radio altimeters used during instrument landing at airports has come into focus. This paper looks at a method of assessing Coexistence and Spectrum Sharing and also suggests closed loop methods to include the functional performance of the radar in the presence of communications signals.

TP-TU-PM-TC4 Electromagnetic Interference – II
(Sponsored by TC-4)

Technical Papers **1:30pm - 3:10pm**

Room: 402B

Chair: John Kraemer, Rockwell Collins Inc., Marion, IA, USA

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

1:30pm **Equivalent Circuit for I/O Electrical Fast Transient Testing** 141

Steven G. Gaskill, Pujitha Davuluri

Intel Corporation, USA

Abstract: The focus of this paper is a linear Thevenin-equivalent model with time-varying sources to capture the voltage waveforms induced in an I/O cable during Electrical Fast Transient (EFT) testing. The model enables accurate prediction when the cable is connected to any linear/nonlinear circuitry --- such as TVS diodes, common mode chokes, and ESD/EFT protection circuitry. Due to the extremely low coupling through a well-shielded cable, this work utilizes direct measurements with a high Common Mode Rejection Ratio (CMRR) optically-isolated oscilloscope probe. A unique linear least squares technique to fit these measurements to an HSPICE model was developed. The model was employed to investigate the effectiveness of common platform solutions for EFT issue and show the development of an example silicon-level specification for EFT.

1:55pm **Predicting Radiated Emissions from a Complex Transportation System Wiring Harness** 146

Fuwei Ma[1], Ruijie He[1], Sameer Walunj[1], Tamar Makharashvili[1], Chulsoon Hwang[1], Daryl Beetner[1], Brian Booth[2], Kerry Martin[2]

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

BEST EMC PAPER FINALIST

Abstract: Low frequency radiated emissions problems are often caused by common mode currents flowing on wiring harnesses. The ability to predict radiated emissions problems early in the design process can save both time and money and result in a better product. Methods have previously been reported for rapidly characterizing common-mode sources driving a harness and then Using these equivalent sources to predict radiated emissions. These methods are extended in the following paper to predict radiated emissions from a complex 32-wire harness bundle connected to an engine control unit. Rapid experimental characterization of the common mode sources is enabled Using an equivalent cable bundle approximation of the original harness, where wires with roughly equivalent source and load impedances are lumped together and treated as a single equivalent wire. Sources driving the equivalent bundle were found Using a specialized measurement fixture. Only a few measurements are required, even if there are many wires associated with the source and they originate at different ports on the component. Full-wave models of the equivalent harness were built and along with the equivalent source were used to predict radiated emissions. This model was able to predict radiated emissions from 20-300 MHz with reasonable accuracy, with peak emissions typically predicted within about 6 dB of measurements, when Using multiple different harness lengths and routings.

2:20pm **A Fast Cascading Method for Predicting the Couplings from External Plane Wave to PCBs** 152

Shengxuan Xia[1], James Hunter[1], Aaron Harmon[1], Mohamed Z.M. Hamdalla[2], Ahmed M. Hassan[2], Chulsoon Hwang[1], Victor Khilkevich[1], Daryl G. Beetner[1]

[1]Missouri University of Science and Technology, USA; [2]University of Missouri Kansas City, USA

Abstract: The radio frequency (RF) coupling to electronic devices impacts their EMC performance. The functionalities of a working electronic device may be disrupted when the electromagnetic (EM) coupling reaches a certain level. Studies of the EM coupling to printed circuit boards (PCBs) are therefore essential for RF susceptibility and EMC purposes. for decades, researchers focused on the analytical modeling of EM coupling to transmission lines. However, when it comes to more realistic PCBs the analysis usually still relies heavily on full-wave simulations because of the complexity of the structures and the lack of analytical solutions. Using a traditional full-wave modeling approach, however, could take hours to investigate the EM coupling from the external plane wave to the structure for one incident angle of arrival and polarization. In this paper, we present a methodology Using reciprocity that allows for rapid estimation of the voltage induced in the terminations for multiple incident angles of the incoming plane wave and load values Based on just one full-wave simulation. This reciprocity-based method is combined with a segmentation technique to enable the capability of studying the coupling to more realistic PCBs. for the cases studied here, estimates could be found in minutes Using this approach rather than hours Using a full-wave simulation. Estimates were within 2-3 dB of estimates Using full-wave simulations for a simple trace structure. Accuracy was not as good for individual angles of arrival of an incident RF wave to a complicated structure including two integrated circuit (IC) packages connected by a trace, but statistical estimates of coupling were within 2-3 dB.

2:45pm **Features of the Search for a Circular Route in Conditions of Interference** 158

Aleksandr Kornilov

Moscow Aviation Institute (National Research University), Russia

Abstract: Route planning tasks are often performed on various networks. The path length criterion is one of the most important. Including for circular routes. Aspects of interference interpretation when modeling data transmission networks are considered. A simplified interpretation of the interference is used. Ant colony algorithms are used to obtain solutions. Several types of impact are considered from the worst case and the corresponding critical factor, to intermediate values of the factor. The impacts on a part of the path are also considered. Numerical values of routes and their relationships in graphs are determined. Conclusions are made about the high resistance of the structure of the complete graph to noise on the way.

TP-TU-PM1-TC10 Numerical Modeling and Simulation Techniques – I (Sponsored by TC-10)

Technical Papers **1:30pm - 3:10pm**

Room: 402C

Chair: Bichen Chen, Facebook Inc., Menlo park, CA, USA

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

1:30pm **PEEC-Based On-Chip PDN Impedance Modeling Using Layered Green's Function** 164

Chaofeng Li, Biyao Zhao, Bo Pu, Xu Wang, DongHyun Kim, Jun Fan

Missouri University of Science and Technology, USA

BEST SIPI PAPER FINALIST

Abstract: This paper presents an impedance model of on-chip power distribution network (PDN), which is an efficient criterion for estimating simultaneous switching noises (SSNs) on 3-D integrated circuit (IC). The impedance of on-chip PDN, including the effect of silicon substrate, is accurately modeled Based on partial element equivalent circuit (PEEC) and layered Green's function (LGF). The equivalent circuit model of PDN is extracted Based on the physical dimensions and electrical material characteristic of PDN at first. And then the LGF is used to consider the effect of silicon substrate for improving the accuracy of on-chip PDN impedance model. The effectiveness of proposed model has been validated by full wave simulation. The high order resonance of PDN impedance can also be accurately predicted.

1:55pm **Optimizing the Placement of Non-Functional Pads on Signal vias Using Multiple Reflection Analysis** 169

Muqi Ouyang[1], Kevin Cai[2], Chaofeng Li[1], Anna Gao[2], Felen Fu[3], Hannah Bian[3], Bidyut Sen[2], DongHyun Kim[1]

[1]Missouri University of Science and Technology, USA; [2]Cisco Systems, Inc., USA; [3]Cisco Systems, Inc., China

Abstract: In this study, the effects of Using non-functional pads to optimize the performance of high-speed signal vias are investigated Based on multiple reflection analysis. The non-functional pads on signal vias introduce more capacitive coupling and are possible to improve the response of the via structure if the original via has relatively larger impedance compared to the system reference impedance. The effectiveness of the non-functional pad optimization is validated through a numerical example, and the eye diagram of the via structure without and with non-functional pads are compared. The eye opening becomes 5.4 times larger after the via optimization Using non-functional pads.

2:20pm **A DNN-Ensemble Method for Error Reduction and Training Data Selection in DNN based Modeling** 175

Ling Zhang[1], Da Li[1], Jiayi He[2], Bhyrav Mutnury[3], Bo Pu[2], Xiao-Ding Cai[4], Chulsoon Hwang[2], Jun Fan[2], James Drewniak[2], Er-Ping Li[1]

[1]Zhejiang University, China; [2]Missouri University of Science and Technology, USA; [3]Dell Inc., USA; [4]Cisco Systems, Inc., USA

Abstract: Deep neural networks (DNNs) have been widely adopted in modeling electromagnetic compatibility (EMC) problems, but the training data acquisition is usually time-consuming through various simulators. This paper presents a powerful approach Using an ensemble of DNNs to effectively reduce the training data size in DNN-based modeling problems. A batch of training data with the largest uncertainties is selected Using active learning through the variance among the ensemble of DNNs. Subsequently, a greedy sampling algorithm is applied to select a data subset Using diversity. Thus, the proposed method can achieve both uncertainty and diversity in data selection. By averaging the outputs of the DNN ensemble, the prediction error can be further reduced. Simple mathematical functions are used to validate the proposed method, and a high-dimensional stripline modeling problem also demonstrates the effectiveness of this DNN-ensemble approach. The proposed method is task agnostic and can be used in other surrogate modeling problems with DNNs.

2:45pm **Analysis of CM-Signal Suppression Effect from DM Signal by Common-Mode Choke Coil Using Chain-Parameter Matrix** 181

Nobuo Kuwabara, Tohlu Matsushima, Yuki Fukumoto

Kyushu Institute of Technology, Japan

Abstract: Common-mode choke coil (CMC) is used in vehicles and electronic devices to improve electromagnetic compatibility (EMC), and the analysis of the CMC effect is essential to improve the design quality of EMC. In this paper, the suppression effect of CMC for the common-mode (CM) signal converted from the differential-mode (DM) signal is analyzed Using a chain-parameter matrix. The chain-parameter matrix of the CMC was obtained from the SPICE model and the measured data. And then, the amount of conversion level from DM signal to CM signal was calculated Using the chain-parameter matrix of the signal source, the termination, the cable, and the CMC. The CM signal level was calculated for the shielded twisted pair cable with one pair considering imbalances of the signal source, the termination, the cable, and the CMC. The calculation value was compared to the measurement value due to confirm the validity of the method, and the calculated results were in close agreement with the measurement value. The investigation results showed that we should pay attention to the CMC imbalance when the cable is well balanced. In addition, the results suggested that the CMC should be prepared at both ends of the cable to reduce the current outside the shield.

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

Room: Exhibit Hall
Chair: Megan McConnell, A2LA, Frederick, MD, USA

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

Accreditation, Designation, and Recognition: Supporting the Global Telecom Regulatory Ecosystem

PLANNED PANELISTS INCLUDE:

- Megan McConnell, A2LA, Frederick, MD, USA
- Amanda McDonald, NVLAP, Gaithersburg, MD, USA
- Ramona Saar, NIST, Gaithersburg, MD, USA
- George Tannahill, FCC, Columbia, MD, USA

Abstract: A panel of Accreditation Bodies, Regulators, and Designating Authorities describe the process from Accreditation to Recognition of Testing Laboratories and Product Certification Bodies as it relates to the Global Telecom Ecosystem. This will include both Government Mutual Recognition Agreements (MRA), and Accreditation Body specific recognitions. Together, the panel will describe the roles and responsibilities of all levels, how all steps fit together, what each party is able to offer, and the different areas that each party supports. The panel will also provide tips and tricks for preparing your organization for recognition and applying for both accreditation and designation. Before a brief Q&A, the panel will identify the different resources available to all parties and instructions on access.

Experiments & Demonstrations 3:00pm - 5:00pm

Room: Hall A Experiments and Demos
Co-Chair: Gabe Alcala, Advanced Test Equipment Corp. (ATEC), San Diego, CA, USA
Co-Chair: Jacob Dixon, IBM, Rochester, MN, USA

Session Abstract: As a result of the Call for Experiment and Demonstration Proposals, we are pleased to announce the accepted proposals below that will be presented at the 2022 IEEE International Symposium on Electromagnetic Compatibility, Signal and Power Integrity, August 1-5, in Spokane, Washington. You will not want to miss the popular Experiments and Demonstrations program that will be held in the Exhibition Hall on August 2-4. This hands-on activity provides a unique learning experience that complements the technical presentations at the symposium. It is traditionally one of the educational highlights of the annual symposium!

Finding Resonances with Near Field Probes in Troubleshooting EMI/EMC Problem...N/A

Arturo Mediano
Electronics Engineering and Comms, Universidad de Zaragoza, Zaragoza, Aragón, Spain

Abstract: In EMI/EMC, resonances create many of the most common and difficult to solve problems.

Discover how to use your near field probes with a network analyser (VNA) or a spectrum analyser combined with a Voltage Standing Wave Ratio (VSWR) bridge, to find resonances in your electronic components, circuits, cables, PC boards, enclosures, etc.

This technique is so powerful!!!!

Alternative EMC Measurements on Large Machines and Complex Machine Installations with the Tubular Wave Coupler (TWC)...N/A

Werner Grommes
Institute for Occupational Safety and Health (IFA), German Social Accident Insurance (DGUV), Sankt Augustin, Germany

Abstract: Large construction machines as well as paper and printing machines do not fit into an EMC laboratory due to their size. An In Situ test can often not be carried out according to standards because the test setup defined in the standards is not possible. The equipment must be modified for the test, which changes the original EMC performance of the equipment. The Tubular Wave Coupler is suitable for checking of the RF-interference radiation as well as the RF-interference immunity. This presentation will detail the applicable EMC standards and the tubular wave coupler technique to characterize such equipment.

Demonstration of Low Cost Software Defined Radio Capabilities...N/A
Karen Burnham
Electro Magnetic Applications, Inc., Lakewood, Colorado, USA

Abstract: Software Defined Radio (SDR) hardware can now be purchased easily for under $30 USD and SDR software packages are available free for any platform you like. Although perhaps most keenly adopted by Ham radio operators, low cost SDRs can be a useful troubleshooting tool for the practicing EMC engineer. We will demonstrate some of the handy capabilities of a low cost SDR system, from determining relative signal strengths to characterizing noise or interfering signals. Multiple SDR systems and software packages will be displayed. Special attention will be given to the use of low cost SDRs for characterizing an RF environment and potentially sharing that data with a broader community.

SS-TU-PM2-TC6 Critical Challenges and Solutions in Spectrum Engineering (Sponsored by TC-6)

Special Session **3:40pm - 5:20pm**
Room: 402A
Co-Chair: Robert Johnk, Institute for Telecommunication Sciences (NTIA/ITS), Arvada, CO, USA
Co-Chair: Sarah Seguin, Resonant Frequency, Maple Grove, MN, USA

3:40pm **Interference Protection Criteria for Realistic Channel Conditions** 187
Robert Achatz, Charles Dietlein, Michael Cotton
National Telecommunications and Information Administration, USA

Abstract: This paper describes a new National Telecommunications and Information Administration (NTIA) effort focused on the development of methods to determine appropriate interference protection criteria (IPC) as a means to resolve contention around spectrum sharing proposals being considered by NTIA and Federal Communications Commission (FCC).

4:05pm **Estimating the Local Mean Voltage of a Radio Signal in a Mobile Channel** 192
Robert Johnk, John J. Lemmon
Institute for Telecommunication Sciences, USA
BEST EMC PAPER FINALIST

Abstract: This paper examines the estimation of the local mean voltage of a radio signal in a Rayleigh fast-fading environment. We focus on the statistical uncertainties of local voltage averages obtained by both integrating the voltage envelope of a specified spatial interval and averaging over a set of discrete spatial samples. We derive new analytical expressions of the variances of both discrete and continuous averaging for selected spatial intervals. We also give recommendations for averaging intervals and sample spacing to achieve a ±1 dB spreading factor. We provide important new results for the variance of discrete averaging with new insight gained on separations required for uncorrelated samples. One significant finding of this work is that criteria in the published literature are incorrect and underestimate the variance. We support these findings with an experimental validation of our variance expressions Using laboratory fading simulator measurements and sample statistics.

4:30pm **Measuring Tropospheric Propagation in the 21st Century** 198
Adam Hicks, John Ewan, William Kozma, Michael Cotton
National Telecommunications and Information Administration, USA

Abstract: This article is intended to motivate and describe a new tropospheric scatter modelling and measurement validation effort that is underway at the Institute for Telecommunication Sciences (ITS). Immediately after World War II, there was a flurry of research conducted to investigate the phenomenon of forward scattering through the troposphere, or troposcatter, for over-the-horizon radio links. During the early 1950s, ITS researchers carried out an extensive measurement campaign now summarized in the ITS technical report Cheyenne Mountain Tropospheric Propagation Experiments [1]. Several propagation models were developed from this effort as well as from similar follow-on measurement campaigns, such as the Irregular Terrain Model (ITM) and IF-77 (ITS-FAA air-to-ground propagation model, circa 1977). These models are Based on simplified assumptions, but they are still used in today's spectrum policy decisions. ITS engineers are currently developing a modern measurement system that incorporates the latest RF hardware capabilities and takes advantage of the extensive information now available about our meteorological and geographical environment to improve the accuracy of these models. This paper describes the current and proposed deployments of this modern and upgraded ITS troposcatter measurement system.

4:55pm **Examination of 1.7 GHz Measured Propagation Loss for Free-Space/Clutter Paths in Salt Lake City** 204

William Kozma Jr., Christopher Behm, Paul McKenna
National Telecommunications and Information Administration, USA

Abstract: In June 2018, ITS performed mobile clutter measurements in Salt Lake City, UT at 1.7 GHz. This measurement campaign was designed for path geometries with larger take-off angles by placing the transmitter in the hills of the nearby mountains. The resulting measurement dataset contains a large percentage of paths that would traditionally be considered line-of-sight (LOS), in that the terminals have an unobstructed view of each other. We present this LOS data and explore what a LOS path implies within a cluttered environment. We integrate high-resolution lidar data into our analysis showing that traditional assumptions of LOS links need further descriptors to clarify the frame of reference. Finally, we present how lidar data can be incorporated into modeling activities to support improved prediction methods and understanding of the expected clutter losses for such geometries.

SS-TU-PM-TC7 Low Frequency Conducted Emissions Issues in Complex Smart Power Grids under Close EMI Coexistence (Sponsored by TC-7)

Special Session **3:40pm - 5:45pm**
Room: 402B
Chair: Erjon Ballukja, University of Nottingham, Nottingham, United Kingdom
Co-Chair: Angel Pena-Quintal, University of Nottingham, Nottingham, United Kingdom

3:40pm **Evaluation of Nonlinear ARX System Identification Technique on Modeling Crosstalk** 210

Muhammad Imam Sudrajat[1,2], Muhammad Ammar Wibisono[1,3], Hermes J. Loschi[1,4,5], Niek Moonen[1], Frank Leferink[1,6]
[1]University of Twente, The Netherlands; [2]Badan Riset dan Inovasi Nasional Republik Indonesia, Indonesia; [3]Institut Teknologi Bandung, Indonesia; [4]University of Zielona Góra, Poland; [5]University of Nottingham, United Kingdom; [6]Thales Netherland B.V., The Netherlands

Abstract: Estimating crosstalk appropriately is very important in the process of mitigating electromagnetic interference. This study evaluates a black-box modeling technique named nonlinear autoregressive with exogenous inputs (NARX) on crosstalk modeling application, especially crosstalk due to random pulse width modulation. The model is developed Using the input and output data from the measurement as regressor inputs. for validation, the mean squared error of this model is calculated by comparing the model output with the real measurement output. for evaluation, the model performance also was compared to a Spice-based SACAMOS model. Although less flexible than the Spice model, NARX model can represent the signal on the victim cable well with a small mean squared error value.

4:05pm **Superposition of Transient Switching Currents for Non-Linear Devices** 216

Alexander Matthee[1], Niek Moonen[1], Frank Leferink[1,2]
[1]University of Twente, The Netherlands; [2]Thales Nederland B.V., The Netherlands

Abstract: Increased power electronics converters on microgrid supplies result in large inrush currents which are not appropriately limited by present-day standards, especially devices commonly switched in large clusters. The currents drawn by switching large clusters, such as LED lights, or systems dominated by power electronics converters are shown by measurement as well as simulations to have worrying trends for electromagnetic compatibility. Superposition of currents from many low power devices, especially in low inertia micro-grids, can significantly impact the stability of the supply and may cause interference or high probability of complete grid failure.

