2021 JOINT IEEE INTERNATIONAL SYMPOSIUM ON ELECTROMAGNETIC COMPATIBILITY, SIGNAL & POWER INTEGRITY, AND EMC EUROPE

26 JULY - 20 AUGUST

EMC SIPI 2021

VIRTUAL

FINAL PROGRAM

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CHAIRMAN'S MESSAGE

A LETTER FROM 2021 GENERAL CHAIR, ALISTAIR DUFFY & BRUCE ARCHAMBEAULT

Message from the co-chairs

Twelve months ago, I think we all genuinely believed that we would have met up this year in either or both of Raleigh and Glasgow. It was virtually inconceivable that we would be in the position of needing to move our two conferences this year to a virtual platform. For those who attended the virtual EMC Europe last year, who would have thought that they would not be heading to Glasgow with its rich history and culture? However, as the phrase goes, "we are where we are".

A "thank you" is needed to all the authors and presenters because rather than the *Joint IEEE International Symposium on EMC + SIPI and EMC Europe* being a "poor relative" of the event that had been planned, people have really risen to the challenge and delivered a program that is a virtual landmark! Usually, a Chairman's message might tell you what is in the program but we will just ask you to browse through the flipbook final program and see for yourselves. Between the tutorials & workshops; the technical papers; the Clayton R. Paul Global University; the experiments & demonstrations; the Ask the Experts panels; the Technical Exhibition from our sponsors with the technical seminars from the higher tier sponsors; the Technical Committee meetings, and the Women in Engineering and Young Professionals meetings (amongst other activities) you will find plenty that will be of value to you.

One of the aspects that we were all less happy with during last year's International Symposium was the opportunities to interact. This year, at the end of each of the technical sessions, we are inviting you to visit a Zoom Room to engage in a much more dynamic discussion.

Something that we should not overlook in the conference is the amount of volunteer time that goes in to putting together the program and ensuring that it is delivered as anticipated. This has involved hundreds (and if we were more easily able to assay it, thousands) of hours of involvement from the conference organising committee and the small number of contractors who work with us, whether that is managing the assembling of the technical program from call-for-papers to submission to IEEEXplore; ensuring that attendees can be registered and that the platforms are updated seamlessly; building an exhibition with a variety of organisations providing valuable opportunities for attendees to extend their technical knowledge; making sure that there are volunteers in the right place at the right time, etc. Like any complex organisation, what is seen at the 'front end' calls for a mixed metaphor: it is the tip of the iceberg with the legs paddling furiously under the surface! As Co-Chairs we are immensely honoured to be part of this Symposium, to be working with such a dedicated and innovative team, that so many researchers and practitioners have decided to publish their new contributions to knowledge with us and that so many experts have chosen the *Joint IEEE International Symposium on EMC + SIPI and EMC Europe* as a meeting to share their knowledge with a wider audience.

If you missed the opportunity to visit Raleigh this year, we will be there in 2025. If you missed the opportunity to visit Glasgow, we will have a joint symposium there in 2027. See you there?

We hope you enjoy this Symposium. However, we also look forward to seeing you all, in person, in Spokane in 2022.

Bruce Archambeault and Alistair Duffy
Co-Chairs

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Signal Integrity Journal

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SCHEDULE AT A GLANCE

MONDAY, 26 JULY	
11:00 AM - 2:00 PM	Technical Advisory Committee Meeting 1
TUESDAY, 27 JULY	
8:00 AM - 10:00 AM	Clayton R Paul Global University Signal Spectra
10:00 AM - 11:00 AM	TC 2 - EMC Measurements
10:30 AM - 12:30 PM	Clayton R Paul Global University Non-Ideal Components
1:00 PM - 3:00 PM	Clayton R Paul Global University Conducted Emissions
3:30 PM - 5:30 PM	Clayton R Paul Global University Antennas
WEDNESDAY, 28 JULY	
8:00 AM - 10:00 AM	Clayton R Paul Global University Shielding
10:00 AM - 11:00 AM	TC 4 - Electromagnetic Interference Control
10:30 AM - 12:30 PM	Clayton R Paul Global University Power Integrity
11:00 AM - 1:00 PM	TC 5 - High Power Electromagnetics
1:00 PM - 3:00 PM	Clayton R Paul Global University Crosstalk
3:30 PM- 5:30 PM	Clayton R Paul Global University PCB & System Design for EMC
THURSDAY, 29 JULY	
8:00 AM - 10:00 AM	Clayton R Paul Global University Electrostatic Discharge
10:00 AM - 11:00 AM	TC 1 - EMC Management / TC 6 - Spectrum Engineering / TC 8 - Aeronautics and Space EMC
10:30 AM - 12:30 PM	Clayton R Paul Global University Radiated Emissions
1:00 PM - 2:00 PM	Clayton R Paul Global University Group Session Ask the Instructors
FRIDAY, 30 JULY	
10:00 AM - 12:00 AM	Chapter Chair Training

WEEK 1: JULY 26 - 30

The Clayton R. Paul Global University (CRPGU) course is the educational highlight of the Society's calendar presenting a range of advanced EMC + SIPI knowledge, delivered by outstanding and internationally renowned teachers from around the world.

When it debuted at the 2006 IEEE EMC Symposium in Honolulu, CRPGU attendance topped out at 59 engineers and featured a series of 10 two-hour sessions presented by a small group of internationally distinguished educators. In 2020, at the first 'virtual' CRPGU, the class size was 70+ engineers.

The program this year has an excellent line up of speakers and topics.

Join us during 27 - 29 July, for the 2021 JOINT IEEE INTERNATIONAL SYMPOSIUM ON ELECTROMAGNETIC COMPATIBILITY, SIGNAL & POWER INTEGRITY AND EMC EUROPE CRPGU.

DAY	US ET (UTC-5)	TITLE *Schedule is subject to change	LECTURER
TU	8:00 - 10:00 am	Signal Spectra	Dr. Flavia Grassi
TU	10:30 am - 12:30 pm	Non-Ideal Components	Mr. Lorandt Foelkel
TU	1:00 - 3:00 pm	Conducted Emissions	Dr. Shuo Wang
TU	3:30 - 5:30 pm	Antennas	Mr. Zhong Chen
WED	8:00 - 10:00 am	Shielding	Dr. Frank Leferink
WED	10:30 am - 12:30 pm	Power Integrity	Dr. Chulsoon Hwang
WED	1:00 - 3:00 pm	Crosstalk	Dr. Todd Hubing
WED	3:30 - 5:30 pm	PCB & System Design for EMC	Dr. Bruce Archambeault
THU	8:00 - 10:00 am	Electrostatic Discharge	Dr. David Pommerenke
THU	10:30 am - 12:30 pm	Radiated Emissions	Mr. Lee Hill
THU	1:00 - 2:00 pm	Group Session Ask the Instructors	All

Attendees qualify for IEEE personal development hours (PDH) and continuing education units (CEU) certificates.

INSTRUCTORS

The course will begin with a short introduction followed by ten presentations that will be designed to encourage attendees' questions and will allow the attendees to have opportunities for discussions with the speakers after the tutorial.