4:30pm **Solving the Grid Overvoltage Caused by Connected PV Systems: DSTATCOM based on MMC** 221

Amr Madi[1,2], Niek Moonen[2], Waseem W. Elsayed[1,2], Abduselam Beshir[3], Piotr Lezynski[1], Robert Smolenski[1]
[1]University of Zielona Góra, Poland; [2]University of Twente, The Netherlands; [3]Politecnico di Milano, Italy

Abstract: With the expansion of photovoltaic cell installation in residential units, the low voltage distribution system faces a new challenge concerning the stability of the distribution network. This problem is associated with sudden flickers – that is overvoltage followed by under voltage due to the uncontrolled connection/disconnection of the photovoltaic units. This paper introduces a distribution static synchronous shunt compensator Based on a modular multilevel converter as a solution to regulate the overvoltage and give the distribution network more stability.

4:55pm **EMI Spectral Aggregation of Modulation Schemes in a Lab-Based DC Microgrid** 226
Angel Pena-Quintal[1], Arun Khilnani[1], Leonardo Sandrolini[2], Mark Sumner[1],
David Thomas[1], Steve Greedy[1]
[1]University of Nottingham, United Kingdom; [2]University of Bologna, Italy

Abstract: DC Microgrid research has developed in the recent years following the increasing integration of power electronic Based switching devices at the point of common coupling in DC grids. This has led to electromagnetic interference problems caused by the spectral aggregation of conducted emissions in the low-frequency range (2-150 kHz). To investigate this, a framework for understanding spectral aggregation resulting from the multiple switching harmonics from the interconnected DC grid devices is analysed. In this work, three modulation techniques are applied to identical \& parallel connected DC/DC converters forming a lab-based DC grid. The harmonics are then analysed for spectral aggregation Using an EMI receiver. This provides insights into the spectral aggregation of conducted emissions in the low-frequency range to promote electromagnetic compatibility and further facilitate a possible framework for standardisation of DC power quality.

5:20pm **Stochastic Modelling of Power Electronic Converters under Uncertainties** 232
Erjon Ballukja, Karol Niewiadomski, Angel Pena-Quintal, David W.P. Thomas,
Sharmila Sumsurooah, Mark Sumner
University of Nottingham, United Kingdom

BEST EMC PAPER FINALIST

Abstract: The aim of this paper is to explore the usage of different sampling schemes in order to build a sparse Polynomial Chaos (PC) model for prediction of the oscillation frequency and its corresponding magnitude of the output voltage in a half-bridge buck converter. The 22 parasitic elements of this converter are modelled as random variables following a uniform distribution. As a result, from the considered sampling schemes, an Latin Hypercube Sampling (LHS) and Sobol' sequences are determined to be the best in prediction of the magnitude, both with respect to accuracy and computational time needed for the creation of the model. The introduced accuracy measure, namely the a posteriori error, shows that the PC model approximates the oscillation frequency well. However, from a visual comparison with a model obtained from 8000 Monte Carlo samples, it can be seen that the PC model is not able to handle such a complex relationship properly.

TP-TU-PM2-TC10 Power Integrity Analysis and Design – I (Sponsored by TC-10)

Technical Papers **3:40pm - 5:40pm**
Room: 402C
Chair: Kinger Cai, Intel Corporation, San Jose, CA, USA
Co-Chair: Bumhee Bae, Samsung Electronics, Suwon-si, Korea

3:40pm **A Methodical Approach for PCB PDN Decoupling Minimizing Overdesign with Genetic Algorithm Optimization** 238
F. de Paulis[1], Y. Ding[2], M. Cocchini[3], C. Hwang[2], S. Connor[3], M. Doyle[3], S. Scearce[4],
D. Becker[3], A. Ruehli[2], J. Drewniak[1]
*[1]University of L'Aquila, Italy; [2]Missouri University of Science and Technology, USA;
[3]IBM Corporation, USA; [4]Cisco Systems, Inc., USA*

Abstract: An optimization routine is applied for the decoupling capacitor placement on Power Distribution Networks to identify the limit beyond which the placement of additional decaps is no longer effective, thus leading to wasting layout area and components, and to a cost increase. A specific test example from a real design is used together with the required target impedance and frequency band of interest for the PDN design. The effectiveness of the decap placement while selecting different layers of the stack-up, and while moving the upper limit of the PDN design band is analyzed. Such analysis leads to helpful insights Based on the progression of the input impedance during the optimization process, and to develop useful guidelines for avoiding over-design of the PDN.

4:10pm **Physics-Based Modeling for Determining Transient Current Flow in Multi-Layer PCB PI Designs** 244

Yifan Ding[1], Matthew S. Doyle[2], Samuel Connor[2], Dale Becker[2], James L. Drewniak[1]
[1]Missouri University of Science and Technology, USA; [2]IBM Corporation, USA

SIPI BEST PAPER AND BEST STUDENT PAPER FINALIST

Abstract: A physics-based modeling methodology for determining the transient current flow path in multi-layer PI designs is given in this paper Using a commercial board with a complicated structure as an example. Board structure analysis is done first to provide a physical basis of post-layout analytical and equivalent circuit modeling. A match of the PDN impedance between commercial tool simulation, post-layout analytical calculation, and the physics-based equivalent circuit modeling was achieved to support the model for the transient simulation. By analyzing the current response in all the vias, a clear representation of transient current flow across all via segments can be given layer-by-layer. The maximum current density in vertical vias can also be extracted in this process, providing a reference for preventing transient overcurrent design.

4:40pm **Application of Continued Fractions to Decoupling Capacitor Modeling in Multilayered Printed Circuits** 250

Ihsan Erdin
Celestica Inc., Canada

Abstract: A continued fraction-based algorithm is developed for the analytical characterization of decoupling capacitors in multilayered printed circuit stackups. The proposed technique depends on modeling a stack of resonant cavities in the form of finite continued fractions. Mathematical models for a variety of configurations are developed including a capacitor and integrated circuit (IC) being (1) on the same side, (2) on the opposite sides and (3) on both sides of a printed circuit board (PCB). The frequency domain responses of the proposed models are observed in good agreement with data from numerical electromagnetic (EM) simulations, which validate the accuracy of the proposed algorithm. The developed models are intended for a quick and practical power integrity (PI) analysis of printed circuits with no limitation on the number of layers.

5:10pm **Analysis of Noise Coupling from Switching Voltage Regulator and Power Distribution Network to Differential Stripline Traces** 255

Yang Wu[1], Wenwu Wang[1], Yinghua Ye[1], Yinglei Ren[1], Michael Leddige[2], Xiaoning Ye[2]
[1]Intel Corporation, China; [2]Intel Corporation, USA

BEST SIPI PAPER FINALIST

Abstract: Differential stripline traces often need to be routed close to switching voltage regulators and their power delivery network for today's high-density designs. To study the risk of the noise coupling, this paper offers a comprehensive discussion on noise coupling mechanisms. It classifies noise sources, analyzes coupling mechanisms of each source and states possible impacts. The coupling mechanisms are explained and verified by simulation data, measurement results and a new proposed fitting model.

WEDNESDAY – AUGUST 3, 2022

TU-WE-AM-1 Tutorial on Site Validation Standards by the American National Standards Committee C63 on EMC

Tutorial **8:30am - 12:00pm**
Room: 401B
Chair: Daniel D. Hoolihan, Hoolihan EMC Consulting, Lindstrom, MN, USA

Session Abstract: This tutorial will elaborate on the EMC Test Site Validation standards recently released or presently under development in the USNC C63 on EMC. It will include an introduction to the C63 Committee and then three separate talks on the three Site Validation Standards in the C63 Committee.

The introduction to the C63 Committee will be handled by Dan Hoolihan, Current Chair, Main Committee of C63. The first standard to be discussed will C63.25.1 – Site Validation for EMC Test sites from 1 -18 GHz which was published in 2019. Zhong Chen, from ETS-Lindgren and the Chair of Subcommittee 1 of C63, will be the presenter of that paper. The second standard to be reviewed will be C63.25.2 – Site Validation for EMC Test Sites from 30 MHz to 1000 MHz which will be covered by Andy Griffin of CISCO who has been actively involved with the content of that DRAFT Standard. The third paper will be presented by Nick Abbondante of Intertek; it will cover C63.25.3 which looks at the frequency range from 18 GHz to 40 GHz. C63.25.3 is currently under development in the C63 Committee.

C63 Committee – Overview
Daniel Hoolihan
Hoolihan EMC Consulting, USA

C63.25.1 – Site Validation from 1-18 GHz
Zhong Chen
ETS-Lindgren, USA

C62.25.2 30 MHz – 1000 MHz Site Validation
Andy Griffin
Cisco Systems, Inc., USA

TU-WE-AM-2 Lessons Learned Creating Reliable Computational Models for SI and EMC Applications

Tutorial **8:30am - 12:00pm**
Room: 401C
Chair: Patrick DeRoy, Analog Devices Inc., Norwood, MA, USA

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

Model Validation...N/A
Bruce Archambeault[1,2]
[1]Missouri University of Science and Technology, USA; [2]IBM Corporation, USA

What I Wish I Knew about EMC Simulation When I First Started...N/A
Scott Piper
General Motors Company, USA

Common Mode Choke (CMC) Conundrums and Related Mysteries in Modeling Magnetic Components...N/A

Patrick DeRoy
Analog Devices Inc., USA

Overcoming Common Obstacles in EMC Simulations...N/A

Grant Riley
Electro Magnetic Applications, Inc., USA

SS-WE-AM1-TC5 Hardware Security for Smart Society – Part I (Sponsored by TC-5)

Special Session **8:30am - 9:45am**
Room: 402A
Chair: Yuichi Hayashi, Nara Institute of Science and Technology, Takayama, Japan
Co-Chair: William Radasky, Metatech Corporation, Goleta, CA, USA

8:30am **Introduction to a Special Session on Hardware Security for Smart Society** ..... N/A

Yuichi Hayashi[1], Naofumi Homma[2], Jong-Gwan Yook[3], William A. Radasky[4]
[1]Nara Institute of Science and Technology, Japan; [2]Tohoku University, Japan; [3]Yonsei University, Korea; [4]Metatech Corporation, USA

Abstract: In the smart society, individualized and comprehensive services, which collect a wide variety of physical/biological data and utilize the knowledge acquired from them, are expected in applications with the real world, such as automobiles, industrial and household robots, and tailor-made medicines. On the other hand, security has become an inseparable issue in utilizing and expanding such next-generation services. In particular, data protection by cryptography is essential for services that handle data containing sensitive and/or private information. However, when encrypted data is queried or processed, it usually needs to be decrypted once. It is difficult to completely prevent data stealing and/or tampering by attackers or malicious parties. In contrast, recently, encrypted-data processing techniques, which prevent information leakage by processing encrypted data without decryption, have seen much attention since Gentry's pioneering work. This process is being researched and developed for social use because it can realize operations on encrypted data, which is difficult to achieve with conventional cryptography. On the other hand, although encrypted-data processing techniques provide a certain level of robustness against cyberattacks, it may be vulnerable to physical attacks at the hardware level. Such attacks may pose a serious security risk. Among them, side-channel attacks that use secondary physical quantities generated during system operations to obtain secret information or control are a real threat because they are non-destructive, non-invasive, and quick to execute. Based on the above background and issues, this special session will focus on side-channel attacks on next-generation cryptosystems, which include encrypted-data processing and the use of the state-of-the-art cryptography (e.g., quantum-resistant cryptography), and introduce the latest related-research trends.

8:55am **On (in)Security of Edge-Based Machine Learning against Electromagnetic Side-Channels** 262

Shivam Bhasin[1], Dirmanto Jap[1], Stjepan Picek[2]
[1]Nanyang Technological University, Singapore; [2]Radboud University, The Netherlands

Abstract: Machine (deep) learning represents mainstream research and development direction. This success can be linked to the ever-increasing computational capabilities and vast amounts of available data, resulting in ever more sophisticated machine learning models. The design and training of such machine learning models are challenging and expensive tasks, which incentivize companies to protect and keep it secret. Additionally, the wide applicability of machine learning results in diverse deployment scenarios. Many machine learning architectures are deployed on edge devices, such as sensors or actuators, making them susceptible to side-channel attacks. This work surveys the research works considering electromagnetic side-channel and edge-based machine learning models. After discussing state-of-the-art attacks and countermeasures, we propose several open problems to be investigated in future research.

9:20am **Learning-Based Denoising Algorithm for the Reconstructed Image Using Electromagnetic Emanations from the Display Device** 268

Taesik Nam, Dong-Hoon Choi, Eui-Bum Lee, Jong-Gwan Yook
Yonsei University, Korea

Abstract: This paper proposes a learning-based denoising algorithm that improves the signal-to-noise ratio (SNR) of the information signal emitted from the display device. The information signal is easily degraded by noise and interference on the channel and has various SNR. In this situation, an algorithm that enhances the model's robustness is required to improve the degraded information signal into a learning-based denoising model. Therefore, this paper proposes a normalization method to enhance the robustness of the model.

TP-WE-AM1-TC7 Low Frequency EMC: Modelling (Sponsored by TC-7)

Technical Papers **8:30am - 9:45am**

Room: 402B

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

Co-Chair: Anne Roc'h, Technische Universiteit Eindhoven

8:30am **Equivalent Circuit Modeling and Analysis of a Metamaterial based Wireless Power Transfer System** 272

Webster Adepoju, Indranil Bhattacharya, Ismail Fidan, Ebrahim Nasr Esfahani, Olatunji Abiodun, Ranger Buchanan, Trapa Banik, Muhammad Enagi Bima
Tennessee Technological University, USA

Abstract: In this study, an equivalent circuit model is presented to emulate the behavior of a metamaterial-based wireless power transfer system. for this purpose, the electromagnetic field simulation of the proposed system is conducted in ANSYS high frequency structure simulator. In addition, a numerical analysis of the proposed structure is explored to evaluate its transfer characteristics. The power transfer efficiency of the proposed structure is represented by the transmission scattering parameter. While some methods, including interference theory and effective medium theory have been exploited to explain the physics mechanism of MM-based WPT systems, some of the reactive parameters and the basic physical interpretation have not been clearly expounded. In contrast to existing theoretical model, the proposed approach focuses on the effect of the system parameters and transfer coils on the system transfer characteristics and its effectiveness in analyzing complex circuit. Numerical solution of the system transfer characteristics, including the scattering parameter and power transfer efficiency is conducted in MATLAB. The calculation results Based on numerical estimation validates the full wave electromagnetic simulation results, effectively verifying the accuracy of the analytical model.

8:55am **Performance Comparison of Different Control Schemes from the Electromagnetic Interference View for Single-Phase Multilevel Inverter** 279

Cathrine E.S. Feloups[1,2], Niek Moonen[1], Frank Leferink[1,3]
[1]*University of Twente, The Netherlands;* [2]*South Valley University, Egypt;*
[3]*Thales Nederland B.V., The Netherlands*

Abstract: When connecting a multilevel inverter to a load or the utility grid, two major factors must be considered: total harmonic distortion and electromagnetic disturbance due to the fast switching of the semiconductor devices. This paper focuses on these electromagnetic interference aspects of a multilevel inverter. The change in the inverter's control scheme and the change in the operating frequency on the conducted electromagnetic interference are investigated. This paper addresses carrier-based level-shifted pulse width modulation as a pulse width modulation control for the multilevel inverter. Three different level-shifted control schemes were compared at different switching frequencies to determine the effect of the control scheme and switching frequency on the electromagnetic interference. As an example of multilevel topology, a reduced device single-phase multilevel inverter is presented in this paper.

9:20am **Model of the Influence of Interference of a 25 kV 50 Hz Traction Network on Parallel 50 Hz Track Circuits** ..... N/A

Volodymyr Havryliuk
Ukrainian State University of Science and Technology, Ukraine

Abstract: The problem considered in the work is related to ensuring the electromagnetic compatibility of track circuits with a parallel traction network. To evaluate the influence of interference from the alternating current traction network on the operation of the track circuits a simplified model has been developed. The model is Based on the well-known multiconductor transmission line method, however, its use for modeling a traction network is difficult due to the longitudinal structural inhomogeneity of the traction system. The simplification proposed in the work assumes that the track circuit equipment connected to the rails insignificantly influence on the distribution of currents in traction network conductors. These assumptions make it possible to neglect the equipment of track circuits at the first stage of modeling, which greatly simplifies the equivalent circuit of the traction network, and allows us to represent it in the form of several homogeneous sections of multiconductor transmission lines with rolling stock units between them. Simulation of induced alternating current interference in the rails of the track with direct current traction is carried out at the second stage, taking into account the design features and electrical parameters of track circuits, as well as specific values of rail-to-ground conductance and earth conductivity, Using the values of the currents in the traction network conductors determined in the first stage.

TP-WE-AM1-TC10 Numerical Modeling and Simulation Techniques – II (Sponsored by TC-10)

Technical Papers **8:30am - 9:45am**

Room: 402C

Chair: Zhichao Zhang, Intel Corporation, Chandler, AZ, USA

Co-Chair: Bichen Chen, Facebook Inc., Menlo park, CA, USA

8:30am **Surface Roughness Effect from Different Surfaces of Microstrip Lines and Reference Plane** ..... N/A

Yuanzhuo Liu[1], Yuandong Guo[1], Chaofeng Li[1], Xiaoning Ye[2], DongHyun Kim[1]
[1]*Missouri University of Science and Technology, USA;* [2]*Intel Corporation, USA*

Abstract: Microstrip line structure comprises different conductors, such as trace and reference planes with different surface roughness levels due to the printed circuit board manufacturing process. The bottom surface of the trace is often rougher than the top surface of the trace, and the roughness level of different reference planes vary on different foil types and manufacturing process. To accurately model additional conductor loss due to such differences in microstrip lines, a new modeling method is proposed with different roughness levels on different surfaces and its reference plane, in contrast to the traditional roughness modeling approach that considers one uniform roughness distribution for all the surfaces. The effect on resistance value contributed by different surfaces is determined Using additional microstrip models to analyze the effect of surface roughness from different surfaces and to improve the accuracy of insertion loss prediction with the modeled total resistance.

8:55am **Parameter Estimation of Silicon Metal Grid Using Supervised Learning** ..... N/A

Allan Sánchez-Masís[1], Sameer Shekhar[2], Christian Chaves Bejarano[1], Mauricio Aguilar Salas[1]
[1]*Intel Corporation, Costa Rica;* [2]*Intel Corporation, USA*

Abstract: Silicon industry needs reduced design time to cater to broad annual product portfolio. Therefore, avoiding complex simulations during product design has immense value. To that end this paper presents machine learning Based parameter estimation method for silicon metal grid Based on past data. Regression results from employed machine learning algorithms and dependency on data standardization is discussed. Over 40 % reduction in root mean square error of grid resistance is reported which is crucial for obtaining accurate transient and AC simulation result.

9:20am **Equalization Optimization for SerDes Channels with Constrained Bayesian Optimization** ..... N/A

Majid Ahadi Dolatsara
Keysight Technologies, USA

Abstract: Assigning parameters of a feed-forward equalizer (FFE) can be a challenging and time-consuming task. In this work we introduce a machine learning algorithm to automatically optimize these parameters without the need to a domain expert. Conventional optimizers are not applicable to this problem because of a constraint over the FFE parameters. Therefore, we reformulate the problem and propose a modified Bayesian optimization algorithm to take this constraint into account. The proposed approach is validated with an example.

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

Room: Exhibit Hall
Chair: Karen Burnham, Electro Magnetic Applications, Denver, CO, USA

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

Electromagnetic Effects

PLANNED PANELISTS INCLUDE:

- Thomas J. Fagan, Aerospace Corporation, Vail, AZ, USA
- Fred Heather, US Navy, Lexington Park, MD, USA
- Frank Leferink, Thales and University of Twente, The Netherlands
- Karen Burnham, Electro Magnetic Applications, Lakewood, CO, USA

Abstract: If you have an interest in the electromagnetic environment (EME); the development of standards for EME measurement and characterization; natural and man-made sources of EME that comprise this environment; the effects of noise (unwanted portions of EME) on systems performance; and/or the effects of international civil and military standards intended to control man-made intentional and unintentional emissions of electromagnetic energy, then this is the panel for you. The experts on this panel have decades of experience addressing the impact and interaction with the EME across military and civilian applications.

Experiments & Demonstrations 10:00am - 12:00pm

Room: Hall A Experiments and Demos
Co-Chair: Gabe Alcala, Advanced Test Equipment Corp. (ATEC), San Diego, CA, USA
Co-Chair: Jacob Dixon, IBM, Rochester, MN, USA

Session Abstract: As a result of the Call for Experiment and Demonstration Proposals, we are pleased to announce the accepted proposals below that will be presented at the 2022 IEEE International Symposium on Electromagnetic Compatibility, Signal and Power Integrity, August 1-5, in Spokane, Washington. You will not want to miss the popular Experiments and Demonstrations program that will be held in the Exhibition Hall on August 2-4. This hands-on activity provides a unique learning experience that complements the technical presentations at the symposium. It is traditionally one of the educational highlights of the annual symposium!

VIRC: Shake It Till you Make It!...N/A

Robert Vogt-Ardatjew, Vasiliki Gkatsi
Universiteit Twente, Enschede, Netherlands

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

Common Mode Energy, Loop Impedance, and the Use of Ferrites...N/A

Patrick Andre
Andre Consulting, Inc., Mill Creek, Washington, USA

Abstract: Starting with a description of common mode energy and how it is generated. Demonstration of return path loop impedance with frequency, explaining the physics behind the signal path taken for the return signal. Showing how the use of ferrites can influence the return path of the signal. Discussing the importance of loop areas when dealing with radiated emissions and susceptibility.

Fast E-Field Mapping...N/A

Samuel Hildebrandt
LUMILOOP GmbH, Dresden, Germany

Abstract: LUMILOOP is a German manufacturer of high performance electronic measurement devices.

The product range covers LSProbe E-Field Probes, LSPM RF Power Meters, LSAOL RF Analog Optical Links and matching accessories.

E-field uniformity evaluation usually takes 1-2 working days. Besides the obvious economic loss by not being able to use/sell this measurement time, it is a tedious job. LUMILOOP will demonstrate highspeed E-field mapping. A LSProbe E-field probe, a LSPM Powermeter and a RF signal generator are orchestrated by our PixEdust® software. PixEdust utilizes the frequency sweep capability of all these devices to iterate quickly through a frequency list. This method reduces measurement time per spatial point down to single-digit seconds. A IEC 61000-4-3 17 point field uniformity evaluation can easily be performed in under one hour. We will demonstrate this live in a small-scale setup.

SS-WE-AM2-TC5 Hardware Security for Smart Society – Part II (Sponsored by TC-5)

Special Session **10:20am - 12:00pm**
Room: 402A
Chair: Yuichi Hayashi, Nara Institute of Science and Technology, Takayama, Japan
Co-Chair: Naofumi Homma, Tohoku University, Sendai, Japan

10:20am **A Study for Improving Signal-to-Noise Ratio Measurement Method in Side-Channel Information Leakage of Cryptographic Hardware** 294

Kengo Iokibe, Masaki Himuro, Yoshitaka Toyota
Okayama University, Japan

Abstract: Once the signal-to-noise ratio (SNR) of the side-channel (SC) leakage trace is known, the intensity of the SC information leakage source inside the integrated circuit (IC) can be identified from measurements carried out outside the IC. SNR observation of SC leakage can also make it possible to set quantitative design targets to achieve the demanded leakage intensity. We discuss an improved method for identifying the SNR of SC leakage traces composed of multiple transient responses of IC switching current. The IC switching current repeatedly occurs as the IC runs the cryptographic operation since the cryptographic algorithm repeats a set of sub-operations. The method was applied to simulated and measured leakage traces to eliminate the effect of transient IC switching current caused before the target sub-operation was processed. As a result, a transient component more extensive than the signal component of side-channel analysis was identified in the decoupling capacitor configuration, where the convergence of the transient response is slow. In addition, the correlation coefficients obtained by the correlation power analysis, a major side-channel analysis method, were plotted as a function of SNR, and the plot of the simulated traces agreed with the theoretical curve. On the other hand, some errors remained in the plot of the measured traces.

10:45am **SASIMI: Evaluation Board for EM Information Leakage from Large Scale Cryptographic Circuits** 299

Daisuke Fujimoto[1], Youngwoo Kim[1], Yuichi Hayashi[1], Naofumi Homma[2], Masanori Hashimoto[3], Takashi Sato[3], Jean-Luc Danger[4]

[1]Nara Institute of Science and Technology, Japan; [2]Tohoku University, Japan; [3]Kyoto University, Japan; [4]Télécom Paris, France

Abstract: In this paper, we propose a common evaluation board(Side-channel Attack Standard IMplementation and evaluation board:SASIMI) for the threat of acquiring information leaked from electromagnetic(EM) noise generated by devices. To prevent this threat, it is necessary to implement circuits that do not leak secret information, like a secret key, via EM side-channel, and conduct actual measurement and evaluation environment, which makes it difficult for a third party to reproduce the results. However, since captured EM activity is affected by the surrounding EM noise, the evaluation results may vary depending on the evaluation environment. The proposed evaluation board can implement various cryptographic circuits. The IC must be capable of reconfiguring logic and implementing large-scale cryptographic blocks such as post quantum cryptography. To reduce the influence of environmental EM noise, an independent power supply network and measurement port are provided for the IC to be evaluated thus improving the measurement reproducibility. In order to evaluate the performance of the SASIMI board, this paper proposes an index to evaluate the strength of the information of the secret key contained in the power supply noise. This index is to find the value of the resistance to be inserted into the power supply network of the prototype board. Measurement results show that the simple amplitude value of EM noise and the intensity of information leakage do not necessarily coincide.

11:10am **The Technological Arms Race in Hardware Security** 303

Shahin Tajik, Patrick Schaumont

Worcester Polytechnic Institute, USA

Abstract: For many years there has been an arms race between designers and adversaries of secure hardware. Improvements in the strategies for attack spur new defense techniques, and better defenses lead to improved attacks. In this contribution, first, we examine the technological dimensions of this arms race. While defenders benefit from increased circuit density and decreasing feature size, attackers benefit from novel side-channel attack vectors Based on optical and electromagnetic interactions with their target. Second, we analyze the feasibility and applicability of various side-channel attacks on primary units of cryptographic hardware. We also discuss the required time, cost, and expertise to mount these attacks. We then examine how well modern defense methods are capable of thwarting modern attack methods.

11:35am **Modeling an ESD Gun Discharge to a USB Cable** 309

Yang Xu[1], Jianchi Zhou[1], Daryl Beetner[1], Javad Meiguni[2], David Pommerenke[3], Sergej Bub[4], Steffen Holland[4]

[1]Missouri University of Science and Technology, USA; [2]Amazon, USA; [3]Graz University of Technology, Austria; [4]Nexperia Germany GmbH, Germany

BEST EMC STUDENT PAPER FINALIST

Abstract: When an electrostatic discharge (ESD) gun discharges to a USB cable, the routing and quality of the cable impacts the waveform seen at the printed circuit board (PCB) connected to the cable and the ability of an on-board transient voltage suppressor (TVS) to protect sensitive electronics. The impact of cable configurations during ESD gun contact discharge tests was investigated for multiple cable configurations. Injection to a cable pin whose shield is “floating” at the injection site can cause a double-peak in the ESD waveform at the PCB and a lower maximum stress level than when the cable shield is connected to the return plane. Poor shielding of the USB connector can further induce a pre-pulse effect, where a smaller ESD pulse arrives at the PCB before the main pulse. This pre-pulse can result in poor firing of the TVS device and thus worsen ESD stress at a sensitive IC. Circuit models were developed to anticipate and explain both of these phenomena. These models were incorporated into a system-level transient simulation including models of a PCB with a TVS and a pair of on-chip diodes. This system-level model was able to predict the quasi-static and peak voltages and currents at the on-chip diode during 1-8 kV ESD contact-discharge tests with various USB cable configurations to within less than 30%. These models were used to develop test and design guidelines to account for the impact of the quality and configuration of a USB cable during an ESD discharge.

TP-WE-AM2-TC7 Low Frequency EMC: Measurement (Sponsored by TC-7)

Technical Papers **10:20am - 12:00pm**

Room: 402B

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

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

10:20am **Evaluation of Three-Axis Magnetic Loop Antenna Cross Coupling for Low-Frequency Measurements** 315

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: Nowadays the majority of electrical devices are complex systems with different operation modes and switching elements. The amount of evaluation procedures that are needed to be done for these devices increases drastically. It is pushing standard radiated EMI measurements to the edge, where the advantage between time and the accuracy of measurements should be chosen. Standard low-frequency measurements as CISPR 36, used to evaluate radiated EMI for frequencies below 30 MHz, became too time-consuming and expensive. Proposed improvements which include time-domain multichannel measurements in combination with a three-axis shielded loop antenna can be more time-efficient. Compared to a conventional single-loop antenna, one of the potential challenges is the coupling between loops for the two- and three-axis antenna. This paper investigates the effect of coupling between the individual loops when illuminated with a complex field, which is shown to be the worst-case scenario. Only some minor coupling is observed implying that such a three-axis loop antenna can be used without sacrificing much accuracy, while still providing a significant improvement in the measurement time-efficiency.

10:45am **Identifying Sources of Conducted Emissions by Measuring the Coherence Function** 321

Xin Yan[1], Fuwei Ma[1], Wei Zhang[1], Kaustav Ghosh[2], Sameer Walunj[2], Philippe Sochoux[2], Victor Khilkevich[1]

[1]Missouri University of Science and Technology, USA; [2]Juniper Networks, USA

BEST EMC PAPER FINALIST

Abstract: Conducted emissions (CE) is one of the electromagnetic interference (EMI) issues that pose serious compliance problems for electronic devices. for a system with several sources, estimating the contribution of each source to conducted emission at different frequencies can be a challenge. In this article, a coherence function-based signal separation method is presented and validated on two commercial power supply units (PSU). The noise generated by the PSU and measured at the line impedance stabilization network (LISN) port contains two predominantly uncorrelated signals associated with the power factor correction (PFC) and H-bridge/rectifier circuits with unknown contributions at different frequencies. Two reference signals are obtained by probing the emission signals close to the sources. By calculating the coherence between the LISN noise signal and the reference signals, the contributions of these two signals to the noise are obtained. The measurement of the signal contributions can help engineers identify the dominant sources and mitigate the emissions more efficiently over a wide range of frequencies.

11:10am **Electromagnetic Influence of AC Traction Network on the Railway Communication Lines** 326

Tetiana Serdiuk, Hossein Taghizade Ansari, Rodica Botnarevscaia

Ukrainian State University of Science and Technologies, Ukraine

Abstract: This paper deals with the evaluation of electromagnetic influence of AC traction network on the overhead railway communication lines. The dependence of voltage on a convergence width of communication lines and traction network are given. The experimental research of harmonics in traction current and the theoretical investigation of their influence on communication lines were carried out.

11:35am **High Density Sensor Network for Monitoring Grid Events** 330

Robert King[1], Theo Laughner[2], Bob Marshall[3], Chris Sloop[3], Jon Wellinghoff[4]

[1]Good Company, USA; [2]Lifescale Analytics, USA; [3]Whisker Labs, Inc., USA; [4]Grid Policy, USA

Abstract: A customer installed residential-based monitoring system has been deployed in multiple areas to help address electrical hazards that cause house fires. Due to the high-density and high-resolution of the expanding distributed sensor network, additional benefits can be realized by utilities from higher visibility into power quality events and disturbances within their networks. This paper describes the technology and the benefits, contrasts other monitoring technologies, and provides a variety of case studies of this new approach to monitoring the grid.

TP-WE-AM2-TC10 Numerical Modeling and Simulation Techniques – III (Sponsored by TC-10)

Technical Papers **10:20am - 11:35am**

Room: 402C

Chair: Matteo Cocchini, IBM, New York, NY, USA

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

10:20am **Performance Judgment of Automotive Wire Harness based on Convolutional Neural Network** ..... N/A

Tadatoshi Sekine, Hiromi Itaya, Shin Usuki, Kenjiro T. Miura

Shizuoka University, Japan

Abstract: This paper describes a performance judgment method Based on a convolutional neural network (CNN) for an automotive wire harness. The proposed method uses the CNN to represent the correlation between the cross-sectional shape of the wire harness and its electric performance. We consider combinations of a few patterns of the inputs and outputs of the CNN and discuss about the usefulness of each input-output pattern for the prohttps://emc-sipi2022.abstractcentral.com/login#per judgment.

10:45am **Simplified Modeling Approach for Extracting Bump Current Profile Using Transfer Function** ..... N/A

Raewoon Yoo, Sungwook Moon, Jiyoung Park, Seungki Nam

Samsung Electronics Co. Ltd., Korea

Abstract: An accurate bump current profile modeling is important to analyze system-level power integrity (PI) performance for target designs. However, it is difficult to directly extract current profile at bumps corresponding to entire desired scenarios due to running time limitation. In this work, we propose an efficient and simple modeling approach to extract current profile Using a transfer function that can reduce significantly the extraction time without accuracy losses.

11:10am **Asymptotic High Frequency Behaviors of the Lossy Transmission Line** ..... N/A

Tao Wang, Brian Brecht

Teradyne Inc., USA

Abstract: Today's high speed signal delivery requires ultra-broad working band for transmission lines from DC all the way to millimeter waves. In this paper, we developed a new asymptotic high frequency input impedance limit for the lossy transmission line, which shows the dependency on the dielectric loss tan. It gives us a convenient limit of return loss to the lossy transmission. We also proposed a new formulation to find the passing length point when the absorbed power in the line surpasses the reflected power. These methods provide new insights to lossy transmission lines' high frequency behaviors.

TU-WE-PM-1 Smart Grid and EMC Issues (Sponsored by SC-1)

Tutorial **1:30pm - 5:30pm**
Room: 401B
Chair: Mike McInerney, Champaign, IL, USA
Co-Chair: William A. Radasky, Metatech Corporation, Goleta, CA, USA

Session Abstract: Smart Grid (as used in electric power systems) continues to be a hot topic worldwide. Smart Grid (SG) interest and installations continue to increase, as do EMC issues to keep the grid operating. This tutorial will begin with a review of the activities of the IEEE EMC Special Committee 1 (SC 1) which coordinates Smart Grid EMC activity within the IEEE EMC Society. The tutorial will focus on the status at the end of 2021.

The tutorial will continue with a review of the activities of the of the key Smart Grid EMC working group in the United States (Smart Electric Power Alliance – SEPA). These activities focus on SG devices that are exposed to the electromagnetic environment where the grid traverses and terminates. The tutorial will also place in perspective the EMC work still needed to make EMC an integral part of the Smart Grid activity/operation. Specific examples of the EMC immunity testing needed for smart devices with communications functions will be provided.

The tutorial will conclude with a presentation on the effect on the Smart Grid of power converters utilizing power line communications.

Introduction to the IEEE EMC Society Special Committee 1 (SC 1) and an Introduction to this Tutorial...N/A

Mike McInerney
Mac and Ernie, USA

SEPA (Smart Electric Power Alliance) Electromagnetic Interoperability Issues Sub-Group (EMIISG) – Its History, Accomplishments and Status...N/A

William Radasky
Metatech Corporation, USA

Testing Requirements for Devices with Communications Functions Used with Electric Power Apparatus...N/A

Jerry Ramie
ARC Technical Resources, USA

The Interoperability of Power Converters with Power Line Communications and their Effect on the Smart Grid...N/A

Dave Thomas
University of Nottingham, United Kingdom

WS-WE-PM-2 Full System EMC Simulation Using Encrypted 3D Components (Sponsored by TC-9)

Workshop **1:30pm - 5:30pm**
Room: 401C
Chair: Juliano Mologni, ANSYS, Rochester, MI, USA
Co-Chair: Timothy McDonald, Electro Magnetic Applications, Inc., Lakewood, CO, USA

Session Abstract: One of the biggest challenges in 3D EMC system simulation is to get access to components from several vendors and integrate them into a system model. One typical example would be connectors, antennas, and components such as common mode chokes placed on a PCB. Usually, vendors are not allowed to provide a 3D model due to IP concerns, and circuit representation such as SPICE or Touchstone files and even near field data links does not provide enough information for an accurate simulation that needs to account for the coupling of the components to the system, such as the coupling of an antenna to a PCB trace. Encrypted 3D components is a technology created to overcome the barrier that exists between component vendors and system integrators, enabling an "electromagnetic simulation collaboration". Component vendors can hide anything in the component model such as 2D/3D solid bodies, material properties, boundary conditions, and provide an encrypted component to system integrators for a full system EMC simulation. This workshop will provide a hands-on demo on how to create 3D encrypted models, how to place real word 3D encrypted components from several vendors into a PCB and run a full conducted emission and radiated emission analysis. A set of examples showing how this technology is leveraged in real word products will also be presented.

Full System EMC Simulation Using Encrypted 3D Components...N/A
Juliano Mologni[1], Tim McDonald[2], Fabio Bauman[3]
[1]Ansys, Inc., USA; [2]Electro Magnetic Applications, Inc., USA, USA; [3]SmartM, USA

Demo on How to Assembly a SO-DIMM to-UDIMM Adapter Using Encrypted and Non Encrypted 3D Components...N/A
Fabio Bauman
SmartM, Brazil

Full System Radiated Emission Example Using Near Field Sources from PCBs Using 3D Encrypted Component Models...N/A
Timothy McDonald
Electromagnetic Applications, USA

TP-WE-PM1-TC9 Computational Electromagnetics – I (Sponsored by TC-9)

Technical Papers **1:30pm - 3:10pm**
Room: 402A
Chair: Yansheng Wang, Rivos Inc., Santa Clara, CA, USA
Co-Chair: Ying Cao, Apple Inc., Santa Clara, CA, USA

1:30pm **Radiated-Emission Analysis of Electrical Interconnection Structures based on a Modal Network Model** 338
Hannes Schreiber, Marco Leone
Otto von Guericke Universitat Magdeburg, Germany
BEST EMC PAPER FINALIST

Abstract: A novel method for calculating the radiated far field of electric interconnection structures Based on an equivalent modal network model is presented. From the amplitudes of the current modes in the system, as obtained by circuit simulation, the radiated field is set up as linear combination of the corresponding radiation modes. This enables an efficient broadband simulation of the radiation of interconnection structures with different, linear loads, facilitating the optimization with respect to the electromagnetic compatibility (EMC) of the system. The proposed method is validated in the frequency domain by comparison with Full-Wave reference results.

1:55pm **Common-Mode Contribution to Currents Induced on a Terminated Multiconductor Transmission Line in a Reverberent Field** 344

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

Abstract: The currents induced on terminated multiconductor transmission lines (MTLs) by stochastic electromagnetic fields in overmoded cavities are examined numerically. Techniques that find the mean-squared currents from a rigorously defined number of deterministic evaluations are applied to classic transmission line and moment method models. The calculations show that line imbalance leads to significant common-mode contributions to the induced currents in approximately matched termination loads that are not predicted by transmission line theory. The relative level of the common-mode contribution is dependent on the level of line imbalance presented by the full MTL cross-section around the termination load under test. A reduction in cross-section dimensions leads to an increase in the relative contribution of the common mode.

2:20pm **On the Vectorial Property of Stochastic Dyadic Green's Function in Complex Electronic Enclosures** 350

Shen Lin, Yang Shao, Zhen Peng
University of Illinois Urbana-Champaign, USA

BEST EMC PAPER FINALIST

Abstract: This paper presents a physics-oriented, mathematically tractable statistical wave model for analyzing the naturally occurring chaotic dynamics of high-frequency reverberation within complex cavity environments. The key ingredient is a vector dyadic stochastic Green's function method derived from Wigner's random matrix theory and Berry's random wave hypothesis. The stochastic Green's function statistically replicates the multipath, ray-chaotic interactions between ports of entry and ports of interference without involving the complex details within the target's enclosure. The work achieves a physics-based modeling and simulation capability that predicts the probabilistic behavior of backdoor coupling to complex electronic enclosures.