Dr. Flavia Grassi
Associate Professor, Politecnico Milano
Past Treasurer, IEEE EMC Society
Italy Chapter

Mr. Lorandt Foelkel
M. Eng, UniTBv, (Transylvania University of Brasov)
Global Business Development Manager for Energy Harvesting & Field Application Engineer
Würth Elektronik eiSos GmbH & Co. KG,
Waldenburg, Germany

Dr. Todd Hubing
Professor Emeritus, Clemson University
IEEE Fellow, ACES Fellow
Past President, IEEE EMC Society

Mr. Zhong Chen, MSEE
MSEE Ohio State University
Director of RF Engineering, ETS-Lindgren
Chair of ASC ANSI C63 Subcommittee 1

Dr. Frank Leferink
Professor, University of Twente
Technical Authority, THALES Nederland
IEEE Fellow

Dr. Chulsoon Hwang
Assistant Professor
Missouri University of Science & Technology

Dr. Shuo Wang
Professor, University of Florida
IEEE Fellow
Director, Power Electronics and Electrical Power Research Lab
Chair, IEEE EMC SC5

Mr. Lee Hill, MSEE
MSEE, Missouri University of Science & Technology
Founding Partner, SILENT Solutions LLC & GmbH
Adjunct Faculty, Worcester Polytechnic Institute (WPI)
Associate Tutor, University of Oxford

Dr. David Pommerenke
Professor, Graz University of Technology, Austria
IEEE Fellow
Associate Editor, IEEE Transactions on EMC

Dr. Bruce Archambeault
Adjunct Professor, Missouri University of Science & Technology
IBM Distinguished Engineer Emeritus
Principal, Archambeault EMI/EMC Enterprises
IEEE Fellow
Immediate Past President, IEEE EMC Society

Please view the instructor biographies available on the Virtual Symposium website.

SCHEDULE AT A GLANCE

WEEK 2: AUGUST 2 - 6

MONDAY, 2 AUGUST

10:30 AM - 11:00 AM	A2LA Break Session							
	WT-MON-1	WT-MON-2	WT-MON-3	WT-MON-4	WT-MON-5	WT-MON-6	WT-MON-7	WT-MON-8
11:00 AM- 1:00 PM	Automotive EMC Joint Tutorial & Workshop	EMC Fundamentals	Modeling of Intentional EMI Scenarios	Smart Grid and EMC issues	EMC Considerations for Amateur Radio Stations	Military EMC Tutorial	EMC and OTA Tests of Wireless Devices in Reverberation Chambers	Product Safety Compliance and Global Market Areas
1:00 PM- 1:30 PM	Lighting EMC Break Session							
	WT-MON-1	WT-MON-2	WT-MON-3	WT-MON-4	WT-MON-5	WT-MON-6	WT-MON-7	WT-MON-8
1:30 PM- 3:30 PM	Automotive EMC Joint Tutorial & Workshop	EMC Fundamentals	Modeling of Intentional EMI Scenarios	Smart Grid and EMC issues	EMC Considerations for Amateur Radio Stations	Military EMC Tutorial	EMC and OTA Tests of Wireless Devices in Reverberation Chambers	Product Safety Compliance and Global Market Areas
1:30 PM - 2:30 PM	Ask Experts - Lightning Protection							

TUESDAY, 3 AUGUST

10:30 AM - 11:00 AM	AR RF/Microwave Instrumentation Break Session							
	WT-TUE-1	WT-TUE-2	WT-TUE-3	WT-TUE-4	WT-TUE-5	WT-TUE-6A	WT-TUE-7A	WT-TUE-8
11:00 AM - 1:00 PM	Automotive EMC Joint Tutorial & Workshop	EMC Fundamentals	The impact of Impulse Noise on the Radio Spectrum Above 1 GHz	Protection of Critical Infrastructures against Intentional Electromagnetic Interference	Basic EMC Measurements	Military EMC Tutorial	EMC and OTA Tests of Wireless Devices in Reverberation Chambers (Part 2)	EMC Testing and Design for Cables and Connectors
1:00 PM- 1:30 PM	Virginia Diodes Break Session							
	WT-TUE-1	WT-TUE-2	WT-TUE-3	WT-TUE-4	WT-TUE-5	WT-TUE-6B	WT-TUE-7B	WT-TUE-8
1:30 PM- 3:30 PM	Automotive EMC Joint Tutorial & Workshop	EMC Fundamentals	The impact of Impulse Noise on the Radio Spectrum Above 1 GHz	Protection of Critical Infrastructures against Intentional Electromagnetic Interference	Basic EMC Measurements	Risk Management for Future Highly-Automated/Autonomous Systems	Reverberation Chambers at the Edge of Chaos	EMC Testing and Design for Cables and Connectors
1:30 PM - 2:30 PM	Ask Experts - Power Electronics EMC							

WEDNESDAY, 4 AUGUST

10:00 AM - 10:30 AM	Sponsored Technical Presentation by EMC Partner							
10:30 AM - 11:00 AM	EMC Partner Break Session							
	WT-WED-1	WT-WED-2	WT-WED-3	WT-WED-4	WT-WED-5A	WT-WED-6	WT-WED-7	WT-WED-8
11:00 AM - 1:00 PM	Impact of Automotive Wireless Power Transfer systems on EMC and EMF Safety	EMC Testing Basics - Part 1	EMC Consultants's Toolkit	Introduction to EMI Modeling Techniques	Near Field Methods for Emissions and Immunity Analysis	EMC for Emergent Wireless Systems	Wireless Coexistence Testing Per ANSI C63.27: Basics and Practical Applications	Grounding and Bonding
1:00 PM- 1:30 PM	ETS-Lindgren Break Session							
	WT-WED-1	WT-WED-2	WT-WED-3	WT-WED-4	WT-WED-5B	WT-WED-6	WT-WED-7	WT-WED-8
1:30 PM- 3:30 PM	Impact of Automotive Wireless Power Transfer systems on EMC and EMF Safety	EMC Testing Basics - Part 1	EMC Consultants's Toolkit	Introduction to EMI Modeling Techniques	EMC design Issues for Power Electronic Converters	EMC for Emergent Wireless Systems	Wireless Coexistence Testing Per ANSI C63.27: Basics and Practical Applications	Grounding and Bonding
1:30 PM - 2:30 PM	Ask Experts - Military EMC							

AUTOMOTIVE Week | EDUCATION Week | IEMI/HEMP Week | STANDARDS Week | ASK THE EXPERTS | SPONSORED SESSIONS

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SCHEDULE AT A GLANCE

WEEK 2: AUGUST 2 - 6

THURSDAY, 5 AUGUST

10:30 AM - 11:00 AM	Rhode & Schwarz Break Session							
	WT-THU-1	WT-THU-2	WT-THU-3	WT-THU-4	WT-THU-5	WT-THU-6	WT-THU-7	WT-THU-8
11:00 AM - 1:00 PM	Advances in Automotive EMC and Connected Car Measurements	EMC Testing Basics - Part 2	HEMP Effects on Electronic Systems	Achieving ESD Robustness through System Efficient ESD Design Simulation	Theory, Techniques and Applications of EMI/EMC in Modern Power Electronics	Emerging Technologies: The Impact of Modern Robotics, Data Analysis, and CEM Simulation on Antenna and EMC Measurements in 2021 and Beyond!	Application of Reverberation Chambers	Overview of the P2716 WG - IEEE Guide for the Characterization of the Shielding Effectiveness of Board Level Shielding
1:00 PM- 1:30 PM	Elite Electronic Engineering Break Session							
	WT-THU-1	WT-THU-2	WT-THU-3	WT-THU-4	WT-THU-5	WT-THU-6	WT-THU-7	WT-THU-8
1:30 PM- 3:30 PM	Advances in Automotive EMC and Connected Car Measurements	EMC Testing Basics - Part 2	HEMP Effects on Electronic Systems	Achieving ESD Robustness through System Efficient ESD Design Simulation	Theory, Techniques and Applications of EMI/EMC in Modern Power Electronics	Emerging Technologies: The Impact of Modern Robotics, Data Analysis, and CEM Simulation on Antenna and EMC Measurements in 2021 and Beyond!	Application of Reverberation Chambers	Overview of the P2716 WG - IEEE Guide for the Characterization of the Shielding Effectiveness of Board Level Shielding
1:30 PM - 2:30 PM	Ask Experts - Input/output Buffer Information Specification (IBIS)							