2:45pm **Modeling Radiated Emissions from PCBs in Shielding Enclosures based on a Numerical Green's Function Approach** 356

Zi An Wang[1], Li Jun Jiang[2], Jun Fa Mao[1], Ping Li[1]
[1]Shanghai Jiao Tong University, China; [2]The University of Hong Kong, China

Abstract: To accurately and efficiently model the radiated emissions from printed circuit boards (PCBs) placed in shielding enclosures, in this work, a novel approach Based on the numerical Green's function (NGF) is proposed. In terms of Schelkunoff's equivalence principle, if the interior of the shielding enclosure is filled up with perfectly electric conductor (PEC), only tangential electric fields over the ventilation slots are sufficient to obtain the radiated emissions. However, due to the presence of the PEC filled shielding box, the in-situ Green's function is not available. To conquer this problem, the proposed approach can be split into two steps. In the first step, the tangential electric fields over ventilation slots are sampled. The NGF over a spherical surface encompassing the perfectly electric conductor (PEC) filled shielding enclosure is obtained by full-wave simulation subsequently. The magnetic field over the spherical surface can be calculated on the basis of the NGF and the sampled electric field. In the second step, the spherical surface is filled up with perfectly magnetic conductor (PMC). The radiated emission outside the spherical surface is predicted according to the previously calculated magnetic field via expanding the Green's function by spherical modal functions. The preponderance of the proposed method in efficiency and versatility is verified by representative numerical examples.

TP-WE-PM-TC8 Aeronautics and Space EMC (Sponsored by TC-8)

Technical Papers **1:30pm - 3:10pm**
Room: 402B
Chair: Jim Lukash, Lockheed Martin Space Systems, Palo Alto, CA, USA
Co-Chair: Jen Dimov, NASA, Bowie, MD, USA
Co-Chair: Manuel Soriano, NASA-Jet Propulsion Laboratory

1:30pm **Superposition of EMI in Multiple Interconnected SMPS** 362
Leonardo Malburg[1], Niek Moonen[1], Frank Leferink[1,2]
[1]University of Twente, The Netherlands; [2]Thales Nederland B.V., The Netherlands

Abstract: Enabling All-Electric Aircraft (AEA) operations result in considerable EMC compliance challenges. Considering its architecture, secondary distribution systems will eventually interact with equipment not regulated by the DO-160 standard. Portable electronic devices (PEDs) introduced by passengers could result in compatibility issues. In this paper, two approaches were compared when assessing EMI on a parallel multi-load circuit. The conducted emissions of four different power supplies representing PEDs were individually measured, then combined resulting in an equivalent full-load assessment. The same loads were simultaneously measured, representing the in situ test. The differences in EMI levels are presented, depicting inherent harmonic components from each approach. The results are discussed, showing reduction in EMI levels between approaches, which can enable filter design optimization on a component level.

1:55pm **EMI/EMC, Lightning, and RF Test Verification for the Virgin Orbit LauncherOne Vehicle** 368
William Elkman, Cheyne Scoby, Umer Qureshi, Andrew Shirali
Virgin Orbit, USA

Abstract: Virgin Orbit has developed the LauncherOne (L1) two stage LOX/RP-1 launch system, capable of deploying payloads up to 300kg to 500km Sun Synchronous Orbit (SSO), and deploying payloads up to 500kg to 200km Low Earth Orbit (LEO). The EMI/EMC Control Program has been tailored from RTCA-DO-160F and MIL-STD-461F. Electromagnetic Compatibility (EMC) for LauncherOne has been verified to Launch Range, EGSE (electrical ground support equipment) and internal launch vehicle (LV) Avionics systems electromagnetic environments, by tailored, limited component/unit test, subsystem test and limited system level test. The EMISMs (electromagnetic interference susceptibility margins) for interfaces internal to L1 and between L1-747, have been verified by System qualification test, and are 6dB for noncritical and 20dB for critical interfaces. This paper reports the test results used to verify functional performance and margins.

2:20pm **EMI/EMC, Lightning, Space Environment and SEE Design for the Virgin Orbit LauncherOne Vehicle** 374
William Elkman, Cheyne Scoby, Umer Qureshi, Andrew Shirali
Virgin Orbit, USA

Abstract: Virgin Orbit has developed the LauncherOne (L1) two stage LOX/RP-1 launch system, capable of deploying payloads up to 300kg to 500km Sun Synchronous Orbit (SSO), and deploying payloads up to 500kg to 200km Low Earth Orbit (LEO). The company has implemented an EMI/EMC Control Program, tailored from RTCA-DO-160F and MIL-STD-461F. Electromagnetic Compatibility (EMC) for LauncherOne has been verified to Launch Range, EGSE (electrical ground support equipment) and internal launch vehicle (LV) Avionics systems electromagnetic environments, by analysis, and tailored, limited component/unit test, subsystem test and limited system level test. The EMISMs (electromagnetic interference susceptibility margins) for interfaces internal to L1 and between L1-747, have been verified by System qualification test, and are 6dB for noncritical and 20dB for critical interfaces. [10] Reports the test methods used to verify functional performance and margins.

2:45pm **Single Event Effects Test Verification for the Virgin Orbit LauncherOne Vehicle** 380
William Elkman, Cheyne Scoby, Umer Qureshi, Andrew Shirali
Virgin Orbit, USA

Abstract: This paper describes the SEE (single event effects) design verification approach and proton beam verification test results for the Virgin Orbit LauncherOne (L1) two stage LOX/RP-1 launch system, capable of deploying payloads up to 300kg to 500km Sun Synchronous Orbit (SSO), and deploying payloads up to 500kg to 200km Low Earth Orbit (LEO). [9] Describes the EMI/EMC Control Program tailored from RTCA-DO-160F and MIL-STD-461F. [10] Reports the Electromagnetic Compatibility (EMC) verification procedures and results for LauncherOne.

TP-WE-PM1-TC10 High-Speed Link/Bus Design – I
(Sponsored by TC-10)

Technical Papers **1:30pm - 3:10pm**
Room: 402C
Chair: Francesco de Paulis, University of L'Aquila, L'Aquila, Italy
Co-Chair: Hanfeng Wang, Google Inc.

1:30pm **Bandpass Negative Group Delay Analysis of VIu-Shaped Trace Crosstalk Effect** 386
Xiaoyu Huang[1], Fayu Wan[1], George Chan[2], Eric Jean Roy Sambatra[3], Samuel Ngoho[4], Blaise Ravelo[1]
[1]Nanjing University of Information Science and Technology, China; [2]ASM Pacific Technology Ltd., China; [3]Institut Supérieur de Technologie, Madagascar; [4]Association Française de Science des Systèmes, France

Abstract: This paper investigates on the bandpass (BP) negative group delay (NGD) effect from printed circuit board (PCB) trace crosstalk. The designed and prototyped PCB proof-of-concept (POC) is constituted by arbitrary traces of Vlu-shaped coupled lines ended by radial open stubs. The BP-NGD function is characterized by the basic qualification parameters as the NGD value, center frequency and bandwidth. The influence of the u- and V-shape trace physical parameters on the main interconnect I-line is illustrated by sensitivity analyses. The Vlu POC BP-NGD behavior is validated by simulation and measurement. The BP NGD analysis reveals the PCB trace crosstalk effect with the apparition of dual-band response characterized by NGD value-center frequencies of about (-1 ns, 2.43 GHz) and (-1 ns, 2.58 GHz).

1:55pm **Copper Roughness Induced Gain for Inductance and Resistance on Stripline Interconnects** 392
Gerardo Romo Luevano, Tim Michalka, Vinit Sonawane, Varin Sriboonlue
Qualcomm Technologies, Inc., USA

Abstract: This paper presents a method for broadband characterization of copper roughness induced gain factor for resistance and inductance on stripline interconnects. The characterization relies on S-parameter measurements of striplines fabricated with smooth (VLP) and rough (RTF) copper finishing on otherwise identical stack-ups. The VLP and RTF interconnects are each characterized from two-line measurements; then the R, L, G, C parameters for each are extracted under the same Tanδ condition, which yields the copper roughness factor for the inductance and resistance of the RTF interconnects accurately characterized up to 40 GHz. The method also allows to uniquely characterize the permittivity of the dielectric and demonstrates that the increase in inductance due to roughness is considerably larger than that for resistance, which is a necessary condition for a causal model. The experimental characterization shows excellent correlation to a newly introduced generalized causal Hammerstad model, and good correlation to the Huray model, when multiple terms in the expansions are used.

2:20pm **Analysis of a TDR Technique to Measure Dielectric Constant** 397
Aditya Rao[1], Eric Bogatin[1], Melinda Piket-May[1], Dan Schofield[2],
Balaji Sankarshanan[2], Aakriti Srivastava[1]
[1]University of Colorado Boulder, USA; [2]GE Healthcare, USA

Abstract: Low cost measurement of material properties is a valuable tool which can aid in pre-layout design and post-layout verification. This paper analyzes a low-cost technique to measure the dielectric constant of a microstrip substrate Using a Time Domain Reflectometer (TDR), explores the artifacts which can arise in these measurements and provides guidelines to reduce these artifacts.

2:45pm **USB4.1 Compliance Test – Procedures and Issues** 402
Sherman S. Chen[1], Zhifei Xu[2], Antoine Moret[2]
[1]Kandou Bus, United Kingdom; [2]Kandou Bus, Switzerland

Abstract: The paper examines the primary testing items & procedures of the USB4.1 Gen3 Compliance Test Specification (CTS), i.e., TX test point (TP) 2 test, TX TP3 test, and RX Stress test. The methodology of validating the device under test (DUT) IBIS AMI model against the USB4.1 CTS is described. The roles and impacts of the key parameters are explained and evaluated. A novel approach for inferring the ISI jitter is introduced. The test results obtained through simulation with channels of two representative characteristics are presented. In addition, some concerns associated with the latest standards are discussed, along with proposals for strengthening the clarity of the standard.

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

Room: Exhibit Hall
Co-Chair: Timothy Wig, Intel, Northborough, MA, USA
Co-Chair: Stephen Eastman, Intel, Rocklin, CA, USA
Co-Chair: Aurelio Rodriguez Echevarria, Intel, Hermosillo, Sonora, Mexico

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

ATX 3.0 PSU and PCIE 5.0 Card Power Delivery: More Power, Flexibility, and Control

PLANNED PANELISTS INCLUDE:

- Stephen Eastman of Intel is a Platform Power Specialist and the author of the ATX 3.0 Multi-Rail Power Supply Design Guide, the industry standard for desktop power supplies, and the new ATX12VO Single-Rail Power Supply Design Guide.
- Timothy Wig of Intel is a central contributor to the PCI Express Card Electromechanical (CEM) Specification and drove the development of new PCIe power delivery and SI strategies for the 5.0 PCIe card spec. Tim also edits the spec document.
- Aurelio Rodriguez - Echevarria is Intel's Server Power Delivery Architect and author of the Modular Common Redundant Power Supply Design Guide

Abstract: The ATX v3.0 power supply specification and the PCI Express 5.0 CEM Specification have been expanded to support the new 600W PCIe card power level while providing a range of features such as compact, high-power connectors, new power rails, and a long-overdue allowance for brief power excursions. The limit on total card power consumption was doubled, from 300 W to 600 W, and a new 48V power rail was added. Two new power connectors were introduced to provide the full 600 W through a single connector on either the 12V or 48V rail. This markedly simplifies the design of card voltage converters vs. the legacy power scheme, which required multiple, mismatched 12V rails for any cards over 75 W. Extensive new content in the ATX power supply spec addresses the power supply requirements that will be needed to support these capabilities. Prior to this 3.0 release, the ATX power supply specification had not been significantly revised since 2003. Taken together, these developments will have a major shift on the architecture of both client and server chassis and will be deployed starting in Q4 2022.

Experiments & Demonstrations 3:00pm - 5:00pm

Room: Hall A Experiments and Demos
Co-Chair: Gabe Alcala, Advanced Test Equipment Corp. (ATEC), San Diego, CA, USA
Co-Chair: Jacob Dixon, IBM, Rochester, MN, USA

Session Abstract: As a result of the Call for Experiment and Demonstration Proposals, we are pleased to announce the accepted proposals below that will be presented at the 2022 IEEE International Symposium on Electromagnetic Compatibility, Signal and Power Integrity, August 1-5, in Spokane, Washington. You will not want to miss the popular Experiments and Demonstrations program that will be held in the Exhibition Hall on August 2-4. This hands-on activity provides a unique learning experience that complements the technical presentations at the symposium. It is traditionally one of the educational highlights of the annual symposium!

Measure Ground Bounce and Power Rail Noise on a Digital IC with This Simple Method...N/A

Eric Bogatin
ECEE, University of Colorado Boulder, Boulder, Colorado, USA

Abstract: Ground bouce can be a terrible problem in many systems, from IC packages, connectors, and even circuit board features. I will show you a very simple method to measure the ground bounce on a board and see the dramatic difference from following good and bad routing practices.

Using this same method, I will show how to measure the voltage noise on the power rail and the role decoupling capacitors can play to reduce this.

Automated Flows for Signal Integrity and EMC Simulations...N/A
Wade Smith, Juliano Mologni
Ansys, Canonsburg, PA USA

Abstract: Signal Integrity and especially EMC simulations can be extremely difficult to setup. Many times a full simulation must consider 3D geometries like the PCB, cables and the test setup required by most of the EMC standards. Also, drivers such as ideal sources, SPICE or IBIS models and even measurement data from oscilloscope or VNA needs to be included to generate meaningful simulation results. These processes are usually performed manually and consume a considerable amount of time. We will be demonstrating how automated and customized workflows were created to speed up the simulation setup process to a few minutes for specific communication protocols such as DDR and specific EMC simulations such as CISPR25.

TP-WE-PM2-TC9 Computational Electromagnetics – II (Sponsored by TC-9)

Technical Papers **3:40pm - 5:20pm**
Room: 402A
Chair: Scott Piper, General Motors Corp., Canton, MI, USA
Co-Chair: Patrick DeRoy, Analog Devices Inc., Norwood, MA, USA

3:40pm **Full Wave Hybrid Simulation of a Transformer in an Equivalent Model Setup** 409
Daniel Lyngby Commerou, Morten Sørensen
University of Southern Denmark, Denmark

Abstract: In power converters, the main contribution to the radiated emission is common-mode current on the attached cables. The coupling path to these cables have previously been investigated with several different methods. This paper suggests an equivalent model hybrid simulation of a transformer, made to reduce modelling effort and simulation time in a step to use full wave simulation as investigation tool. The H-fields were measured Using an in-house near-field scanner. The equivalent model hybrid simulation was performed and results were compared. A fair to good agreement of the results from approx. 80 MHz to approx. 600 MHz is visible.

4:05pm **A Segmentation Strategy for Structures with Common Mode Coupling** 415
James Hunter[1], Shengxuan Xia[1], Aaron Harmon[1], Mohamed Z.M. Hamdalla[2], Ahmed M. Hassan[2], Victor Khilkevich[1], Daryl G. Beetner[1]
[1]Missouri University of Science and Technology, USA; [2]University of Missouri Kansas City, USA
BEST EMC STUDENT PAPER FINALIST

Abstract: The level of electromagnetic coupling to electronic devices can vary widely from one device to another. When considering the induced voltage from an incoming plane wave on printed circuit boards (PCBs) and their attached cable harnesses, there is significant variety in the configuration of the devices that could be seen. This encourages the use of segmentation, so that the components of these devices (PCBs, connectors, and harnesses) can be modeled separately to alleviate simulation burden. This allows for a more flexible model and a "toolbox" to construct devices with. The goal of this work is to use segmentation to model the external electromagnetic radiation from these devices. The radiation pattern and reciprocity theory can later be used to calculate the voltage coupled from an incident plane wave. Most realistic devices exhibit strong common mode (or antenna mode) coupling that cannot be ignored during segmentation. When segmenting such structures, a multi-modal approach is needed to incorporate coupling from both the common (CM) and differential (DM) modes and to allow these currents to flow properly between the blocks. This work introduces the concept by segmenting a simple dipole, which requires the common mode only, and then applies the complete methodology to a more complicated structure that requires the incorporation of both modes.

4:30pm **Safety and Availability Considerations in a Triple Modular Redundant Time Diverse System with Over-Voltage Detection** 421

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

Abstract: In this paper, an analysis is done for safety and availability considerations in a Triple Modular Redundant (TMR) communication channel that is subjected to a multiharmonic electromagnetic disturbance under reverberation conditions. Time diversity is used as an EM-resilience measure along with over-voltage detection in order to incorporate fault tolerance in the system design. The study shows that combining over-voltage detection with an EM-resilience measure like time diversity is quite effective in dealing with Electromagnetic Interference (EMI) induced failures over a broad range of Signal to- Interference Ratios (SIR). The results show a considerable reduction in failure probability and a marked improvement in fault tolerant capacity.

4:55pm **The Impact of the RS103 Excitation on the Differential Received Eye Patterns for Digital Interconnects – A Time-Domain Approach** 427

David Norte
Ball Aerospace, USA

Abstract: Compliance to the RS103 standard for space applications is generally required by many programs. Although the test requirements for this standard are well known, it is not always well known how the RS103 excitation affects the received signals for digital applications, for example. This paper utilizes a transmission line model to help enable a better understanding of the degradations that can be induced upon the received eye patterns from shielded differential transmission lines for digital applications that are exposed to a constant 20V/m RS103 excitation. It is determined that the most serious degradations occur in the form of increased timing jitter, as well as reduced eye openings that can increase the bit-error-rate for the given digital interconnect and for operational bit rates up to 3.0 Gbps. It is also emphasized that low end-to-end transfer impedances that include the effects of the shields, connectors, and pigtails, as well as highly balanced transmissions, can help mitigate these degradations.

TP-WE-PM-TC3 Electromagnetic Environments (Sponsored by TC-3)

Technical Papers **3:40pm - 5:45pm**
Room: 402B
Chair: Karen Burnham, Electro Magnetic Applications, Inc., Lakewood, CO, USA
Co-Chair: Frederick Heather

Session Abstract: The papers within this session detail a number of different electromagnetic environments and how to characterize them. The overall electromagnetic environment in our surroundings is complex and only getting more so as technology progresses. The papers here describe specific environments such as accelerators and automotive, and also techniques that can be used for characterization.

3:40pm **Resilience of Reed-Solomon Codes against Single-Frequency Electromagnetic Disturbances: Fault Elimination through Encoder Tuning** 433

Pejman Memar, Jens Vankeirsbilck, Dries Vanoost, Tom Holvoet, Jeroen Boydens
Katholieke Universiteit Leuven, Belgium

Abstract: In increasingly electromagnetic-polluted environments, communication networks are becoming more vulnerable. Even networks equipped with error control techniques suffer from this problem. Electromagnetic disturbances can result in corrupted data which are undetectable by error control techniques. Such scenarios are extremely dangerous as the system is unaware of the corruption. This could lead to critical failures. Thus, protecting communication networks against this type of undetected corrupted data is of the utmost importance. In this regard, this paper presents an effective fault elimination approach through encoder tuning. This technique enhances the resiliency of a well-known forward error correction code, known as primitive Reed-Solomon Codes, against steady-state single-frequency electromagnetic disturbances. It is found that this approach outperforms the previously proposed multi-layer inversion-based fault elimination approach in mitigating undetected corrupted data. Furthermore, it is shown that encoder tuning has two main implementation advantages over our previous approach. First, it does not require an extra layer to perform fault elimination. Second, it eliminates the overhead of performing double syndrome calculation at the consumer side.