FRIDAY, 6 AUGUST

10:00 AM - 10:30 AM	Sponsored Technical Presentation by Cadence								
10:00 AM - 10:45 AM	Experiments & Demos Live Q&A Session								
10:30 AM - 11:00 AM	ANSYS UK Break Session								
	WT-FRI-1	WT-FRI-2	WT-FRI-3	WT-FRI-4	WT-FRI-5A	WT-FRI-6	WT-FRI-7	WT-FRI-8	WT-FRI-9
11:00 AM - 1:00 PM	Modern Automotive EMC Technology – Ensuring Safety and Reliability	Learn EMC Now! For the Self-Learner or the Classroom	Recent Advancements in HEMP, EMP, and IEMI Protection – A Global Perspective	Lessons Learned Creating Reliable Computational Models for SI and EMC Applications	Theory, Techniques and Applications of EMI/EMC in Modern Power Electronics	mmWave Devices: 5G Test Challenges and Solutions	Update on Key ANSI C63 Standards on EMC - A Tribute to Don Heirman's Contributions to ANSI C63.4	EMC Testing and EMI Mitigation for Flight Critical Systems	EMC Compliance Techniques for Silicon Carbide (SiC) Power Converters (Li)
	WT-FRI-1	WT-FRI-2	WT-FRI-3	WT-FRI-4		WT-FRI-6	WT-FRI-7	WT-FRI-8	WT-FRI-9
1:30 PM- 3:30 PM	Modern Automotive EMC Technology – Ensuring Safety and Reliability	Learn EMC Now! For the Self-Learner or the Classroom	Recent Advancements in HEMP, EMP, and IEMI Protection – A Global Perspective	Lessons Learned Creating Reliable Computational Models for SI and EMC Applications		mmWave Devices: 5G Test Challenges and Solutions	Update on Key ANSI C63 Standards on EMC - A Tribute to Don Heirman's Contributions to ANSI C63.4	EMC Testing and EMI Mitigation for Flight Critical Systems	EMC Compliance Techniques for Silicon Carbide (SiC) Power Converters (Li)

AUTOMOTIVE Week
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STANDARDS Week
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WORKSHOP & TUTORIALS WT-MON-1

AUTOMOTIVE EMC JOINT TUTORIAL AND WORKSHOP – TUTORIAL PART 1

AUTOMOTIVE

Chair: Marco Klingler, *Stellantis, Vélizy-Villacoublay, France*
Co-Chair: Hermes Jose Loschi, *Early Stage Research of SCENT Project, Zielona Gora, Poland*

Automotive electric/electronic systems are endlessly growing in complexity with a permanent constraint of a constant or reduced time-to-market. Therefore, there is a strong need to improve constantly the efficiency of the EMC related tasks throughout the entire development process, starting from the design phase until the full-vehicle validation phase. Thus, this Automotive EMC Joint Tutorial & Workshop contemplates two parts: Part I will be a tutorial on numerical simulation in the automotive environment, focusing on EMC. Aiming to provide a holistic and educational approach to understand the different methods and techniques used to mitigate EMI problems in the automotive environment. Part I presentations will cover EMC issues at a system, sub-system, equipment, and component levels. In particular, the speakers' topics will include virtual EMC automotive simulation environments, considering: cables, transistors, PCBs, electric powertrains systems, and electrified vehicles. Part II will be a workshop on automotive EMC. Aiming to present an overview of the most recent industry advances in the field of automotive EMC design, modeling, and simulation, as well as in the field of automotive standards, testing, and measurements. Part II presentations will cover EMC issues at a system, sub-system, equipment, and component levels. In particular, the speakers' topics will include hybrid power-train systems EMC analysis, low frequency magnetic field, antenna implementation, equipment design, printed-circuit-board optimization, electric/electronic component characterization, testing, standards, and regulations.

Multiphysics Simulation for Virtual EMI and EMC Test Environment
Jiyoun Munn, *COMSOL, Inc., USA*

Electric Vehicles Devices Characterization using Finite Element Analysis and Multiphysics
Hermes Jose Loschi, *Douglas Aguiar do Nascimento, University of Zielona Góra & University of Twente, Zielona Góra, Poland*

EMC Shielding of HV Motor Cables
Andreas Barchanski, *Dassault Systèmes, Germany*

EMC Simulation of Electrified Vehicles with Ansys Solutions
Antea Perrotta[1], Frederic Bocquet[2], Flavio Calvano[1]
[1]ANSYS, Inc., Italy; [2]ANSYS, Inc., France

Efficiently Simulating EMI Emissions of PCBs Inside Vehicles to Analyze and Solve EMC Problems
Swapnil R. Kulkarni
Altair Engineering Inc., USA

EMC Simulation of Hybrid and Full Electric Powertrain Systems
Flavio Calvano[1], Frederic Bocquet[2], Antea Perrotta[1]
[1]ANSYS, Inc., Italy; [2]ANSYS, Inc., France

WORKSHOP & TUTORIALS WT-MON-2

EMC FUNDAMENTALS

EMC EDUCATION

Chair: *University of Twente, Enschede and THALES, Hengelo, Netherlands*
Co-Chair: John Cardinal McCloskey, III, *NASA/Goddard Space Flight Center, College Park, MD, USA*

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.

Inductance and Capacitance
Bruce Archambeault, *Missouri University of Science and Technology, USA*

Crosstalk
Eric Bogatin,
Teledyne LeCroy, Longmont, CO, USA

Transmission Lines and Basic Signal Integrity
Xiaoning Ye, *Intel Corporation, USA*

PCB Decoupling on Multi-Layer PCBs for Power Integrity Design
James Drewniak[1], Biyao Zhao[1], Shuang Liang[1], Siqi Bai[1], Xiaolu Zhu[1], Chulsoon Hwang[1], Samuel Connor[2], Matteo Cocchini[2], Dale Becker[2], Michael Cracraft[2], Brice Achkir[3], Stephen Scearce[3], Quinn Gaumer[3], Albert Ruehli1
[1]Missouri University of Science and Technology, USA; [2]IBM Corporation, USA; [3]Cisco Systems, Inc., USA

Grounding
Todd H. Hubing
LearnEMC, LLC, USA

ASK THE EXPERTS

MONDAY, 2 AUGUST
1:30 – 2:30 PM EDT

LIGHTNING PROTECTION

- Carlos Mata, *Scientific Lightning Solutions, Titusville, FL, USA (Moderator)*
- Farhad Rachidi, *EMC Laboratory, EPFL, Lausanne, Switzerland*
- Fridolin Heidler, *University of the Federal Armed Forces Munich, Munich, Germany*

Because of the high energy and current levels associated with lightning and the very rapid rise time of a lightning strike the design and maintenance of lightning protection systems is an engineering challenge on its own. Our Lightning Protection "Ask the Experts" panelists represent a diversity of academic research and lightning protection consultants. They are available to share their expertise in lightning testing and measurements, its parameters, effects, lightning protection, lightning detection, and even the physics of the phenomenon.