4:05pm **Magnetic Field Noise in the Ultra-Low Frequency (ULF) Band and Historical Comparisons** 439

Chenming Zhou[1], David P. Snyder[1], Benjamin Epstein[2], Zachary T. Robinson[3], George Y. Jin[3], Priscilla Y. Tang[3], Ronald G. Polcawich[4], Mike Roper[5]
[1]NIOSH, USA; [2]ECS Federal, LLC, USA; [3]Johns Hopkins University Applied Physics Laboratory, USA; [4]US Army Research Laboratory, USA; [5]Vital Alert Communications, Inc., Canada

Abstract: The results of low-frequency (< 6 kHz) magnetic field noise measurements at underground coal mines are presented. A comparison of these results to measurements made 35 to 40 years ago suggests that the magnetic field noise has increased substantially (20-30 dB) since this period of time. The ambient noise level is an important factor in the operation of Through-The-Earth (TTE) communications systems, and the data presented herein are an essential consideration in the design of future TTE systems.

4:30pm **On-Site Automotive Environment Measurements for a Risk-Based EMC Approach** 443

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: Due to the on-going changes in modern technologies, deeper investigation of the complex automotive electromagnetic environments is necessary. Since conventional standardized testing methods are lacking characteristics met in real automotive electromagnetic environments, a risk-based electromagnetic compatibility approach can conclude to detection of potential electromagnetic interference threats. A measurement of a real automotive electromagnetic environment is proposed and investigated Using two different measurement methods addressing the temporal and spatial variations of the electromagnetic environment. This investigation reveals the complexity of real electromagnetic environments and the difficulty of them being sufficiently described to warrant electromagnetic compatibility due to continuously varying parameters over space, time, and frequency. The random-walk technique is applied and compared with a discrete static measuring technique of acquiring data. Examination of the collected data is made along with discussion on their possible application through statistical tools.

4:55pm **Near Field Radiation from an Electromagnetic Accelerator** ..... N/A

F. Albarracin, G. Appiah, A. AlAli, C. Kasmi, N. Mora
Technology Innovation Institute, United Arab Emirates

Abstract: This work presents the preliminary analysis on the electromagnetic fields radiated from a 15 mm squared bore, 1 m length electromagnetic accelerator when connected to a 37-kJ pulsed energy source.

5:20pm **A Novel Stochastic Vibration-Based Algorithm for Electromagnetic Leakage Detection** 450

Bin Ye[1,2]
[1]Chinese Academy of Sciences, China; [2]University of Chinese Academy of Sciences, China

Abstract: In the safety detection of the current electromagnetic leakage of electronic equipment, weak leakage signal frequencies are easily missed, involving other problems. This paper presents a new algorithm connecting with stochastic vibrating electromagnetic leakage detection, which uses the principle of stochastic vibration to enhance the leak signal strength and reduce the noise strength by migrating the noise signal energy from the original signal to the leak signal, thus solving the problem arising from leak detection of spectrum. The algorithm is implemented by frequency shifting, a new genetic algorithm and segmented biostability to overcome the shortcomings in the traditional bistatic random algorithm. This paper demonstrates the effectiveness of the method in electromagnetic leakage detection through experiments and simulations.

TP-WE-PM2-TC10 2.5D/3D/Exotic ICs and Packing Technologies (Sponsored by TC-10)

Technical Papers **3:40pm - 5:20pm**

Room: 402C

Chair: DongHyun Kim, Missouri University of Science and Technology

Co-Chair: Baolong Li, CA, USA

3:40pm **Overcoming Design Challenges for High Bandwidth Memory Interface with CoWoS** ..... N/A

Victor Chen[1], Bassem Abdel-dayem[1], Changhua Wan[2], Feng Ling[2]

[1]Amazon, USA; [2]Xpeedic, USA

Abstract: High bandwidth memory (HBM) with Chip-on-Wafer-on-Substrate (CoWoS) packaging technology to achieve chiplet-based heterogeneous integration systems is increasingly adopted by the industry. Due to the number of IOs and micron-scale structures, signal integrity analysis becomes challenging. This paper presents a novel EM solver with high capacity and scalability. An automated design flow is developed on top of the solver to facilitate the simulation of HBM interfaces for CoWoS. Various HBM interfaces are simulated for both CoWoS-R and CoWoS-S. Their performance is compared.

4:05pm **On Package Optics for the High-Speed Serdes Interconnects** ..... N/A

Ajay K. Vaidyanathan, Praveen Kumar Yenubari, Shanmugapriya D, Sathish Kumar R

Intel Technology India Pvt Ltd, India

Abstract: Owing to the ever-increasing data rate requirements on the Data Center Graphics (DCG) products, technologists are always looking for methodologies to improve power efficiency and channel performance of the High-speed IO interconnects. On-package optics provides the opportunity to shorten the Common Electrical IO (CEI) 112G channel length by tens of millimeters to enable a very short distance between ASIC and optics. This paper presents the on-package optical IC implementation that shrinks the electrical channel length drastically and thereby the losses and noise coupling between serdes channels.

4:30pm **Analysis of Switching Voltage Regulator Noise Coupling to a High-Speed Signal** 460

Junho Joo[1], Soumya Singh[2], Seema PK[2], Chulsoon Hwang[1], Bhyrav Mutnury[3], James Drewniak[1]

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

BEST SIPI STUDENT PAPER FINALIST

Abstract: In this paper, a real-world signal and power integrity problem due to the switching noise of buck converter IC coupling to a high-speed signal line in a server system is studied. The rapid switching field effect transistors (FETs) of the voltage regulator module (VRM) are the main source of the performance degradation on the nearby signal lines. A simplified mock-up simulation setup is proposed Based on the actual board design to investigate the coupling mechanism of the VRM noise. The mechanism of the switching noise coupling is explained with the phenomenon of capacitive and inductive coupling. Based on this finding, the solutions will be identified as decreasing the inductive coupling by optimizing the board layout.

4:55pm **FPC Design Guidelines for Enabling High-Speed Intra-Panel Interface in Large-Size LCD TVs** ..... N/A

Jinho Kim, Sungwook Moon, Jihyun Lee, Seonha Lee, Hyun-Wook Lim

Samsung Electronics Co. Ltd., Korea

Abstract: In this work, the eight cases of independently designed flexible printed circuit (FPC) for a large-size and high-resolution liquid crystal display (LCD) TV module were analyzed in a perspective of signal integrity (SI) by comparing the eye-opening simulation results from the measured channel models. Although the case of two-layer FPC with a ground plane has advantages in terms of impedance matching and crosstalk mitigation, the case of single-layer FPC was found to have better SI performance than the two-layer FPC as long as crosstalk is properly suppressed by optimizing the layout design even if the impedance matching is not perfectly satisfied.

THURSDAY – AUGUST 4, 2022

TU-TH-AM-1 Ham Radio through History and Today

Tutorial **8:30am - 12:00pm**
Room: 401B
Chair: Karen Burnham, Electro Magnetic Applications, Inc., Lakewood, CO, USA
Co-Chair: Kimball Williams, IEEE, Dearborn, MI, USA

Session Abstract: The overlap between Ham radio enthusiasts and EMC professionals has always been significant. Many EMC folks find a fun way to put their skills to use in the hobby, and some Hams find out that they've developed all the skills they need for the profession just by having fun. Ham radio can be life changing in many ways, from finding friends, finding a job, or offering critical aid in a disaster situation. Join us and learn about the development of Ham radio, how it has operated, changed lives, and evolved over the past century or more, and learn some tricks that can improve both your technical and soft skills.

Amateur Radio and Disaster Relief in Italy: A 100 Years Journey...N/A
Domenico Festa
IBD International Business Development, Italy

Childhood Activities Can Shape Your Life...N/A
Connie Kelly
IEEE, USA

What's keeping Morse Code Alive?...N/A
Kimball Williams
IEEE, USA

Using Propagation Analysis Software and Antenna Modeling to Choose an Antenna...N/A
Ed Hare
American Radio Relay League, USA

TU-TH-AM-2 Signal Integrity Methods for Card, Connector, and Baseboard: PCI Express 64.0 GT/s Performance on a Budget (Sponsored by TC-10)

Tutorial **8:30am - 12:00pm**
Room: 401C
Chair: Timothy Wig, Intel Corp., Hudson, MA, USA

Session Abstract: Developers of the PCI Express Card specification will present key methods for achieving data rates of 64.0 GT/s rates through the PCIe card/connector interface. While improvements to the connector components have improved their useful bandwidth, numerous key baseboard layout and routing enablers proved pivotal in extending the life of inexpensive thru-hole mount connectors to 16.0 GT/s PCIe 4.0 speeds. More recently, improvements to surface mount connectors, combined with additional SMT layout enablers, offer baseboard and connector operation up to 64.0 GT/s PCIe 6.0 data rates.

Similarly, several additional updates to the Edge Finger PCB interface were developed for each generation to mitigate multiple signal integrity challenges identified on the Add-in Card side, including nuanced configuring of ground paths and resonance damping to allow high speed performance without exotic PCB materials or methods.

Numerous underlying crosstalk and resonance mechanisms will be thoroughly explored, as well as other bandwidth-limiting mode conversion, loss, and reflection signal integrity impediments that directly degrade within-lane performance. Corresponding remediations, for each will be described,

with supporting measured data. Additional case studies will be shown that demonstrate the consequences of omitting these optimizations. Application of these methods to other connector systems will also be investigated.

A high-level overview of several new power delivery factors will be presented, addressing a doubling of the card power limit to 600W, the introduction of new 12V and 48V power rails, and new power connectors and sideband signals to support them. The limitations of the legacy card power delivery scheme, and the benefits of migrating to the new rails will be explored.

Signal Integrity Methods for Card, Connector, and Baseboard: PCI Express 64.0 GT/s...N/A
Timothy Wig, Umair Khan
Intel Corporation, USA

Signal Integrity Methods for Card, Connector, and Baseboard: PCI Express 64.0 GT/s Performance on a Budget...N/A
Umair Khan
Intel Corporation, USA

TP-TH-AM1-SC5 Conducted EMI Research (Sponsored by SC-5)

Technical Papers **8:30am - 9:45am**
Room: 402A
Chair: Cong Li, GE Global Research, Niskayuna, NY, USA
Co-Chair: Chulsoon Hwang, Missouri University of Science and Technology, Rolla, MO, USA

8:30am **On Measuring the Response to Differential Mode Noise of Common Mode Chokes** 466
A. Ojeda-Rodríguez, C. Domínguez-Palacios, J. Bernal-Méndez, M.A. Martín-Prats
University of Seville, Spain

Abstract: This work analyzes different techniques to measure the attenuation of differential mode noise provided by common mode chokes. The proposed setups are alternatives to the direct and symmetrical setups described in CISPR-17, which are also investigated in this work. This study is Based on a modal analysis of a high-frequency circuit model of the common mode choke that allows for obtaining analytical expressions for the insertion loss of the common mode choke when excited in different setups in terms of the admittances of the modes excited in each setup. This provides additional insight to understand which modes are excited in each setup. We demonstrate that the setups are equivalent at low frequencies and we identify the key differences between them at high frequencies, in particular regarding their different frequencies of resonance. To validate our analysis, we have measured and characterized different commercial common mode chokes, and we have verified that in all the cases the measured transmission coefficients exhibit the behaviour predicted by the theoretical analysis.

8:55am **Simple and Accurate Characterization of Nanocrystalline Common Mode Chokes** 472
A. Ojeda-Rodríguez, C. Domínguez-Palacios, J. Bernal-Méndez, M.A. Martín-Prats
University of Seville, Spain

Abstract: This work proposes a quick and simple method to obtain the parameters of a circuit model of a common mode choke with nanocrystalline core. Common mode chokes with nanocrystalline cores, unlike chokes with cores made of ferrite or iron powder, exhibit a strong dependence with the frequency of its magnetic permeability, which makes it difficult to find a simple circuit model able to account for the response of the choke to both common mode and differential mode signals in a wide frequency range. We propose a circuit model along with a simple method to obtain the parameters of the model, and we demonstrate that the circuit model of the choke accounts for the response of the choke within a frequency range that encompasses the frequencies where most electromagnetic compatibility regulations limit the conducted emissions of electronic devices. To validate the proposed model, different commercial common mode chokes have been measured and the predicted performance of the model has been compared with the measured responses. We have checked that in most cases the proposed approach yields accurate models of nanocrystalline common mode chokes up to 50 MHz.

9:20am **Preliminary Study on Conducted Emission of a Dynamic Wireless Power Transfer System for Automotive** 478

Tommaso Campi[1], Silvano Cruciani[2], Francesca Maradei[2], Mauro Feliziani[1]
[1]*University of L'Aquila, Italy;* [2]*Sapienza University of Rome, Italy*

Abstract: Aim of this work is an investigation on the conducted emission (CE) of a dynamic wireless power transfer (DWPT) system for automotive applications. The main difference of DWPT systems compared to stationary charging systems is due to the fast transients produced by the on/off and off/on transitions of the transmitting coils during the passage of the vehicle in motion. These transients could represent a significant issue in terms of CE, especially if multiple vehicles are moving along the electrified road. Real components such as coupled inductive coils, compensation networks, converters and battery are suitably modeled by equivalent circuits which are analyzed by SPICE models. The CE is investigated considering different scenarios with single and multiple electric vehicles (EVs) absorbing each 10 kW at 85 kHz in a section of an electrified road with short track architecture. The obtained results demonstrate that higher order harmonics of currents produced by electronic converters are not negligible in both ground and vehicle circuits.

SS-TH-AM1-TC5 E1 HEMP Coupling to Power Substation Cables – Part 1 (Sponsored by TC-5)

Special Session **8:30am - 9:45am**
Room: 402B
Chair: William Radasky, Metatech Corporation, Goleta, CA, USA
Co-Chair: Robert Olsen, Washington State University, Pullman, WA, USA

8:30am **Simulation of EMP Coupling Using Electromagnetic Transient Solvers** 483

Joshua Butterfield, Randy Horton
Electric Power Research Institute, USA

BEST EMC PAPER FINALIST

Abstract: This paper develops an approach Using electromagnetic transients (EMT)-type software tools to perform electromagnetic pulse coupling analysis of arbitrarily oriented above-ground cabling systems. The proposed approach allows modeling of large, complex systems such as cabling systems within electrical substations with less complexity than previous methods. Additionally, the approach allows non-linear elements to be included in the model. The results from simulations Using the proposed method are compared with results from testing of a four-conductor cabling system inside an RS-105 guided wave test facility.

8:55am **Coupling of E1 High-Altitude Electromagnetic Pulse to Signal and Control Wires in an Electric Power Substation Yard Trench** 489

Robert G. Olsen[1], Joshua M. Butterfield[2], Johnny J. Moore[3], Timothy M. Minteer[3]
[1]*Washington State University, USA;* [2]*Electric Power Research Institute, USA;* [3]*Schweitzer Engineering Laboratories Inc., USA*

BEST EMC PAPER FINALIST

Abstract: High-altitude electromagnetic pulse (HEMP) from a nuclear detonation 30 kilometers or more above the surface of the Earth may pose a threat to digital protective relays connected to conductors routed in an electric power substation yard. This paper compares the results from four different simulation tools for three simplified models representing the coupling of E1 HEMP to one signal and control wire located in a trench of an electric power substation yard. The coupling of E1 HEMP to multiple signal and control wires within unshielded cables in the trench of a substation yard containing multiple cables is also investigated.

9:20am **Experimental Studies of E1 HEMP Coupling and Propagation Effects for Power Substation Yard Cables** 496

Edward B. Savage, William A. Radasky
Metatech Corporation, USA

Abstract: Experimental time domain measurements of the E1 HEMP response of power substation yard cables are presented. These look at how velocity differences and attenuation affect the E1 HEMP driven pulses on such cables. One test looks at the effect on the external cable signal due to being near the ground, and the other looks at the effects inside a shielded yard cable.

TP-TH-AM1-TC10 High-Speed Link/Bus Design – II
(Sponsored by TC-10)

Technical Papers **8:30am - 9:45am**

Room: 402C

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

Co-Chair: Chenming Zhou, National Institute for Occupational Safety and Health, Pittsburgh, PA, USA

8:30am **Challenges for Enabling Multiple High-Speed Interfaces on a Reference Validation Platform** ..... N/A

Esha Kondapuram, Chong-Jin Ong, Benjamin Silva, Brandon Lambacher

Intel Corporation, USA

Abstract: For a product to be validated with all use cases, several reference designs would be required. This would increase the overall cost and time to market the product. A single reference validation platform solution with limited routing layers utilizing hardware configurable topology options was developed to enable validation. A single High-Speed IO interface was configurable to allow for the validation of three different platform configurations. This paper discusses the signal integrity challenges like interfaces violating the platform design guidelines, includes review of validation data, and review of the mitigation plans for a successfully validated platform.

8:55am **Artificial Intelligence based Advanced Signal Integrity Predictions** ..... N/A

Prerna Kumari, Nithya Ramalingam, Zaman Zaid Mulla, Archana Ganeshan, Ranjul Balakrishnan, Anoop Karunan

Intel Corporation, India

Abstract: As the signaling speeds continue to increase, maintaining Signal Integrity (SI) for the complete customer design space is a huge challenge. These constraints, along with the limitations of traditional methods of design space inclusion and channel behavior prediction pose significant risk to system design. Specific focus is needed on design space utilization techniques used for factoring in platform variability. Interfaces like PCIe Gen5/Gen6/Gen4 etc. exhibit higher order behaviors that current prediction algorithm like Response Surface Method (RSM) simply cannot model. This leads to inaccurate system behavior understanding and results in unreliable platform design recommendations. To minimize design risk and achieve highly reliable scaling of Platform Design Guide (PDG) solution, this paper discusses the implementation of an Artificial Intelligence (AI) Based methodology to cover complete design space and predict higher order system behaviors with high accuracy. The goal is to achieve a model with at least 90 % R square and maximum 5% of result range Root Mean Square Error (RMSE). Current SI method of Design of Experiments (DOE) creation and results prediction consists of creating a combined RSM type DOE table and fitting it with second order RSM modelling in JMP. It has limitations since RSM uses only three variable levels therefore doesn't cover the entire design space. It can only model up to second order system behavior. These issues can be addressed Using proposed AI Based methodology which effectively captures the complete design variance Using space filling algorithm. Paired with this, various AI Based algorithms are explored for advanced SI results prediction. These techniques have been encapsulated into an AI based tool which supports automatic DOE creation and predicts the system behavior post simulation in a SINGLE ITERATION. This helps reduce manual interventions and improve efficiency along with highly desirable R square and RMSE values.

9:20am **Advanced Chip Interposer with Micro-Bump Duality** ..... N/A

Omer Vikinski, Alexander Waizman

Intel Corporation, USA

Abstract: Silicon technology and chip design constraints are the main drivers to tile architecture development. In tile architecture, packaged silicon is disaggregated into smaller tiles assembled on a chip interposer, enabling usage of different process node for each tile. This paper describes an advanced 2.5D chip interposer that enables disaggregation Using dual micro-bump connectivity. Small geometry, fine pitch micro-bumps, used for die-to-die signals interconnect through the chip interposer. Regular geometry, regular pitch micro-bumps, used for external signals connectivity and power delivery. Majority of regular pitch micro-bumps, use straight through vertical path connection to the package bumps. On a need basis, chip interposer die is used for redistribution routing to package bumps.

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

Room: Exhibit Hall
Chair: Randy Wolff, Micron Technology Inc., Boise, ID, USA
Co-Chair: Zhiping Yang, Waymo LLC, San Francisco, CA, USA

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

Input/Output Buffer Information Specification (IBIS)

PLANNED PANELISTS INCLUDE:

- Randy Wolff, Micron Technology Inc.
- Zhiping Yang, Waymo LLC
- Ken Willis, Cadence Design Systems Inc.
- Bob Ross, Teraspeed Labs
- Michael Mirmak, Intel Corp Folsom
- Wei-Hsing Huang, ANSYS

Abstract: IBIS (I/O Buffer Information Specification) is a standard that enables silicon vendors, simulation software vendors, and end customers to exchange modeling data and electronic behavioral specifications of integrated circuit input/output analog characteristics. The intention of this standard is to specify a consistent format that can be parsed by software, allowing simulation vendors to derive models compatible with their own products. The IBIS version 7.1 was officially ratified on December 10, 2021. Version 7.1 adds more technical advances and some editorial changes documented in 15 BIRDs. Some highlighted new features are Touchstone and IBIS-ISS impedance model, IBIS Algorithmic Modeling Interface (IBIS-AMI) improvements, the IBIS-AMI "back-channel" link training protocol enhancement, simplified on-die PDN model, etc. The IBIS "Ask the Experts" panelists consists of active members of the IBIS Open Forum and represents semiconductor companies, EDA tool vendors, IBIS model providers, and system users. Please attend this panel and bring your questions related to the released IBIS features and future IBIS development directions.