WORKSHOP & TUTORIALS WT-MON-3

MODELING OF INTENTIONAL ELECTROMAGNETIC INTERFERENCE (IEMI) SCENARIOS

EMP/IEMI

Chair: Frank Sabath, *Bundeswehr Research Institute for Protective Technologies and NBC Protection, Garstedt, Germany*

The tutorial is dedicated to the specification of the intentional electromagnetic (IEMI) threat scenario. A detailed discussion shows that the well-known electromagnetic coupling model requires an extension by a human dimension to map all aspects, which are relevant offender, source, interference channel, target system and user provides a basic structure for an IEMI scenario model. The model of a generic offender is developed to describe the unknown attacker. The model consists of probability distribution functions for the aspects expertise and financial resources, which are derived from statistical data and an expert's survey. The second unknown aspect of the IEMI scenario, the IEMI source used by the attacker, is considered in the following part of the tutorial. This part starts by introducing the principle structure of IEMI sources and a brief description of necessary modules. In addition to the technical performance and operating parameters non-technical aspects as expertise required for design and operation, availability of modules and components and related costs are also considered. The modeling procedure for possible IEMI sources starts with the breakdown of the usable volume of possible carrier platforms into partial volumes for the modules. The main performance data of the modules are estimated from the partial volumes via the module models. In a subsequent modeling step the performance of the modules are combined into performance data for the overall system. The comparison of non-technical characteristics (e.g. required expertise, availability and costs) with the capabilities of the generic offender enables the estimation of the probability that the considered IEMI source occurs in a criminal activity. The applicability of the introduced modeling method is demonstrated by modeling an existing IEMI source. The modeling of the electromagnetic threat scenario is completed in chapter 9 by estimating its likelihood. For this purpose, the environment of the target system is evaluated in terms of the accessibility and the necessary mobility. The probability that an EMI source of a considered type occurs at a given location in the surrounding of the target system is estimated by comparing the necessary mobility at the location with the mobility of the IEMI source.

Introduction to IEMI Scenario
Frank Sabath[1,2]
[1]Bundeswehr Research Institute for Protective Technologies and NBC Protection, Germany; [2]Leibniz Universität Hannover, Germany

Modeling of IEMI Scenarios
Frank Sabath[1,2]
[1]Bundeswehr Research Institute for Protective Technologies and NBC Protection, Germany; [2]Leibniz Universität Hannover, Germany

Modeling of Generic IEMI Sources
Frank Sabath[1,2]
[1]Bundeswehr Research Institute for Protective Technologies and NBC Protection, Germany; [2]Leibniz Universität Hannover, Germany

Modeling of Generic IEMI Scenario
Frank Sabath[1,2]
[1]Bundeswehr Research Institute for Protective Technologies and NBC Protection, Germany; [2]Leibniz Universität Hannover, Germany

WORKSHOP & TUTORIALS WT-MON-4

SMART GRID AND EMC ISSUES

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

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 2020. 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 is terminated. The tutorial will also give specific examples of the EMC immunity testing needed for smart devices used in power station and substation environments based on EMC work accomplished in the IEC. The tutorial will also place in perspective the EMC work still needed to be done to make EMC an integral part of the Smart Grid activity/operation. As part of the tutorial we will present links for free SEPA webinars on the extent/severity of the EMC problems in the SG, test setups needed to perform realistic EMC immunity tests, and what to consider in planning long term EMC applications as the SG ages. An update of the effects of conducted emissions in the 2 – 150 kHz frequency band on the operation of the SG will also be presented.

Introduction to the IEEE EMC Society Special Committee 1 (SC 1) and an Introduction to this Tutorial
Mike McInerney
Mac and Ernie, USA

SEPA (Smart Electric Power Alliance) Electromagnetic Interoperability Issues Working Group (EMIIWG) – Its History, Accomplishments and Status
William Radasky
Metatech Corporation, USA

Immunity for Power Station and Substation Environments
William Radasky
Metatech Corporation, USA

Conducted Emissions (2 kHz-150 kHz) and Their Effects on the Smart Grid
Dave Thomas
University of Nottingham, United Kingdom

WORKSHOP & TUTORIALS WT-MON-5

EMC CONSIDERATIONS FOR AMATEUR RADIO STATIONS

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

Amateur Radio Operators have needed to deal with EMC (RFI) problems on a very personal level when neighbors experience interference with their commercial entertainment services or a home-owners association (HOA) objects to the presence of a 'sender' in their home. Even if the amateur is not the source of the interference signal, their prominent and highly visible antennas often make them the recipient of complaints. In the interests of domestic tranquility, approaches that combine both personal interactions and technical solutions are needed, in that order, to manage these conflicts. Amateur Radio antennas often become the tallest electrical conductor in the immediate area and therefore also become the local focus of potential cloud electrical discharges (lightning). As such the grounding for the antenna and all the equipment in the radio station is vital. For safety, ground protection should be the first element installed, before even the antenna. This tutorial session will contain useful information for both current and future Ham radio enthusiasts.

Basics of Lightning Protection for Communication Towers
Jim Bacher
JBRC Consulting LLC, USA

Urban RFI and Ham Radio
Kenneth Wyatt
Wyatt Technical Services LLC, USA

Stealth Antennas that can make HOA's and Neighbors Happy
Thomas J. Fagan
Aerospace Corporation, Vail, AZ, USA

Antennas & Trees & Squirrels
Kimball Williams
DENSO Corporation (Retired), USA

WORKSHOP & TUTORIALS WT-MON-6

MILITARY EMC TUTORIAL

Chair: Robert Davis, *Lockheed Martin Corp, Manlius, NY, USA*
Co-Chair: Larry Cohen, *Naval Research Laboratory, Washington, DC, USA*
Co-Chair: Carl Hager, IV, *NSWC Dahlgren, Dahlgren, VA, USA*

The objective of this tutorial is to enhance our attendee's knowledge and understanding of key aspects of Military EMC that will help them in the performance their jobs. Achieving electromagnetic compatibility with military equipment, systems, and platforms requires significant effort. EMC must be considered at all lifecycle stages and involves first characterizing the operational electromagnetic environment (EME) and then design/testing military systems at various stages of production, assembly and integration. Numerous Military EMC standards and handbooks have been developed for electromagnetic environmental effects (E3) measurements and analysis to reduce the risk of equipment and systems failing to meet their operational performance requirements due to detrimental E3. Additionally, significant spectrum is being shared with commercial entities and hence E3 challenges are increasing. The tutorial will cover a broad range of Military EMC topics specifically including "Standards and DoD Directives & Instructions", "RF Spectrum Engineering", "Hazards of Electromagnetic Radiation to Ordnance", "Military Electromagnetic Modelling Techniques" and "RF Test & Measurement Techniques". The presenters are subject matter experts, representing a cross section of the DoD EMC agencies (Air Force, Army and Navy).

DoD Directives and MIL-STD Update Status
Brian Farmer
Naval Sea Systems Command, USA

MIL-STD-464 and MIL-STD-461 Status
Jose Pabon Soto
US Air Force, Wright-Patterson AFB, USA

MIL-HDBK-240 Updates
Andy Rash
Naval Surface Warfare Center, USA

NATO Electrical and Electromagnetic Environmental Conditions – AECTP 250 Series with Updates
Marsellas Waller
US Army Redstone Test Center, USA

Shipboard Below Deck Wireless E3 Assessment Methodology
Timothy Baseler
Naval Surface Warfare Center, USA

NATO Electromagnetic Environmental Effects Tests and Verification Methods: Updates to the AECTP 500 Series
Greg Hiltz
National Defence, Canada

Loads of Shipboard Antennas
Amy Pinchuk
InField Scientific Inc., Canada

CEM Not!(Computational Electromagnetics)
Fred Heather

WORKSHOP & TUTORIALS WT-MON-7

EMC AND OTA TESTS OF WIRELESS DEVICES IN REVERBERATION CHAMBERS

Chair: Valter Mariani Primiani, *Università Politecnica delle Marche, Ancona, Italy*
Co-Chair: Gabriele Gradoni, *University of Nottingham, Nottingham, United*

The rich stochastic variability of the reverberation chamber (RC) field is useful in electromagnetic compatibility (EMC) testing, immunity and emission, as well as in material characterization, shielding effectiveness, antenna characterization, and for the assessment of human exposure limits to electromagnetic fields. Modern wireless communication systems face very complex propagation conditions within urban and indoor channels supporting rich multi-path fading. The fading is stochastic as it is underpinned by the presence of moving scattering objects and people. These real-life propagation conditions are well reproduced by the RC stochastic field, more realistic than anechoic chambers for wireless device testing. RCs reproduce different propagation environments by the optimal insertion of absorbing materials, which mitigate reflections and tailor the chamber losses to match the real environment ones. Testing of wireless devices and systems is becoming increasingly important in the technological development of Long Term Evolution (LTE) and 5G mobile networks. Both mobile and base station manufacturers are interested in assessing system performance and user perceived quality in realistic propagation environments, including indoor and outdoor conditions. Beside the classical statistical analysis of the field inside an RC, to carry out complete over-the-air (OTA) tests also other physical quantities are of vital interest, such as the power delay profile (PDP), the Rician K- factor, the coherence bandwidth, the time delay spread, and so on. OTA tests can be efficiently carried out on wireless devices and on entire base stations by tuning the above parameters accordingly. In addition, the EMC problems of 5G systems are exacerbated by the presence of complex high-frequency, multifunctional, digital circuits and numerous wireless devices deployed throughout the propagation channel. Not only the EMC tests need to evaluate emission and immunity, but also identify the key sources of EMC failures. Due to the complexity of 5G systems, the analysis and identification of EMC failure sources are particularly intricate and challenging. Therefore, new test solutions and post-processing techniques are needed to address the challenges of 5G EMC tests, also assessing for coexistence constrains with existing fixed and mobile installations. The variation of the signal-to-interference-plus-noise ratio (SINR), for combined immunity and coexisting analysis inside the RC, allows for creating enhanced immunity tests tailored to the wireless systems, also including real-life base stations (to substitute current base station emulators). Inside the RC, emission tests can be easily extended to in-band radiated power tests aimed at checking EMF exposure and its minimization. Therefore, the combination inside the same facility of EMC and OTA tests makes the production/certification cycle efficient and reliable.

Verifying the Performance of Reverberation Chambers for Wireless Device Testing
Kate A. Remley
National Institute of Standards and Technology, USA

EMC Testing trends in Reverb Chambers
Garth D'Abreu
ETS-Lindgren, USA

Reconfigurable Intelligent Surfaces: A Efficient Alternative to Mechanical Stirrer for EMC and OTA Tests in Reverberation Chamber
Jean-Baptiste Gros[1], Geoffroy Lerosey[2], Ulrich Kuhl[2], Olivier Legrand[2], Fabrice Mortessagne[2]
[1]Greenerwave, France; [2]Institut de Physique de Nice, France

Channel Characterization of Reconfigurable Intelligent Radio Environment
Mir Lodro[1], Jean-Baptiste Gros[2], Steve Greedy[1], Geoffroy Lerosey[2], Gabriele Gradoni[1]
[1]University of Nottingham, United Kingdom; [2]Greenerwave, France

Comprehensive Uncertainty Analyses of TRP and TIS Measurements in Reverberation Chamber
Xiaoming Chen, Wei Xue
Xi'an Jiaotong University, China

IO-Link Wireless OTA Testing in Reverberation Chambers
Christoph Cammin[1], Dmytro Krush[1,2], Gerd Scholl[1]
[1]Helmut-Schmidt-Universität, Germany; [2]Kunbus GmbH, Germany

WORKSHOP & TUTORIALS WT-MON-8

PRODUCT SAFETY COMPLIANCE AND GLOBAL MARKET AREAS

Chair: Grant Schmidbauer, *Nemko USA, Inc., Carlsbad, CA, USA*

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.

IEEE / PSES Tutorial – Product Safety Compliance and Global Market Access
Ken Kapur, John Allen, Grant Schmidbauer
Nemko USA, Inc., USA

Compliance 101 – The Basics of Product Safety and Regulatory Compliance
Ken Kapur
Thermo Fisher Scientific, Inc., USA

Compliance 201 – The Basic Certification requirements for any Product
John Allen
Product Safety Consulting, Inc., USA

"Global Market Access" Worldwide market access for Electrical Products
Grant Schmidbauer
Nemko USA, Inc., USA

WORKSHOP & TUTORIALS WT-TUE-1

AUTOMOTIVE EMC JOINT TUTORIAL AND WORKSHOP – WORKSHOP PART 2

AUTOMOTIVE

Chair: Marco Klingler, *Stellantis, Vélizy-Villacoublay, France*
Co-Chair: Douglas Aguiar do Nascimento, *University of Zielona Góra & University of Twente, Zielona Góra, Poland*

Automotive electric/electronic systems are endlessly growing in complexity with a permanent constraint of a constant or reduced time-to-market. Therefore, there is a strong need to improve constantly the efficiency of the EMC related tasks throughout the entire development process, starting from the design phase until the full-vehicle validation phase. Thus, this Automotive EMC Joint Tutorial & Workshop contemplates two parts: Part I will be a tutorial on numerical simulation in the automotive environment, focusing on EMC. Aiming to provide a holistic and educational approach to understand the different methods and techniques used to mitigate EMI problems in the automotive environment. Part I presentations will cover EMC issues at a system, sub-system, equipment, and component levels. In particular, the speakers' topics will include virtual EMC automotive simulation environments, considering: cables, transistors, PCBs, electric powertrains systems, and electrified vehicles. Part II will be a workshop on automotive EMC. Aiming to present an overview of the most recent industry advances in the field of automotive EMC design, modeling, and simulation, as well as in the field of automotive standards, testing, and measurements. Part II presentations will cover EMC issues at a system, sub-system, equipment, and component levels. In particular, the speakers' topics will include hybrid power-train systems EMC analysis, low frequency magnetic field, antenna implementation, equipment design, printed-circuit-board optimization, electric/electronic component characterization, testing, standards, and regulations.

Time-Domain Comparisons Measurements vs. Simulation between 300 MHz and 3 GHz
Marco Klingler, Thomas Picon
Stellantis, France

Extension of the Reverberation Chamber Below its Lowest Usable Frequency
Martin Aidam
Mercedes-Benz AG, Germany

Simulation and Measurement of Transportation System Low Frequency Magnetic Field Exposure to Occupants
Scott Piper
General Motors Corporation, USA

Is Your Magnetic Component Misbehaving? Extrapolating 2D Data to 3D Analysis
Patrick DeRoy, Abhishek Ramanujan, Pete Sealey
Analog Devices Inc., Ireland

WORKSHOP & TUTORIALS WT-TUE-2

EMC FUNDAMENTALS

EMC EDUCATION

Chair: Frank Leferink, *University of Twente, Enschede and THALES, Hengelo, Netherlands*
Co-Chair: John Cardinal McCloskey, III, *NASA/Goddard Space Flight Center, College Park, MD, USA*

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.