Experiments & Demonstrations 10:00am - 12:00pm

Room: Hall A Experiments and Demos
Co-Chair: Gabe Alcala, Advanced Test Equipment Corp. (ATEC), San Diego, CA, USA
Co-Chair: Jacob Dixon, IBM, Rochester, MN, USA

Session Abstract: As a result of the Call for Experiment and Demonstration Proposals, we are pleased to announce the accepted proposals below that will be presented at the 2022 IEEE International Symposium on Electromagnetic Compatibility, Signal and Power Integrity, August 1-5, in Spokane, Washington. You will not want to miss the popular Experiments and Demonstrations program that will be held in the Exhibition Hall on August 2-4. This hands-on activity provides a unique learning experience that complements the technical presentations at the symposium. It is traditionally one of the educational highlights of the annual symposium!

Inductance Demonstration...N/A

Bruce Archambeault
International Business Machines Corp., Four Oaks, North Carolina, USA

Abstract: The EMC Society has built a number of different PCBs to demonstrate different inductance effects. This Demo will use these PCBs to show various inductance efffects.

Simulation of Conductive and Radiated Emission for Off and On-Board Radio Receivers according to CISPR 12 and 25 for Automotive Applications...N/A

C.J. Reddy, Albert Dunford
Altair Corporation, Troy, MI, USA

Abstract: Two of the most exercised standards for electromagnetic compatibility (EMC) by automotive engineers are CISPR 12 and CISPR 25. While CISPR 12 is imposed as a regulation to ensure uninterrupted communication for off-board receivers, CISPR 25 is often applied to ensure the quality of services of on-board receivers. Performing these tests becomes challenging until the vehicle is prototyped which may prolong the production time in case of failure or need for modification. However, conducting these tests in a simulation environment can offer more time and cost-efficient ways of analyzing the electromagnetic environment of automotive vehicles. In this software demo, a computational approach will be presented to predict electromagnetic disturbance from on-board electronics/electrical systems using 3D computational electromagnetic (CEM) tool; Altair Feko. The Demo also elaborates on radiated and conductive emission simulations performed for both vehicular and component/module level EMI testing according to CISPR 12 and 25. A high-frequency dynamic circuit network of a DC wiper motor is considered as a source of emission while different receiving antennas have been used according to regulation. The demo also includes simulations to analyze effects of different types of cable harness on radiated and conducted emissions.

Debugging a Failed EMC Chamber above 1 GHz Using Chamber Imaging Method...N/A

Yibo Wang, Zhong Chen
ETS-Lindgren, Cedar Park, Texas, USA

Abstract: Site VSWR test is specified in the CISPR 16 standards for evaluating sites above 1GHz. The CISPR Svswr method consists of a series of scalar measurements and offers no additional information on how one can debug a chamber failure. The time domain impulse view, obtained through inverse Fourier transform of the vector response measurement in the frequency domain, can provide valuable chamber debugging information. The path length of a large reflection can be identified in the time domain. However, no information about the directions of the unwanted reflection signal can be extracted. In this demonstration, a chamber imaging method is presented from phase coherent measurements Using a 2D planar scanner. Angular spectrum in K-space is computed from the Fourier transform of the planar scanned 2D data. An image of chamber reflections is constructed after mapping the K coordinates to azimuth-elevation angle coordinates. The chamber image shows both the signal levels and the directions, allowing a more comprehensive reflection signal analysis and chamber debugging. An explanation of how chamber imaging method "work" will be provided via a presentation and in real time Using a vector network analyzer and 2D planar scanner. The demonstration shows the effectiveness of the measurement process, the data post-processing, and analysis of the results.

TP-TH-AM2-SC5 EMI Modeling for Power and Renewable Applications (Sponsored by SC-5)

Technical Papers **10:20am - 11:35am**
Room: 402A
Chair: Junesang Lee, Altair Engineering Inc., Yongin, Korea
Co-Chair: Shuo Wang, University of Florida, Gainesville, FL, USA

10:20am **Radiated EMI Prediction in Power Converters with Power Cables based on Cable Antenna Voltage Gain Extraction** 510

Zhedong Ma[1], Yirui Yang[1], Juntao Yao[1], Shuo Wang[1], Honggang Sheng[2], Liang Jia[2], Zhenxue Xu[2], Srikanth Lakshmikanthan[2]
[1]*University of Florida, USA;* [2]*Google LLC, USA*

Abstract: Radiated Electromagnetic interference (EMI) issue becomes more and more important in power electronics systems in recent years. To fully understand the generation and propagation mechanism of the radiated EMI, radiated EMI modeling and prediction techniques are very important. In this article, an active-clamp Flyback converter with long power cables is taken as an example, the radiated EMI model is developed, a step-by-step guide to predict the radiated EMI spectrum is proposed, some important issues are pointed out for EMI prediction. The predicted EMI Based on the proposed guide can match the measured EMI very well within 6dB error in the range of 30MHz – 230MHz Based on EN55032 3m class B standard.

10:45am **Modeling and Analysis of Grid Tied Combined Ultracapacitor Fuel Cell for Renewable Application** ..... N/A

Webster Adepoju[1], Indranil Bhattacharya[1], Olufunke Mary Sanyaolu[2]
[1]Tennessee Technological University, USA; [2]University of Johannesburg, South Africa

Abstract: In this manuscript, the performance of an ultracapacitor fuel cell in grid connected mode is investigated. Voltage regulation to the ultracapacitor was achieved with a three level bidirectional DC-DC converter while also achieving power flow from the grid to the ultra-capacitor via the bidirectional converter. The choice of a bidirectional three level converter for voltage regulation is Based on its inherently high efficiency, low harmonic profile and compact size. Using the model equations of the converter and grid connected inverter derived Using the switching function approach, the grid's direct and quadrature axes modulation indices, Md and Mq, respectively were simulated in MATLAB for both lagging and leading power factors. Moreover, the values of Md and Mq were exploited in a PLECS Based simulation of the proposed model to determine the effect of power factor correction on the current and power injection to grid.

11:10am **High-Frequency Modeling of a BLDC Motor for Radiated Emission Prediction** ..... N/A

Joomin Park[1], Sungjun Park[2], Kyung-Hun Jung[2], Ick-Jae Yoon[1]
[1]Chungnam National University, Korea; [2]Hanon System, Korea

Abstract: This paper presents a high-frequency modeling for a stator winding of a BLDC motor as a means of predicting the relative RE noise feature through simulation. Noting that the high-frequency signal flow in a three-phase electric motor can be expressed through a T-network modeling and the radiation feature can be estimated by antenna impedances, we carry out full-wave EM simulations on the stator winding. The proposed high-frequency modeling technique is used to predict the change in radiated electric field according to the motor housing structures. It is verified by the manufactured prototype and measurement that the relative change in RE value can be predicted.

SS-TH-AM2-TC5 E1 HEMP Coupling to Power Substation Cables – Part 2 (Sponsored by TC-5)

Special Session **10:20am - 11:35am**
Room: 402B
Chair: Robert Olsen, Washington State University, Pullman, WA, USA
Co-Chair: William Radasky, Metatech Corporation, Goleta, CA, USA

10:20am **Protection Issues for Power Substations from HEMP Adverse Effects** 524

Edward B. Savage, William A. Radasky
Metatech Corporation, USA

Abstract: It is well known that modern society is very dependent on a reliable electric power system. However, that system can be compromised by electromagnetic threats. One threat is the effect of HEMP from a high altitude nuclear burst [1]. One concern is the late time part of HEMP, E3, which is briefly discussed here. The early time part, E1, is the major emphasis of this paper – specifically, adverse E1 effects on the control systems, housed in substation buildings. To address this concern, the EM (electromagnetic) vulnerability of substation electronics should be evaluated and hardening applied if necessary. The paper will enumerate and discuss various issues that affect the EM response of substations and its hardening. Two major concerns are E1 coupling to yard cables and E1 field leakage into the substation building.

10:45am **The Application of NEC-4 to E1 High-Altitude Electromagnetic Pulse Coupling to Electric Power Substation Yard Cables** 529

Johnny J. Moore, Timothy M. Minteer
Schweitzer Engineering Laboratories Inc., USA

BEST EMC PAPER FINALIST

Abstract: A thorough validation of the ability of Numerical Electromagnetics Code, 4th edition (NEC-4) to simulate the voltage induced across a termination impedance of a wire structure from a high-altitude electromagnetic pulse (HEMP) was conducted to gain confidence in the tool for future work. This involved developing a segmentation and gap scheme for an electrically small dipole bounded by the limitations of NEC-4 and ensuring that it agreed with theory. This technique was then extended to transmission line structures (comprising a signal or control wire located in the trench of an electric power substation yard) by Using the dipole as the termination for the transmission line. The implementation of the termination impedance of the transmission line and grounding scheme is also discussed.

11:10am **Use of IEC E1 HEMP Standards to Determine the Coupled Levels and Impacts of Induced Currents to Power Substation Control House Yard Cables** 537
William A. Radasky
Metatech Corporation, USA

Abstract: This paper reviews the coupling of E1 HEMP fields to buried control cables that are connected to protection relays in power substation control houses. This review is performed by examining the publications of the International Electrotechnical Commission (IEC) and the work of IEC Subcommittee 77C, which deals with high power EM phenomena.

TP-TH-AM2-TC10 Power Integrity Analysis and Design – II (Sponsored by TC-10)

Technical Papers **10:20am - 11:35am**
Room: 402C
Chair: Chulsoon Hwang, Missouri University of Science and Technology, Rolla, MO, USA
Co-Chair: Zhichao Zhang, Intel Corporation, Chandler, AZ, USA

10:20am **Systematic Analysis for Tabbed Line Design** ..... N/A
Eleonora Palma[1], Alessandro Pali[2], Laura Fabbri[2], Francesco de Paulis[1]
[1]University of L'Aquila, Italy; [2]SECO spa, Italy

Abstract: The tabbed lines have been shown to be effective for the reduction of the far-end crosstalk (FEXT) in high speed data buses. However the amount of tabbed lines in a specific line or bus is usually left to the layout designer without having at hand clear guidelines on how to implement them. The work proposed in this abstract aims at clearly analyzing the impact of the tabbed section percentage with respect to the overall line (bus) length. The presented parametric analysis demonstrates that a FEXT minimum can be always found in the percentage of tabbed portion. The corresponding percentage is function of the specific geometry of the tabs.

10:45am **Board Level Probe-on-Pin Power Delivery Network Characterization** ..... N/A
Patt Chang[1], Y.L. Li[1], Jimmy Hsu[1], Yang Hung Cheng[2], Chien Hsun Chen[2], Hao Wei[2], Falconee Lee[1], Shijuan Qin[1], Kevin Liang[1], Kate Tzeng[1]
[1]Intel Corporation, Taiwan; [2]MPI Corporation, Taiwan

Abstract: The Artificial Intelligence (AI) and High- Performance Computing (HPC) demand high power from mother board voltage regulators. It's getting more challenging to design a robust power delivery network (PDN) to meet the voltage specifications to the processor because of the fast slew rate and large load step. Conventional power validations utilize voltage regulator testing tools (VRTTs) to mimic load transient behaviors of processors. Comparing to time domain transient results, the PDN impedance is a good frequency domain approach to ensure robust power design without applying fast load transients. This paper provides power design engineers a semi-robotic power delivery network impedance test methodology.

11:10am **Power Design Validation of Two-Stage Power System** ..... N/A
Y.L. Li[1], Falconee Lee[1], Kevin Liang[1], Kate Tzeng[1], Ming Tien[1], Donghan Wu[1], Bryant Tsai[1], Patt Chang[1], Jim Tseng[1], Shijuan Qin[2]
[1]Intel Corporation, Taiwan; [2]Intel Corporation, China

Abstract: With FIVR, Intel power system was upgraded to two-stage power system. To validate two-stage power system, a new approach is proposed. Based on tests Using the approach, 100% board MLCC capacitors removal doesn't see any impact to a two-stage power system.

TP-TH-PM1-TC2 EMC Measurements – I (Sponsored by TC-2)

Technical Papers **2:00pm - 3:15pm**
Room: 401C
Chair: Thomas J. Fagan, Aerospace Corporation, Vail, AZ, USA
Co-Chair: Monrad Monsen, Oracle, Broomfield, CO, USA

2:00pm **Quantitative Analysis of the "Shimada" Isolating, 1:1, Series-Series, Equal-Delay Balun** 549
James McLean
TDK R&D Corp., USA

Abstract: The "Shimada" isolating, 1:1, series-series, equal-delay balun is analyzed Using odd/even mode transmission line analysis and is shown to behave as a current balun over a broad bandwidth. Numerical results indicate that when the electrical length of the odd mode of the constituent bifilar transmission lines is near an odd-integer multiple of 90 degrees, the general behavior of the device degrades from that of a current balun to simply that of a symmetric balun. Additionally, when the common-mode structure is lossless, a narrowband undulation in the short-circuit output currents occurs in the immediate vicinity of the same odd-integer multiples of the odd-mode quarter-wave frequency. However, this only occurs for short-circuit or very low impedance loads. Finally, we show that the widely used "Shimada" balun is equivalent to the conventional 1:1 isolating bifilar transformer with a compensating delay line added to the non-inverting output.

2:25pm **Comparison of EMC Chamber Debugging Techniques above 1GHz** 555
Yibo Wang, Zhong Chen
ETS-Lindgren, USA

Abstract: Site VSWR test is specified in the CISPR 16 standards for evaluating sites above 1GHz. The CISPR Svswr method consists of a series of scalar measurements and offers no additional information on how one can debug a chamber failure. The Time Domain site VSWR method specified in ANSI C63.25.1 standard is an alternative site validation method. The TD Svswr method yields more consistent data and provides equivalent results to the CISPR Svswr method. The time domain impulse view, obtained through inverse Fourier transform of the vector response measurement in the frequency domain, can provide valuable chamber debugging information. The path length of a large reflection can be identified in the time domain. However, no information about the directions of the unwanted reflection signal can be extracted. In this study, a chamber imaging method is presented from phase coherent measurements Using a 2D planar scanner. Angular spectrum in K-space is computed from the Fourier transform of the planar scanned 2-D data. A 2-D image of chamber reflections is constructed after mapping the K coordinates to azimuth-elevation angle coordinates. The chamber image shows both the signal levels and the directions, allowing a more comprehensive reflection signal analysis and chamber debugging. In this paper, the two techniques (i.e., time domain method and chamber imaging method) are presented and compared for chamber debugging in a 3m EMC anechoic chamber.

2:50pm **Methodology to Validate the Radiated Immunity of Very Complex Systems by a Succession of Simple Component Radiated Immunity Tests at System Level** 561
Nadir Fouad Bedjiah[1,2], Marco Klinger[1], Moncef Kadi[2], Romain Rossi[2]
[1]Stellantis NV, France; [2]Université de Rouen Normandie, France

Abstract: The validation of automotive autonomous and complex functions will be crucial in the coming years. The cost and duration of EMC immunity tests are constantly increasing with the number of functions to validate. In addition, the more complex are the functions, the more difficult will be their validation. Currently, the immunity validation tests for complete electrical functions or architectures at vehicle level are performed indoor on a roller-bench in a semi-anechoic chamber. These complex systems rely on several sensors such as radars, cameras, etc. To perform the immunity validation tests of these systems, one needs therefore to recreate the outdoor scenarios indoor, by stimulating the different sensors, and most of all, by synchronizing these stimulations between each other. However, synchronizing the stimulation of all the sensors in a realistic way is very challenging. Furthermore, autonomous functions will automatically disable themselves in case of incoherencies in the data and information provided by the sensors and the external communication links (e.g. Car-to-X). Therefore, the current methodology will not allow one to validate these complex autonomous functions as desired. In this paper, a new methodology to validate the radiated immunity of complex systems is investigated. The aim of this methodology is to validate automotive electrical functions independently of their level of complexity. This methodology is Based on a succession of simple component radiated immunity tests performed directly on vehicle.

TP-TH-PM1-TC9 Surrogate Modeling and Optimization (Sponsored by TC-9)

Technical Papers **2:00pm - 3:15pm**

Room: 402A

Chair: Shaohui Yong, Marvell Technology, San Jose, CA, USA

Co-Chair: Yuchu He, Google Inc, Mountain View, CA, USA

2:00pm **Automatic SPICE-Integrated Reinforcement Learning for Decap Optimization for EMI and Power Integrity** 565

Jingook Kim[1], Sangyeong Jeong[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 automatic SPICE-integrated reinforcement learning (RL) is proposed for decap optimization for radiated electromagnetic interference (EMI) and power integrity. A power distribution network (PDN) structure is modeled in a circuit fashion to be solved in a SPICE solver. for EMI optimization, the branch currents for radiated EMI calculation were obtained from ac simulations. for PI optimization, the voltage fluctuations in time domain were obtained from transient simulations. Finally, it is demonstrated that a consistent RL environment integrated with SPICE solvers can be utilized in the optimization for both radiated EMI and PI.

2:25pm **Black-Box Behavioral DC-DC Converter IC Emission Model** 570

S.R. Rao[1], N. Ishibashi[2], B. Nayak[1], H. Muniganti[1], N. Ambasana[1], V. Sahu[1], D. Gope[1,3], A. Devi[1]

[1]Simyog Technology Pvt. Ltd., India; [2]Panasonic Holdings Corporation, Japan;
[3]Indian Institute of Science, India

Abstract: Electrified, automated, connected, and shared mobility trends have led to stringent EMC requirements for in-vehicle equipment. In addition to noise countermeasure technology, it is becoming important to predict EMC risk from the early design stage. Simulation is an effective method to analyze and monitor EMI/EMC performance such that possible upstream problems can be addressed cost-effectively. A primary challenge towards such a simulation methodology is the non-availability of models for Integrated Circuits (ICs) which are the sources of noise. In this work, an operating condition-dependent behavioral model for ICs is developed Using measured data on a specially designed test-PCB followed by training a machine-learning network. 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.

2:50pm **Evolutionary Algorithms as a Tool for Shielding Design** 575

Stanislav Kovar[1], Iva Kavankova[1], Michael Renzler[2], Jan Valouch[1], Tomas Kadavy[1], Dominik Mair[2]

[1]Tomas Bata University in Zlín, Czechia; [2]University of Innsbruck, Austria

Abstract: The paper deals with the shielding enclosure design Using evolutionary algorithms without predetermined conditions. The designed shield consists of an array of elements that represent conductive or non-conductive parts. The expected output is to design a shield with sufficient balance between shielding effectiveness and transparency in systems that need an optical line of sight. The wide frequency transparent shielding design is a complex task that researchers so far mostly solved by composite polymers. The authors use a different approach Using traditional conductive material and element folding technology. Element assembly is performed by an evolutionary algorithm that decides the properties of the material used and creates the optimal structure to achieve the desired results. The paper describes the design concept for planar shielding with metaheuristics and the preliminary results.

TP-TH-PM-TC1 EMC Management (Sponsored by TC-1)

Technical Papers **2:00pm - 3:15pm**
Room: 402B
Chair: Tom Braxton, Elite Electronic Engineering Inc., Downers Grove, IL, USA
Co-Chair: Stephanie Zajac, Jet Propulsion Laboratory, Arcadia, CA, USA

2:00pm **Effects of the MHz Frequency Range Electromagnetic Immunity of the Swept Frequency Pulse Coupled on the kHz Frequency Range G3 Power Line Communication** 580
Arash Nateghi[1], Niek Moonen[2], Martin Schaarschmidt[1], Sven Fisahn[1], Heyno Garbe[3]
[1]Wehrwissenschaftliches Institut fur Schutztechnologien ABC-Schutz, Germany; [2]University of Twente, The Netherlands; [3]Leibniz University Hannover, Germany

Abstract: This contribution evaluates the vulnerability of narrowband power line communication in the kHz frequency range through the implementation of frequency swept pulse intentional electromagnetic interference (IEMI) in the MHz frequency range. for this experiment, different types of digital modulation as well as different types of transmission mode are evaluated. The data frame error rate of the transmitter and receiver are compared when a low power frequency-swept pulse IEMI is coupled to the G3 power line communication. Finally, a mitigation plan to manage the risk of intentional EMI in power line communications is recommended.

2:25pm **Risk-Based EMC Approach for the Ship's Semi-Enclosed Reverberant Indoor Environment to Evaluate EMI Generated by Wireless Devices** 584
Mumpy Das, Robert Vogt-Ardatjew, Frank Leferink
University of Twente, The Netherlands

Abstract: Ships are one of the most complex semi-reverberant electromagnetic environments. To lower the cost and weight of the cabling in ships, wired devices are being replaced by wireless ones. This increment, with the presence of the multipath reflective environment, will increase the chance of electromagnetic interference. Although the electronic devices placed within satisfy various electromagnetic compatibility standards, the risk of interference still exists because of the complexity of the environment. A full risk-based electromagnetic compatibility approach can significantly help to mitigate the interference risks. In this paper, we discussed how a semi-enclosed reverberant environment increases the field strength below the deck of the ship and can cause electromagnetic interference within. We also discussed the risk-based electromagnetic compatibility approach Using the Accessibility, Susceptibility, and Consequence cube to overcome electromagnetic interference risks

2:50pm **Electromagnetic Interference Risk Assessment for the Use of LED Lights on Board of Ships** 589
Nancy Omollo[1,2], Jan-Kees van der Ven[1], Robert Vogt-Ardatjew[2], Frank Leferink[2,3]
[1]RH Marine, The Netherlands; [2]University of Twente, The Netherlands;
[3]Thales Nederland B.V., The Netherlands

Abstract: The very high frequency band is a critical band that is used for safety and distress communication on board ships. Use of some commercial off the shelf equipment have been found to cause interference in this band. This paper describes the use of a risk-based approach to evaluate EMC risk due to commercial-off-the – shelf light emitting diodes in the wider band surrounding the very high frequencies, and define measures for the integration without causing disturbance. Measurements have been carried out on a sample of generic lights that are intended both for the indoor and outdoor use, to establish any likelihood of electromagnetic interference occurring. The results show some of the lights have higher emissions above the recommended limits, in which case risk-based EMC has been used to define mitigation measures for integration to achieve EMC.

TP-TH-PM1-TC4 EMI in Transportation Systems (Sponsored by TC-4)

Technical Papers **2:00pm - 3:15pm**

Room: 402C

Chair: Mark Steffka, University of Detroit Mercy, Detroit, MI, USA

Co-Chair: Shengxuan Xia, Missouri University of Science and Technology, Rolla, MO, USA

2:00pm **HFSS Simulation Predicts the Radiated Emission from Complex Cable Harness Configuration** ..... N/A

Shahid Ahmed
Ansys, Inc., USA

Abstract: We have considered a hybrid approach for a full-wave radiated emission from a complex cable harness configuration that involves a 3-D simulation with HFSS coupled with a 2-D simulation of the cable cross-sections for extracting RLGC parameters and distributing them in a 1-D transmission line model for an accurate determination of voltages and currents. Semi-empirical models are used to model the transfer impedance of braided shields. This hybrid approach greatly reduces the solve time and provides high fidelity simulations of radiated emission from cable harnesses in complex environments such as automotive and aerospace, which, otherwise would have been difficult. for real-life applications, twisted pairs, shielded, and insulated jackets can be conveniently modeled. Moreover, the design workflow is fully automated and scriptable, which significantly enhances its usefulness. A comprehensive study will be presented.

2:25pm **Multi-Objective Design of Filter Installed in Brush Motor by Preference Set-Based Design Accounting for Cable Length** ..... N/A

Shohei Kan, Ryuta Nakanishi, Zhenhong Xu, Kengo Iokibe, Yoshitaka Toyota
Okayama University, Japan

Abstract: In designing automotive products, it is often required to pursue a solution which satisfies multi-objective performances with conflicting requirements simultaneously. This paper finds the cable length range as well as the design range of an EMI filter for an automotive brush motor, which satisfy required performances by applying the multi-objective satisfactory design method called Preference Set-based Design (PSD)

2:50pm **EMI Control for a Multi-Cell Battery** ..... N/A

Yongjun Zhang, Chenming Zhou, Justin Srednicki
National Institute for Occupational Safety and Health, USA

Abstract: Electromagnetic emissions from multi-cell batteries were previously observed to cause electromagnetic interference (EMI) that can cause nearby electronic safety and health devices to malfunction. While shielding and filtering are the two most common EMI mitigation methods, both have pros and cons and are not applicable in all situations. In this paper, we propose an innovative approach for mitigating EMI emissions from a multi-cell battery. The new approach takes advantage of the coherent nature of the currents in battery cells, and their structural symmetry found in certain battery packs, and then rearranges them into magnetic mutual cancellation loops so that the magnetic fields produced from the battery cells are cancelling each other. Using an electronic device typically used in underground coal mines as an example, the proposed approach can effectively reduce the EMI from the device by 25dB by simply rearranging the position of the battery cells.

TP-TH-PM2-TC2 EMC Measurements – II (Sponsored by TC-2)

Technical Papers **3:40pm - 5:20pm**
Room: 401C
Chair: Thomas J. Fagan, Aerospace Corporation, Vail, AZ, USA
Co-Chair: Monrad Monsen, Oracle, Broomfield, CO, USA

3:40pm **Development and Evaluation of a CNN-LSTM Architecture based Neural Network for Time Optimization during EMI Measurements** 597
Hussam Elias[1], Ninovic Perez[2], Holger Hirsch[1]
[1]Universitat Duisburg-Essen, Germany; [2]Cetecom GmbH, Germany

Abstract: In this paper, an approach is proposed to find the worst-case positions during the final measurement phase on critical frequencies in electromagnetic interference (EMI) measurements according to 47 CFR § 15.209 by Using a developed measurement software and deep neural networks (DNN). Firstly, because of its advantage of incomplete connection, relatively simple model structure and strong data features extraction, a dimensional convolution neural network (1D CNN) was present to predict the positions that meet the maximum radiation emission level. Secondly, a hybrid deep learning neural network framework, that combines CNN with long short term memory(LSTM) was adopted to forecast the worst-case of the high variance emission levels. The DNNs were trained Using real EMI measurements for different equipment under test (EUT) in a Semi Anechoic Chamber (SAC) by Cetecom GmbH in Essen, Germany. By predicting the position azimuth of the turntable and the height of the antenna, the required time to carry out the final measurement phase is effectively reduced.

4:05pm **Measurement of Current Waveform Due to Different Load of ESD Gun, TLP-HMM, and CR-HMM** ..... N/A
Masahiro Yoshida[1], Yusuke Yano[1], Takeshi Ishida[2], Jianqing Wang[1]
[1]Nagoya Institute of Technology, Japan; [2]Noise Laboratory Co., Ltd., Japan

Abstract: The discharge current waveform of ESD gun, TLP- HMM (Transmission line pulse - human metal model), and CR- HMM (Capacitance resistance - human metal model) is calibrated with a 2 Ω load impedance. However, the load impedance structure of TLP- and CR-HMM is different from that of ESD gun. In this study, to investigate their influences, we measured their discharge current waveforms for two types of load impedances, 2 Ω and 50 Ω, with the same load impedance structure as that of the ESD gun. The results show that not only the load impedance value but also the load impedance structure affects the discharge current waveform.

4:30pm **Justification of Balanced VHF-LISN Termination** ..... N/A
Kunihiro Osabe[1], Nobuo Kuwabara[2], Hidenori Muramatsu[1]
[1]VCCI Council, Japan; [2]Kyushu Institute of Technology, Japan

Abstract: Mains cable termination of equipment for radiated emission testing is currently under discussion in CISPR/A-I Joint Ad-hoc Group-6 (JAHG-6), with both balanced and unbalanced Very High Frequency Line Impedance Stabilization Networks (VHF-LISN) being proposed for standardization. Based on the results of Round Robin Testing (RRT), this paper discusses the justification for Using balanced VHF-LISN termination of the EUT power cable in radiated emission testing. The paper concludes that balanced VHF-LISN is suitable for current radiated emission testing of the enclosure port of Equipment under Test (EUT), and where consideration of emission from an unbalanced power supply network is necessary, an unbalanced VHF-LISN is effective.

4:55pm **Automotive Transients Measurement Methodology Assessment for High-Speed Communication Buses** ..... N/A
Patrick DeRoy[1], Mohit Gopalraj[1], Sachinkumar Goudnoor[1], Jay O'Halloran[1], Abhishek Ramanujan[2]
[1]Analog Devices Inc., USA; [2]Analog Devices International, Ireland

Abstract: With the emergence of new high-speed Automotive networking systems Using unshielded twisted pair (UTP) cables, the challenges around meeting stringent Automotive requirements have become tougher than ever. Robustness to Automotive transient pulses according to ISO 7637-2 [1], ISO 7637-3 [2] has been a key customer requirement on any networking system physical layer. Several customer specifications also mandate special fixtures to couple the pulses to the communication lines, either the capacitive coupling clamp (CCC) or the 3-slot fixture [3]. This paper studies and compares the effect of these pulses and/or fixtures to help understand the severity on UTP differential data lines.

TP-TH-PM2-TC9 Computational Modeling Applications (Sponsored by TC-9)

Technical Papers **3:40pm - 4:55pm**

Room: 402A

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

Co-Chair: James Hunter, Missouri University of Science and Technology, Rolla, MO, USA

3:40pm **RF-Induced Heating for Cardiac Rhythm Management (CRM) in Patients with Different Postures** 606

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

Abstract: This paper investigates the impacts of posture on the radio frequency (RF)-induced heating for patients with CRM devices exposed to a 1.5T MRI RF field. Three different arm postures are developed Using the poseable human body model. The RF-induced heating of the CRM system, in terms of temperature rise, is calculated Based on the transfer function approach. The statistical analysis of temperature increment, including the average value, standard deviation, and 95th percentile, is performed for four different postures. Although the relative differences of these statistical results between the arm postures and original posture are less than 5%, for one specified configurations, the maximum variation on temperature increment can be 66%. The results indicate that the arm postures studied in this paper slight effect on the RF-induced heating of the CRM system.

4:05pm **RF-Induced Heating Evaluation for Passive Device in Tissue-Reduced Virtual Family Models at 1.5 T** 610

Meiqi Xia, Ran Guo, Jianfeng Zheng, Ji Chen
University of Houston, USA

Abstract: Tissue-reduced virtual family models are developed for the RF-induced heating assessment of passive implantable medical devices. The models are developed Based on the Gaussian mixture model. The RF-induced heating of four representative passive device systems is evaluated inside the original human models, tissue-reduced human models, and the ASTM phantom at three landmark positions under a 1.5 T MRI system. From the results of these simulations, it is observed that the RF-induced heating from the tissue-reduced virtual family models is highly correlated to that obtained from the original human body models. It demonstrates the feasibility of Using tissue-reduced models for the RF-induced heating testing of implantable medical devices.

4:30pm **A Plane-Wave Superposition Method for Improved Spatial Correlation Accuracy in Simulated Reverberation Chambers** ..... N/A

Valerio De Santis[1], Antonio Di Francesco[1], Giorgi Bit-Babik[2], Antonio Faraone[2]
[1]University of L'Aquila, Italy; [2]Motorola Solutions Inc., USA

WITHDRAWN

Abstract: In this study, the random [illegible] environment within an ideal reverberation chamber is synthesized Using a superposition of plane-waves (PWs). Randomness in the EM environment is achieved by assigning randomly generated complex amplitudes associated with each PW propagating in fixed directions determined by an efficient spiraling sampling scheme over a spherical surface. Comparisons with the analytical statistics show that the proposed method yields a better prediction of the spatial EM field distribution with respect to currently used numerical techniques while requiring far less computation time.

4:55pm **Machine Learning-Based Coupling Modeling and Prediction for Multiple Transmission Lines** 615

Xiaolin Wu, Junling Ji
Chongqing University of Posts and Telecommunications, China

Abstract: The existence of electromagnetic fields in ambient space will lead to coupling effects on transmission lines. Different from conventional electromagnetics computation method, in this work, a multi-wire coupling model is constructed, and a shallow neural network algorithm with only two hidden layers is adopted to realize the modeling and analysis of multi-wire coupling effects. With this trained model, it is convenient to rapidly predict multi-wire coupling effect on the field. The results show that the training time of the algorithm on the training set, which contains 7030 sets of data, is only 5 minutes, and the prediction error, measured in root mean squared error (RMSE), on the test set is less than 6dB. Moreover, the single prediction time is only 0.3 seconds. These results significantly improve the efficiency of multi-wire coupling analysis and prediction.

SS-TH-PM-TC7 Noise and Interference in Modern Electrical Power Networks (Sponsored by TC-7)

Special Session **3:40pm - 5:20pm**
Room: 402B
Chair: Antonella Ragusa, De Montfort University, Leicester, United Kingdom
Co-Chair: Alistair Duffy, De Montfort University, Loughborough, United Kingdom
Co-Chair: Arun Khilnani, The University of Nottingham, Nottingham, United Kingdom

3:40pm **Determination of Electromagnetic Noise from a Power Supply Substation of Railway Traction Systems** 619
Petre-Marian Nicolae, Ileana-Diana Nicolae, Iurie Nuca, Marian-Ştefan Nicolae
University of Craiova, Romania

Abstract: This paper deals with 2 methods for the evalution of the electromagnetic noise that occurs when supplying electric trains from substations. The waveforms corresponding to the supply voltage from the substation and the current absorbed through the supply line by electric trains in different operational contexts are analyzed. Aspects of electromagnetic interference and electromagnetic noise in railway traction systems are discussed. Specialized standards that address the electromagnetic noise and effects produced by the electromagnetic interference in the railway electrical network are briefly presented. Two methods were used for the evaluation of the electromagnetic noise: the method of mean signal and the method relying on the decomposition/recomposition of individual periods Using Wavelet Packets. 7 real datasets of 50 consecutive periods are analyzed with both methods, computing signal to noise ratios and other quantities (extreme and mean values and percentage relative differences between results provided by different methods). Conclusions are drawn considering the analysis results.

4:05pm **Recommended Wavelet based Practices for the Estimation of Electromagnetic Noise in Different Operational Contexts** 625
Ileana-Diana Nicolae, Dusan Kostic, Petre-Marian Nicolae, Marian-Ştefan Nicolae
University of Craiova, Romania

Abstract: Signals acquired from an industrial environment with many sources of electromagnetic interferences may be polluted by white noise. The decompositions Based on the Stationary and Discrete Wavelet Transformations, respectively the Wavelet Packet Decomposition can be used to estimate the power of noise affecting a certain waveform. Original linear combinations of powers of vectors of details hosted by the nodes of the unbalanced trees generated by the Stationary and Discrete Wavelet Decompositions were conceived in order to evaluate the power of noise which is used afterward by thrashing trees. Tests were made on currents and voltages acquired in different operational contexts. „Smoothed" versions of denoised signals, obtained in an original way with Wavelet Packet Trees were used as reference. The paper is meant to provide a usefull tool for deciding which is the best thrashing practice considering criteria like: minimum relative percentage difference (estimated vs reference) between the powers of noise, maximum deviation, mean square error and runtime. Two wavelet mothers (symlet with filter of 8 components and Daubechies with filter of 28 components) were studied for signals with 512 components per period and trees with 7 levels.

4:30pm **Numerical Study on Explosion Characteristics of Wind Turbine Blade under Lightning Induced Arc** 631
Wanshui Yu[1], Qingmin Li[1], Zixin Guo[2], Hanwen Ren[1], Wah Hoon Siew[3]
[1]North China Electric Power University, China; [2]China Electric Power Research Institute, China; [3]University of Strathclyde, United Kingdom

Abstract: For enhancing the lightning protection abilities of wind turbine blades, there is the need to study the mechanical explosion characteristics when the blades suffer from lightning induced arc intrusion. In this paper, a magnetohydrodynamic (MHD) model of lightning induced arc intrusion into the blade was developed, and the airflow and gas pressure distribution were calculated accordingly. The simulation results show that the huge pressure generated at the trailing edge of the blade should be the main cause of the trailing edge cracking. The research presented in this paper provides a theoretical basis for improving the structural design of the blade from the lightning protection perspective.

4:55pm **Practical Evaluation of Electromagnetic Time Reversal to Locate Partial Discharges on Power Networks in the Presence of Noise** 635

A. Ragusa, H. Sasse, A. Duffy

De Montfort University, United Kingdom

BEST EMC PAPER FINALIST

Abstract: The paper proposes an analysis of the performance of a new method to localize Partial Discharges (PDs) on power cables under noisy conditions. The new method is Based on the use of the Electromagnetic Time Reversal (EMTR) theory and the Transmission Line Matrix (TLM) numerical method. The investigations have been carried out in a voltage reduced experimental set up, Using a RG223 coaxial cable. The effectiveness of the EMTR-based method has been evaluated with different noise levels injected into the cable in order to determine how the method works under noisy conditions. The experimental results have shown that the EMTR method is able to localize PD source with an error that is always less than 1%. Averaging is used over several PD signal recordings at the observation point when the reflected signal is hidden by the noise.

TP-TH-PM-TC4 EMI at the IC/Package Level (Sponsored by TC-4)

Technical Papers **3:40pm - 5:20pm**

Room: 402C

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

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

3:40pm **Electrically Conductive Silicones as Elastomeric Solutions for EMI Applications** ..... N/A

Julia Sunderland, Joe Sootsman

The Dow Chemical Company, USA

Abstract: Electrically conductive silicones are advanced elastomeric solutions for shielding, grounding, and bonding of electronic components such as automotive, communication and consumer electronics. The tunability of the electrical and mechanical performance of these silicone composites offers unique solutions to demanding electronic applications. Dispensable silicones allow for application onto challenging module geometries and greater module design freedom. A novel heat curable adhesive presented herein was analyzed and evaluated for electrical, mechanical, and thermal aging stability performance.

4:05pm **Improve the Shielding Effectiveness of a BGA Package by Using VSS Ring Structure** ..... N/A

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. This I/O pin counts increase brings challenges to breaking out signals and ensuring sufficient shielding effectiveness (SE). Shielding can is often used to enhance the SE of the package but in many devices, conformal sputtering shielding is a better option. This paper presents a method to improve the SE by adding a VSS ground ring structure to the sputtering coat. The simulated results show the proposed structure provides 20 dB more SE compare to the structure without a VSS ground ring.

4:30pm **System and Package-Level EMI Shielding Effectiveness Analysis for AR/VR Devices** ..... N/A

Hanqiao Zhang, Sam Sarmast, Soumyadipta Basu, Patrick Codd

Meta Platforms Inc., USA

Abstract: Conformal metal sputtering on package mold compound provides an alternative to meet package and system electromagnetic interference (EMI) and RF interference (RFI) requirements without sacrificing product form factors. However available coating thickness and material options on the outsourced semiconductor assembly and test (OSTA) market is limited and inadequate. An EM-circuit co-simulation method was developed for conformal shielding effectiveness (SE) analysis for augmented and virtual reality (AR/VR) applications. SE results of various coating thickness and materials are presented to show the custom needs for thicker Cu coating and high permeability coating materials such as Ni.