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

Fundamentals of EMC – Conducted Emissions
Lee Hill[1,2]
[1]SILENT Solutions LLC & GmbH, USA; [2] Worcester Polytechnic Institute, USA

Radiated Emissions
Cheung-Wei Lam
Apple Inc., USA

Radiated Electric and Magnetic Field Emissions Shielding Mitigations
Pablo Narvaez
NASA Jet Propulsion Laboratory, USA

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

ASK THE EXPERTS

TUESDAY, 3 AUGUST
1:30 – 2:30 PM EDT
POWER ELECTRONICS EMC

- Shuo Wang, Chair SC 5, *Power Electronics and Electrical Power Research Lab, University of Florida, Gainesville, FL, USA (Moderator)*
- David Thomas, *George Green Institute for Electromagnetics Research, University of Nottingham, Nottingham, UK*
- Robert Smolenski, *Institute of Electrical Engineering, University of Zielona Gora, Poland*
- Sebastian Koj, *IAV GmbH, EMC & Antenna, Gifhorn, Germany*

Our Power Electronics EMC "Ask the Experts" panel is concerned with power electronics converters EMI/EMC issues. These are mainly, converters that use switching frequency schemes to control the output parameters, such as voltage and current. The panelists represent a diversity of academic research, industry and consultants. They are available to share their expertise in conductive, near field and radiated EMI and EMC issues as well as advanced solutions to the EMI/EMC issues in the state-of-the-art power electronics technologies in emerging areas.

WORKSHOPS & TUTORIALS

11:00 - 15:30 EDT

WORKSHOP & TUTORIALS WT-TUE-3

THE IMPACT OF IMPULSE NOISE ON THE RADIO SPECTRUM ABOVE 1 GHZ

EMP/IEMI

Chair: Jens Medler, *Rohde & Schwarz GmbH & Co. KG, Muenchen, Bayern, Germany*
Co-Chair: Toshio Chiyojima, *JEITA, Yokohama, Kanagawa, Japan*

Many devices such as computers, multimedia equipment and microwave ovens generate impulsive disturbances in the gigahertz range, even though they are not radios. They must comply with internationally standardized emission limits to ensures an agreed level of radio protection. The weighting of an impulsive disturbance for its effect on the radio communication services is important for the definition of those emission limits. Usage of the APD measurement function is the key for addressing this topic. The APD is the cumulative distribution of the amplitudes of a disturbance within a defined time interval and bandwidth and so it can show how strongly the device under test disturbs digital communications systems. The workshop will address the applicability of the APD measurement function for EMI compliance testing against international CISPR standards and how APD emission limit for electromagnetic pulsed disturbance with low probability of occurrence are defined. It also gives an inside view on the technology of receivers with such measurement function and will conclude with practical use cases.

The Impact of Impulse Noise on the Radio Spectrum above 1 GHz – Applicability of the APD Measurement Function in Current and Future CISPR EMI Standards
Jens Medler
Rohde & Schwarz GmbH & Co. KG, Germany

Method for Defining APD-Based Emission Limit for Electromagnetic Pulsed Disturbance with Low Probability of Occurrence
Toshio Chiyojima
Japan Electronics and Information Technology Industries Association, Japan

APD Measurement Function – A Faster Route to Disturbance-Free Microwave Bands
Tobias Groß
Rohde & Schwarz GmbH & Co. KG, Germany

A Study on the Measurement Uncertainty of Amplitude Probability Distribution in EMI Tests
Y. Yamanaka, Y. Matsumoto, S. Shiota, K. Gotoh
National Institute of Information and Communications Technology, Japan

11:00 - 15:30 EDT

WORKSHOP & TUTORIALS WT-TUE-4

PROTECTION OF CRITICAL INFRASTRUCTURES AGAINST INTENTIONAL ELECTROMAGNETIC INTERFERENCE

EMP/IEMI

Chair: Michael Suhrke, *Fraunhofer INT, Munster, Germany*
Co-Chair: Martin Schaarschmidt, *Wehrwissenschaftliches Institut fur Schutztechnologien ABC-Schutz, Munster, Germany*

Intentional electromagnetic inference (IEMI) becomes more and more a threat to modern society since the availability of IEMI sources increases, while modern electronic systems are becoming more vulnerable. Due to the widespread use of electronic systems, that are necessary to build up critical infrastructure, even partial breakdown can lead to a substantial interruption of public life. This workshop focuses on the vulnerability, resilience and protection of typically involved electronic systems.

Protection of Civil Infrastructures against Intentional Electromagnetic Interference – Introduction
Martin Schaarschmidt
Bundeswehr Research Institute for Protective Technologies and NBC Protection, Germany

Concepts for Quantifying IEMI Resilience of Critical Infrastructures
T. Pusch, M. Lanzrath, M. Suhrke
Fraunhofer INT, Germany

Coupling of HPEM Threats into Complex Systems
Felix Burghardt
Leibniz Universität Hannover, Germany

Resilience of Redundant Server Infrastructures under IEMI Influence
Sven Fisahn[1], Isa Wegmann[2], Sebastian Lange[1]
[1]Bundeswehr Research Institute for Protective Technologies and NBC Protection, Germany; [2]Meinberg Funkuhren GmbH & Co. KG, Germany

Vulnerability of Smart Home Application Systems to (Intentional) HPEM
Henrik Brech
Leibniz Universität Hannover, Germany

IEMI Vulnerability of Smart Grids
Marian Lanzrath

Protection of Critical Infrastructures against Intentional Electromagnetic Interference – Conclusion and Open Discussion
Michael Suhrke
Fraunhofer INT, Germany

WORKSHOP & TUTORIALS WT-TUE-5

BASIC EMC MEASUREMENTS

Chair: Monrad Monsen, *Oracle, Broomfield, CO, USA*
Co-Chair: Thomas J. Fagan, *Aerospace Corporation, Vail, AZ, USA*

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
Ghery S. Pettit
Pettit EMC Consulting LLC, USA

CISPR 32 Edition 2, Amendment 1
Ghery S. Pettit
Pettit EMC Consulting LLC, USA

Performing Immunity Testing to Transient Signals
Thomas E. Braxton[1,2]
[1]Shure Incorporated, USA; [2] Life Senior Member, IEEE, USA

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

WORKSHOP & TUTORIALS WT-TUE-6A

MILITARY EMC TUTORIAL

Chair: Robert Davis, *Lockheed Martin Corp, Manlius, NY, USA*
Co-Chair: Carl Hager, IV, *NSWC Dahlgren, Dahlgren, VA, USA*
Co-Chair: Larry Cohen, *Naval Research Laboratory, Washington, DC, USA*

The objective of this tutorial is to enhance our attendee's knowledge and understanding of key aspects of Military EMC that will help them in the performance their jobs. Achieving electromagnetic compatibility with military equipment, systems, and platforms requires significant effort. EMC must be considered at all lifecycle stages and involves first characterizing the operational electromagnetic environment (EME) and then design/testing military systems at various stages of production, assembly and integration. Numerous Military EMC standards and handbooks have been developed for electromagnetic environmental effects (E3) measurements and analysis to reduce the risk of equipment and systems failing to meet their operational performance requirements due to detrimental E3. Additionally, significant spectrum is being shared with commercial entities and hence E3 challenges are increasing. The tutorial will cover a broad range of Military EMC topics specifically including "Standards and DoD Directives & Instructions", "RF Spectrum Engineering", "Hazards of Electromagnetic Radiation to Ordnance", "Military Electromagnetic Modelling Techniques" and "RF Test & Measurement Techniques". The presenters are subject matter experts, representing a cross section of the DoD EMC agencies (Air Force, Army and Navy).