4:55pm **Metallic/Magnetic Multilayer for Wide-Band Direct-on-Chip EMI Shielding** ..... N/A

A. Kikitsu[1], Y. Kurosaki[1], S. Shirotori[1], A. Fujita[2], H. Nishigaki[2], S. Matsunaka[2]
[1]Toshiba Corporation, Japan; [2]Shibaura Mechatronics Corp., Japan

Abstract: Metallic/ magnetic multilayer systems Using a base unit of [Cu(100 nm)/NiFeCuMo(100 nm)]10 were investigated as the EMI shielding layer for the sub-100 MHz range. Addition of soft magnetic multilayers was found to exhibit a shielding effect at less than 20 MHz, which may have been originated from domain wall resonance in the base unit. The magneto-static interaction seems to induce magnetic resonances in the other units.

FRIDAY – AUGUST 5, 2022

TU-FR-AM-1 Basic EMC Measurements

Tutorial **8:30am - 12:00pm**
Room: 401A
Chair: Monrad Monsen, Oracle, Broomfield, CO, USA

Session Abstract: There continues to be those entering the EMC field who are performing measurement activity for both emissions and immunity. In addition, there are practitioners who want to get a second opinion to support what they are doing. They are all at least familiar with basic EMC immunity measurements methods that cover a wide range of electromagnetic phenomena. This tutorial will cover both emissions and immunity by highlighting the latest amendment to a major multimedia emissions standard and a selection of immunity testing standards for transients that are more difficult to implement. The transient discussion will also delve into signals that are high power in a very short time. Also included: a description of emission and immunity test sites, the sites that are becoming popular and their validation requirements, as well as an overview of test setups in these facilities. Where appropriate and if time permits, attendees will be asked questions as to what they have learned and will be given an opportunity to question the speakers at a panel discussion at the end of the session.

Use of Basic Measurement Facilities, Methods and Associated Errors...N/A
Ghery S. Pettit
Pettit EMC Consulting LLC, USA

CISPR 32 Edition 2, Amendment 1...N/A
Ghery Pettit
Pettit EMC Consulting LLC, USA

Performing Immunity Testing to Transient Signals...N/A
Thomas E. Braxton
Elite Electronic Engineering Inc., USA

Continuous Wave Immunity Testing...N/A
Ross Carlton
Gibbs & Cox, USA

High Power Electromagnetics Test Facilities and Measurement Methods...N/A
William A. Radasky
Metatech Corporation, USA

WS-FR-AM-2 Risk-Based EMC Initiatives in Europe (Sponsored by TC-1)

Workshop **8:30am - 12:00pm**
Room: 401B
Chair: Marc Kopf, Technische Universiteit Eindhoven, Eindhoven, Netherlands
Co-Chair: Geon George Bastian, IDNEO Technologies, Barcelona, Spain
Organizer: Anne Roc'h, Technische Universiteit Eindhoven, Eindhoven, Netherlands
Organizer: Jordi Vila Planas, Nextium by Idneo, Barcelona, Spain

Session Abstract: With the latest implementation of EU rules (the European "Blue Guide" [1]), risk-based approaches replaced the conventional rule-based ones and became mandatory for the compliance of any new piece of electrical and electronic equipment.

A substantial portion of industry as well as many users of electronic systems are struggling with these risk-based requirements, as there are neither clearly prescribed risk-assessment methodologies nor sufficient knowledge of the matter. The distinct challenge is that those methodologies require more than formalization: They need an assessment of systems' complexity by trained specialists, as well as contribution and coordination of all individuals and institutions involved in design process and the product's lifecycle. Especially small and medium-sized enterprises may need assistance with adapting to this shift of paradigm.

The workshop specifically introduces the Risk-based approach on EMC and points out the contrasts with the traditional, Rule-based one. It will start with a general introduction to the topic, given by Frank Leferink, followed by the systematic analysis of EMI risks, presented by Frank Sabath. The third topic will be about techniques and measures for practical management of functional safety risk levels in regards of EMI over the lifecycles of electronic equipment, in accordance with the recent IEEE 1848-2020 standard [2]. It will be presented by Keith Armstrong. The workshop will be completed by the introduction of the two large European Marie Skłodowska-Curie networks (PETER and ETERNITY) which are developing risk-based methodologies and training 29 Early-Stage Researchers on this topic. This will be done by the respective project coordinators, Davy Pissoort and Anne Roc'h.

Risk based EMC...N/A
Frank Leferink[1,2]
[1]THALES, The Netherlands; [2]University of Twente, The Netherlands

Systematic Analysis of EMI Risks...N/A
Frank Sabath
Bundeswehr Research Institute for Protective Technologies and CBRN Protection, Germany

Techniques and Measures for Managing Functional Safety and Other Risks that Can be Caused by EMI (IEEE 1848–2020) — And an Outlook on Draft IEC TS 60601-4-X on Managing the Essential Performance Risks that Can be Caused by EMI...N/A
Keith Armstrong
Cherry Clough Consultants Ltd, United Kingdom

Introducing the PETER Project...N/A
Davy Pissoort
Katholieke Universiteit Leuven, Belgium

ITN ETERNITY – Project Introduction...N/A
Anne Roc'h
Technische Universiteit Eindhoven, The Netherlands

TU-FR-AM-3 Product Safety Compliance and Global Market Access

Tutorial **8:30am - 12:00pm**
Room: 401C
Chair: Grant Schmidbauer, Nemko North America, Inc., Carlsbad, CA, USA
Co-Chair: Ken Kapur, Thermo Fisher Scientific Inc., Saratoga, CA, USA
Co-Chair: John Allen, Product Safety Consulting, Inc., Bensenville, IL, USA

Session Abstract: The goal of most companies is not to only design products to be safe, perform according to customer demands, and to meet regulatory requirements, it is to sell those products globally. While your product must comply with the EMC and SIPI requirements, there are a myriad of other technical requirement that must also be considered to facilitate the sale of the product.

The plan for this tutorial is to delve into some of the "other technical requirements" that products must comply with, including product safety requirements (ie, concepts such as fire, shock, mechanical, temperature, and radiation); and then once your products are compliant, we will discuss the commercialization of the product through obtaining the many country approvals that are needed in order to legally sell the product around the world.

This tutorial should be attended by product realization managers, design engineers, test technicians, product regulatory personnel, project managers, marketing personnel, and others interested in learning more about product safety and global market access requirements.

Compliance 101...N/A
Ken Kapur
Thermo Fisher Scientific, USA

Compliance 201...N/A
John Allen
IEEE Product Safety Engineering Society, USA

Global Market Access...N/A
Grant Schmidbauer
Nemko North America, Inc., USA

WS-FR-AM-4 EMC Test and Design for Cables and Connectors

Workshop **8:30am - 12:30pm**
Room: 402A
Chair: Charles Jullien, Safran Electrical and Power, Blagnac, France
Co-Chair: Huadong Li, Molex LLC, Naperville, IL, USA

Session Abstract: This workshop will give a general introduction to cable construction, termination and grounding for product EMC, present some testing methods for cable and connector shielding, introduce some methods for cable and connector EMC modelling and analysis, demonstrate some examples on EMC simulation and design for cables and connectors dedicated to aerospace applications.

The workshop is divided into topics as: Crosstalk between Differential Channels of a High-Speed Connector, Innovative High Frequency Harness Shielding Design, Cabling simulation for aerospace applications, Model of screening effectiveness and the 6-port scattering matrix, Optimization of segregation distances between electric cable-bundles embedded in a structure.

The workshop will help the audience to properly test and design cables, connectors and their assemblies for product EMC.

A Study of Crosstalk between Differential Mode Signals...N/A
Huadong Li
Molex, LLC, USA

Innovative High Frequency Harness Shielding Design Part I...N/A
Charles Jullien, Anca Dieudonné
Safran Electrical & Power, France

Innovative High Frequency Harness Shielding Design Part II...N/A
Charles Jullien, Anca Dieudonné
Safran Electrical & Power, France

Cabling Simulation for Aerospace Applications...N/A
Grant Riley
Electro Magnetic Applications Inc., USA

Model of Screening Effectiveness and the 6-Port Scattering Matrix...N/A
Thomas Hähner
Nexans Aerospace France, France

Optimisation of Segregation Distances between Electric Cable-Bundles Embedded in a Structure...N/A
J.P. Parmantier[1], I. Junqua[1], S. Bertuol[1], J. Morio[1], D. Romano[2], M.D. Astorino[2], G. Antonini[2], A. Mori[3], P. di Bartolomeo[3], M. Bandinelli[3], A. Bonsignore[3], N. Muot[4], C. Girard[4], G. Prin[4], C. Jullien[5]
[1]ONERA, France; [2]University of L'Aquila, Italy; [3]I.D.S. Ingegneria dei Sistemi S.p.A., Italy; [4]AxesSim, France; [5]Safran Electrical & Power, France

TU-FR-AM-5 Innovative Wireless Test Methodologies for 5G New Radio and mmWave Applications (Sponsored by TC-12)

Tutorial **8:30am - 12:00pm**
Room: 402B
Co-Chair: Michael Foegelle, ETS-Lindgren, Cedar Park, TX, USA
Co-Chair: Harry Skinner, Intel Corporation, Hillsboro, OR, USA
Organizer: Janet O'Neil, ETS-Lindgren, Bainbridge Island, WA, USA

Session Abstract: As 5G begins to take center stage in the enterprise IOT and consumer markets, the wireless industry continues to develop the required test and measurement capabilities for the latest technologies to ensure that these products perform as intended. While considerable progress has been made, various industry organizations are still working on new test plans and test requirements that will be implemented throughout the industry. Although much of the low hanging fruit have been covered in test requirements to date, some of the toughest problems still remain to be solved.

For example, current wireless networks are relying on much more integrated end-to-end (E2E) system architecture than ever before. The base stations (gNB) and the user equipment (UE) must understand how the RF environment is constantly changing around them and they must be able to make decisions in a fraction of a second in order to maintain connectivity with the network. All this must be done while maintaining the adequate bi-directional data throughput with the network. The presentations in this tutorial will provide examples of the need for established industry metrics and test scenarios not only on the chip and module level, but for full scale implementation of a real life network in order to help designers to build fast and reliable networks for modern day requirements.

In addition, 5G's massive machine type communication (mMTC) implies the need to test the performance of millions of different types of wireless IoT devices and sensors quickly and cost effectively. The reverberation chamber has long been proposed as a suitable device for testing total radiate power (TRP) of wireless devices, and has been adopted by CTIA as a method for testing large form factor IoT devices that would be problematic for testing in traditional antenna pattern measurement systems used for handset testing. However, efforts to use the reverberation chamber as an "isotropic channel model" emulation device revealed that the traditional "Uniform Plane Wave Distribution" model traditionally assumed to represent the nature of the reverberation chamber is

significantly flawed. Correcting this flaw is critical, especially when considering the possibility of using the reverberation chamber to test highly directional antennas at mmWave frequencies.

Attendees at the tutorial will learn about solutions to address the challenges generated by the 5G New Radio and mmWave applications through system planning and innovative wireless performance verification testing methodologies.

An Analysis of the Uniform Plane Wave Distribution Model for the Reverberation Chamber
Michael Foegelle
ETS-Lindgren, USA

Wireless Interference/Immunity: Product Quality as a Driver of Test Standards...N/A
Harry Skinner
Intel Corporation, USA

Health and Safety Issues of 5G...N/A
Daniel Hoolihan
Hoolihan EMC Consulting, USA

EMC 101: A Beginners Guide to EMC for Multimedia Equipment...N/A
Aaron Cohen
Skyworks, USA

WS-FR-AM-6 Advancing Simulation Tools and Computational Methods with Packaging Benchmarks (Sponsored by TC-10)

Workshop **8:30am - 12:00pm**
Room: 402C
Co-Chair: Heidi Barnes, Keysight Technologies Inc, Santa Rosa, CA, USA
Co-Chair: Vladimir Okhmatovski, University of Manitoba, Winnipeg, Canada

Session Abstract: The mission of the IEEE EPS EDMS Packaging Benchmarks Committee is to produce a Packaging Benchmark Suite that will encourage research & development by providing information about the electromagnetic, electrical, and circuit modeling and simulation problems encountered, and the state-of-the-art solution methods used when analyzing and designing electronic packages. This workshop will explore the available benchmarks and how each one provides unique challenges for simulation and modeling tools. The workshop will use the benchmarks that are publicly available on-line at https://packaging-benchmarks.org along with additional benchmarks that are in review:

- Benchmark I: Single-ended Microstrip Transmission Line
- Benchmark II: Plasma Package
- Benchmark III: Power-Integrity Test Package
- Candidate Benchmark IV: PCB Laminate Parameter Extraction for Simulation

The format of the workshop will start with a clear definition of the science behind benchmarking and how it is being used in this special case of electronic packages. Then separate speakers for each of the benchmarks will demonstrate an example simulation and the challenges when trying to achieve simulation to measurement correlation.

Tutorial: Advancing Simulation Tools and Computational Methods with Packaging Benchmarks – Benchmark I: Single-Ended Microstrip Transmission Line...N/A
Zhichao Zhang
Intel Corporation, USA

Tutorial: Advancing Simulation Tools and Computational Methods with Packaging Benchmarks – Benchmark II: Plasma Package...N/A

Pavel Roy Paladhi
IBM Corporation, USA

Tutorial: Advancing Simulation Tools and Computational Methods with Packaging Benchmarks – Benchmark III: Power Integrity Test Package...N/A

Heidi Barnes[1], Wui-Weng Wong[2]
[1]Keysight Technologies, USA; [2]AMD Packaging Group, USA

Tutorial: Advancing Simulation Tools and Computational Methods with Packaging Benchmarks – Benchmark IV: PCB Laminate Parameter Extraction for Simulation...N/A

Kaisheng Hu
Ciena, Canada

TU-FR-PM-1 About Electromagnetic Compatibility of Track Circuits with the Traction Supply System of Railway (Sponsored by TC-7)

Tutorial **1:30pm - 5:30pm**

Room: 401A

Chair: Tetiana Serdiuk, Ukrainian State University of Science and Technologies, Dnipro, Ukraine

Co-Chair: Volodymyr Havryliuk, Ukrainian State University of Science and Technologies, Dnipro, Ukraine

Session Abstract: Track circuits are of fundamental importance for the safety in railway systems. Thus, they must be immune from electromagnetic interference (EMI). To this aim they must be accurately characterized. This topic deals with the determination of spectrum composition of traction current with the electric traction with the car-laboratory "Automatics, telemechenics and communication". A method of measuring the parameters of track circuits (time and amplitude parameters of code current, flowing in rail lines, characteristic impedance and propagation constant) is considered. Automated method of measurement of parameters of track circuits and harmonics of return traction current was elaborated. The harmonics coinciding with the code frequency are inadmissible for the track circuits.

About Electromagnetic Compatibility of Track Circuits with the Traction Supply System of Railway...N/A

Tetiana Serdiuk
Ukrainian State University of Science and Technologies, Ukraine

Electromagnetic Compatibility Power Traction System with the Tonal Track Circuits...N/A

Volodymyr Havryliuk
Ukrainian State University of Science and Technologies, Ukraine

Control of Radio Communication Parameters with the Car-Laboratory "Automatics, Telemechanics and Communication"...N/A

Rodica Botnarevscaia
Ukrainian State University of Science and Technologies, Ukraine

TU-FR-PM-2 EM Resilience: Managing Functional Safety and Other Risks with Regard to Electromagnetic Disturbances

Tutorial **1:30pm - 5:30pm**
Room: 401B
Chair: Davy Pissoort, Katholieke Universiteit Leuven, Bruges, Belgium
Co-Chair: Keith Armstrong, Cherry Clough Consultants Ltd., Stafford, United Kingdom

Session Abstract: The rapid and unrelenting pace of development in electrical and electronic technologies since the 1950s has brought us to the point where reliable-enough operation of most modern products, applications, systems and networks now relies on ensuring freedom from significant EMI problems.

As these developments continue at an accelerating pace into the future, controlling EMI will soon be vital for managing all kinds of risks, including: functional safety; financial; defense; security; mission-critical; medical risks (so-called Essential Performance), etc.

This becomes especially clear when we consider the current very rapid growth of smart/autonomous automation in aircraft, automobiles, trains, aircraft, mining, surgery, agriculture, industrial manufacturing, public utilities, etc.

At the same time, EMI problems appear to be growing exponentially due to the very developments in semiconductor technologies that are encouraging more powerful processing of signals, data, and control; more efficient power conversion, and more wireless datacoms. Machine Learning and Artificial Intelligence algorithms are hoovering up millions of person-years of knowledge and experience to create automation that will never make a 'human error' – but they will suffer unique errors due to EMI.

For risks caused by EMI, all this means that our past experience as engineers and engineering managers is no longer a good guide to the future. The high-tech future we are busy creating right now will simply not happen without the application of electromagnetic resilience techniques and measures such as those described in IEEE 1848. This tutorial introduces this new standard and approach, its requirements, and its detailed guidance.

Managing Risks with Regard to Electromagnetic Disturbances – But What Does "Risk" Actually Mean?...N/A
Davy Pissoort
Katholieke Universiteit Leuven, Belgium

Why It Is Increasingly Important to Risk-Manage Electromagnetic Disturbances?...N/A
Davy Pissoort
Katholieke Universiteit Leuven, Belgium

The History of "EM Resilience" and IEEE 1848...N/A
Davy Pissoort
Katholieke Universiteit Leuven, Belgium

Details of the Techniques and Measures in IEEE 1848 for Increasing Resilience against the Effects of EMI...N/A
Keith Armstrong
Cherry Clough Consultants Ltd, United Kingdom

Ongoing and Future Research in EM Resilience...N/A
Davy Pissoort
Katholieke Universiteit Leuven, Belgium

Overall Discussion and Q&A...N/A
Davy Pissoort
Katholieke Universiteit Leuven, Belgium

WS-FR-PM-3 EMC Overview of Tests Applicable to 5G and WLAN Devices in Brazil (Sponsored by TC-12)

Workshop **1:30pm - 5:30pm**
Room: 401C
Chair: Elizabeth Perrier, ORBIS Compliance LLC, Morgan Hill, CA, USA

Session Abstract:

- Describe and comment item by item of act 1120;
- Identify the biggest challenges in each item of the EMC tests, relating between WLAN and 5G;
- Identify/research the biggest failure cases during EMC tests;
- Describe the test setup for each item;
- Interview laboratory technicians and register in the presentation;
- Projection into the future of EMC in WLAN/5G equipment;
- Describe what OTA Chamber is and identify how studies are being carried out for implementation in Brazil

Regulatory Compliance Engineer...N/A
Elizabeth Perrier, Deiverson Flausino
ORBIS Compliance LLC, USA

EMC Overview of Tests Applicable to 5G and WLAN Devices in BRAZIL...N/A
Elizabeth Perrier
ORBIS Compliance LLC, USA

WS-FR-PM-5 Becoming a Successful Book Author for the IEEE EMC Society

Workshop **1:30pm - 5:30pm**
Room: 402A
Chair: Reinaldo Perez, Jet Propulsion Laboratory, Denver, CO, USA
Organizer: Eric Bogatin, University of Colorado, Boulder, CO, USA
Organizer: Kenneth Wyatt, Wyatt Technical Services LLC, Woodland Park, CO, USA
Organizer: Doug Smith, D.C. Smith Consultants, Boulder City, NV, USA

Session Abstract: This workshop is inteded to equip interested IEEE EMCS members with the principles and processes needed to become successful EMCS book authors. In the workshop, attendees will hear from five (5) succesful EMCS book authors (i.e.presenters) about their experiences in developing their books, from the selection of their different publishers, to how their crafted their books. Lessons learned will be included. At the end of their presentations the authors will respond to questions from the audience in a panel session. The workshop will be tailored to EMC content only.

My Experiences Writing Books...N/A
Eric Bogatin
University of Colorado, USA

Self-Publishing with Less Pain – More Profit...N/A
Kenneth Wyatt
Wyatt Technical Services LLC, USA

Becoming a Successful Book Author for the IEEE EMCS...N/A
Reinaldo Perez
Jet Propulsion Laboratory, USA