Radar Emission Spectra as a Function of Transmitter Final-Stage Amplifiers
Frank Sanders[1], Larry Cohen[2]
[1]Institute for Telecommunication Sciences, USA; [2]US Naval Research Laboratory, USA

Reconfigurable Impedance Tuning for Radar Transmitter Spectrum Sharing
Charles Baylis, Robert Marks, Sarah Seguin
Baylor University, USA

The Radar, Communication, and Passive Device Spectrum Environment: Issues and Solutions
Sarah A. Seguin, Charles Baylis, Robert J. Marks
Baylor University, USA

WORKSHOP & TUTORIALS WT-TUE-7A

EMC AND OTA TESTS OF WIRELESS DEVICES IN REVERBERATION CHAMBERS

Chair: Gabriele Gradoni, *University of Nottingham, Nottingham, United Kingdom*
Co-Chair: Valter Mariani Primiani, *Università Politecnica delle Marche, Ancona, Italy*

The rich stochastic variability of the reverberation chamber (RC) field is useful in electromagnetic compatibility (EMC) testing, immunity and emission, as well as in material characterization, shielding effectiveness, antenna characterization, and for the assessment of human exposure limits to electromagnetic fields. Modern wireless communication systems face very complex propagation conditions within urban and indoor channels supporting rich multi-path fading. The fading is stochastic as it is underpinned by the presence of moving scattering objects and people. These real-life propagation conditions are well reproduced by the RC stochastic field, more realistic than anechoic chambers for wireless device testing. RCs reproduce different propagation environments by the optimal insertion of absorbing materials, which mitigate reflections and tailor the chamber losses to match the real environment ones. Testing of wireless devices and systems is becoming increasingly important in the technological development of Long Term Evolution (LTE) and 5G mobile networks. Both mobile and base station manufacturers are interested in assessing system performance and user perceived quality in realistic propagation environments, including indoor and outdoor conditions. Beside the classical statistical analysis of the field inside an RC, to carry out complete over-the-air (OTA) tests also other physical quantities are of vital interest, such as the power delay profile (PDP), the Rician K-factor, the coherence bandwidth, the time delay spread, and so on. OTA tests can be efficiently carried out on wireless devices and on entire base stations by tuning the above parameters accordingly. In addition, the EMC problems of 5G systems are exacerbated by the presence of complex high-frequency, multifunctional, digital circuits and numerous wireless devices deployed throughout the propagation channel. Not only the EMC tests need to evaluate emission and immunity, but also identify the key sources of EMC failures. Due to the complexity of 5G systems, the analysis and identification of EMC failure sources are particularly intricate and challenging. Therefore, new test solutions and post-processing techniques are needed to address the challenges of 5G EMC tests, also assessing for coexistence constrains with existing fixed and mobile installations. The variation of the signal-to-interference-plus-noise ratio (SINR), for combined immunity and coexisting analysis inside the RC, allows for creating enhanced immunity tests tailored to the wireless systems, also including real-life base stations (to substitute current base station emulators). Inside the RC, emission tests can be easily extended to in-band radiated power tests aimed at checking EMF exposure and its minimization. Therefore, the combination inside the same facility of EMC and OTA tests makes the production/certification cycle efficient and reliable.

ASIC-Correlators with Embedded Cognition for Smart OTA Test
Sidina Wane
eV-Technologies, France

Wireless Cable Testing for 5G Radios: A future-Proof Compact 5G Radio Performance Test Solution
Wei Fan
Aalborg University, Denmark

Testing of Real Base Stations in Reverberation Chambers
L. Bastianelli[1], F. Moglie[1], V. Mariani Primiani[1], G. Gradoni[2], M. Barazzetta[3], D. Micheli[4], R. Diamanti[4]
[1]Università Politecnica delle Marche, Italy; [2]University of Nottingham, United Kingdom; [3]Nokia Solutions and Networks, Italy; [4]Telecom Italia, Italy

WORKSHOP & TUTORIALS WT-TUE-8

EMC TEST AND DESIGN FOR CABLES AND CONNECTORS

Chair: Huadong Li, *Molex LLC, Naperville, IL, USA*
Co-Chair: Charles Jullien, *Safran Electrical and Power, Blagnac, France*

This workshop will give a general introduction to cable construction, termination and grounding for product EMC. A new test vehicle is proposed for cable and connector assembly EMC testing. Common existing EMC characterization methods for cable and connector shielding will be generalized. Examples of using EMC simulation to control connector radiated emissions and help on harness EMC design will be demonstrated. Approaches of using various cable connector parameters in simulations tools to facilitate cable and connector design for effects such as lightning and HEMP will be described. The tutorial is divided into topics as: Proper Cable Construction and Shielding Termination Techniques; A New Vehicle for Cable and Connector Assembly EMC Testing; EMC Design for an I/O Connector; Using Simulation Tools to Facilitate Cable and Connector Design; Harness EMC Design by Simulation and Validation by Experiment. The workshop will help the audience to properly test and design cables, connectors and their assemblies for product EMC.

Proper Cable Construction and Shielding Termination Techniques
Robert Scully
NASA Jet Propulsion Laboratory, USA

Characterization of Magnetic Shielding of Connectors used for Electrophysiology Studies in Medical Devices
Eugene Mayevksiy
TE Connectivity, USA

EMC Design for an I/O Connector
Egide Murisa
Molex LLC, USA

Validation of Emission Bench Testing
René Fiedler, Eddy Jehamy
Altair Engineering Inc., USA

Modelling EM-Coupling on Multiconductor Transmission Line Networks with the BLT Equation
Jean-Philippe Parmantier
ONERA, France

Harness EMC Design by Simulation and Validation by Experiment
Charles Jullien
Safran Electrical and Power, France

13:30 - 15:30 EDT

WORKSHOP & TUTORIALS WT-TUE-6B

RISK MANAGEMENT FOR FUTURE HIGHLY-AUTOMATED/AUTONOMOUS SYSTEMS

Chair: Davy Pissoort, *Katholieke Universiteit Leuven, Bruges, Belgium*
Co-Chair: Keith Armstrong, *Cherry Clough Consultants Ltd, Stafford, United Kingdom*

Autonomous systems offer humankind tremendous opportunities, like freeing us from mundane tasks, carrying out risky procedures and generally giving us more time to enjoy the things we like doing. As long as these systems are operating in a human-less environment, like enclosed surroundings in a factory, they are readily accepted. However, people lack trust in autonomous systems if their own safety is dependent on a machine's correct operation. Whenever someone mentions self-driving cars, the question of safety is raised immediately. It is often argued that if deployed tomorrow, existing self-driving cars would have fewer accidents than those driven by humans. But this doesn't mean that people are ready to hand-over the steering wheel. We tolerate many thousands of deaths on the road every year, but the very first autonomous- vehicle crash involving a fatality was already headline news all over the world. In the near future, we'll be interacting with "cobots" – robots intended to assist humans in a shared workspace. For this to happen smoothly, we need to ensure that these cobots will never accidently harm us. This question of safety is paramount and a key- issue for just about every autonomous system. Future applications of autonomous systems will rely heavily on different (wireless) communication technologies to connect and interact with other devices, infrastructure, the "cloud", etc. Although adding connectivity has its benefits, it also adds challenges and new risks, among which are most definitely its ElectroMagnetic (EM) robustness and resilience. In this tutorial, an overview will be given about the latest evolutions in the area of safety assurance of autonomous systems, with a specific focus on the EMI-related aspects.

Latest Developments in Safety Assurance of Autonomous Systems
Davy Pissoort
Katholieke Universiteit Leuven, Belgium

The Meaning of EMC, EM Resilience, Risk-Based EMC
Davy Pissoort
Katholieke Universiteit Leuven, Belgium

Making the Case for an "EMC Assurance Case"
Davy Pissoort
Katholieke Universiteit Leuven, Belgium

Techniques and Measures for Managing the Functional Safety and Other Risks that can be caused by EMI
Keith Armstrong
Cherry Clough Consultants Ltd., United Kingdom

Risk Management of EMI for Highly-Automated/ Autonomous Medical Devices and Systems
Keith Armstrong
Cherry Clough Consultants Ltd., United Kingdom

13:30 - 15:30 EDT

WORKSHOP & TUTORIALS WT-TUE-7B

REVERBERATION CHAMBERS AT THE EDGE OF CHAOS

Chair: Ramiro Serra, *Eindhoven University of Technology, Eindhoven, Netherlands*
Co-Chair: Gabriele Gradoni, *University of Nottingham, Nottingham, United Kingdom*

In recent years, the reverberation chambers community has been engaged in conversations and disputations regarding the pertinence, the applicability and the usefulness of models inspired in the so-called chaotic cavities Curved diffusers can induce chaos in a closed cavity? Does this chaos yield better performance of a reverberation chamber? Plane wave spectrums or non-Hermitian effective Hamiltonians? Random eigenmodes and the central limit theorem or random matrix theory? However, most of these discussions happen during very brief and limited moments, like, for instance: the five-minute Q&A session after the presentations, during coffee- or lunch-breaks, etc. Moved by the potential interest in having an open and significant discussion, we organized a series of quæstiones disputatæ on the topic of (chaotic) reverberation chambers. These quæstiones will not follow the traditional setup of a workshop or tutorial, i.e. with a series of presentations with limited opposition. On the contrary, they are meant to favor debate, with contrasting positions on crucial questions in the area of chaotic vs. traditional RCs. In this series of dialectics we aim at sharing and confronting valuable clarifications, explanations and definitions which will help the RC (and beyond) community as a whole. Furthermore, we will introduce and recover the, probably forgotten, healthy exercise of debating, which is a very old and very valuable habit of University education and scientific conversation. The debate aims at exchanging, in a polite and educated manner, different points of view, while practicing the gymnastics of argumentation, without shouting, offending or being rude. The goal is not to provide a final and definitive solution to these "disputed questions" in such a short session, but to facilitate the healthy exchange of ideas and opinions.

Reverberation Chambers at the Edge of Chaos
Ramiro Serra[1], Gabriele Gradoni[2]
[1]Eindhoven University of Technology, The Netherlands; [2]University of Nottingham, United Kingdom

WORKSHOP & TUTORIALS WT-WED-1

IMPACT OF AUTOMOTIVE WIRELESS POWER TRANSFER SYSTEMS ON EMC AND EMF SAFETY

AUTOMOTIVE

Chair: Tommaso Campi, *University of L'Aquila, Terni, Italy*
Co-Chair: Mauro Feliziani, *University of Aquila, L'Aquila, Italy*

The workshop will focus on the EMC and EMF safety aspects related to the wireless power transfer system applied to electric vehicles (EV). The spread of the static wireless charging system for electric vehicles is increasing sharply and, in the future, the use of the dynamic charging system will also be widely used to extend the range of electric vehicles. These systems based on inductive coupling are very useful because they allow a safe and comfortable charging procedure of batteries in electric vehicles. However, there are several aspects that need to be considered. One of the most important is the magnetic field produced since WPT systems are intentional sources of time varying magnetic fields; field levels can be very high due to the power required by the charging process. Therefore, compliance with current EMC and EMF safety standards is very critical to the success of this technology. The magnetic field generated by automotive WPT systems will be characterized. Subsequently, mitigation techniques based on innovative shielding and compensation circuits will be presented. The impact of the magnetic field on the passengers or pedestrians of electric vehicles will be studied by a numerical dosimetric analysis using sophisticated models of the human body. An overview of standardization and compliance testing methods to evaluate wireless power transfer related to human exposure will also be provided.

Analysis and Mitigation of the Magnetic Field in Static and Dynamic WPT Systems for Automotive
Mauro Feliziani[1], Tommaso Campi[1], Francescaromana Maradei[2], Silvano Cruciani[2]
[1]University of L'Aquila, Italy; [2]Sapienza University of Rome, Italy

Mitigation of Electromagnetic Field from Wireless Charging Electric Vehicle
Seungyoung Ahn
Korea Advanced Institute of Science and Technology, Korea

Computational Assessment of Electromagnetic Safety from Wireless Power Transfer Systems
Akimasa Hirata, Keishi Miwa, Yinliang Diao
Nagoya Institute of Technology, Japan

Uncertainty Quantification and Metamodeling in the Design of Inductive Power Transfer Systems
Yao Pei, Paul Lagouanelle, Lionel Pichon
Université Paris-Saclay, France

WPT-EV: A Real-World View of EMC and EMF
Ky Sealy, Morris Kesler, Jon Sirota
WiTricity Corporation, USA

Numerical Challenges for the Evaluation of EMF Safety in WPT for Automotive Applications
Fabio Freschi, Luca Giaccone
Politecnico di Torino, Italy

Simulation-based EMF Safety Assessment for 7.7kVA Wireless Power Transfer System for Electric Vehicle Charging
Hongseok Kim[1], Anfeng Huang[1], Dongwook Kim[1], Hee Hoon Yi[2], Jun Fan[1]
[1]Missouri University of Science and Technology, USA; [2]Hyundai Motor Group, Korea

WORKSHOP & TUTORIALS WT-WED-2

EMC TESTING BASICS – PART 1

EMC EDUCATION

Chair: Ross Carlton, *ETS-Lindgren, Cedar Park, TX, USA*
Co-Chair: Alistair Duffy, *De Montfort University, Leicester, United Kingdom*

Due to the popularity of this tutorial when it was presented for the first time at the 2020 IEEE EMC+SIPI Virtual Symposium, we have brought it back with the original speakers and updated topics! This tutorial will cover basic topics in EMC testing – from designing a new laboratory or test capability to achieving accreditation. Presentations will provide practical information and real-world knowledge that can be immediately implemented. 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 assessing EMC test facilities. Attendees will quickly learn the best practices in each topic area and have an opportunity to share their own experience and recommendations with the audience. NOTE: This tutorial is designed as a two-part session. For a complete discussion of the topic, attendees should also attend the EMC Testing Basics – Part 2 tutorial.

Antennas for EMC
Alistair Duffy
De Montfort University, United Kingdom

EMC Test Planning
Ross Carlton
ETS-Lindgren, USA

EMC Lab Automation for Efficiency and Quality
Jack McFadden
ETS-Lindgren, USA

EMC Lab Design: An Overview of the Process, Possibilities, and Issues
Bob Mitchell
TUV Rheinland North America, USA

4 AUGUST • 10:00 - 10:30 AM

METHODS FOR TESTING SPDS SPECIFIED IN IEEE/ANSI C62.41.2, SCENARIO I

EMC PARTNER

WORKSHOP & TUTORIALS WT-WED-3

EMC CONSULTANTS' TOOLKIT

Chair: Jerry Meyerhoff, *JDM Labs LLC, Buffalo Grove, IL, USA*

Provide a wide variety of tools and skills required to be a successful EMC consultant in today's market. Content: Practical tools & skills expected by Clients from the productive EMC consultant. The major topics will be presented by well experienced practicing EMC consultants and will conclude with an open audience Q & A session engaging all the speakers as panel of experts. Abstract: In the current economic conditions, trends show that many engineering and design firms are focusing on core competencies and outsourcing or reducing staff and other functions such as EMC. Thus unfortunately, many experienced EMC engineers become separated from their corporate work lives.. With the strong rise in the "Internet of Things" (IoT) digital and coding skills are emphasized, yet the underlying complexity and RF basis of wireless is undervalued. Also there is huge growth in Power Electronics applications, which focus on efficiency, often to the detriment of EMC. Many companies like IoT start-ups, that simply do not have the resources to hire a full-time EMC engineer. The purpose of this workshop is to provide an introduction to the technical, business and marketing skills needed by interested EMC engineers, so that they can successfully locate, market and provide effective services to such target companies, all at a fair profit and with high job satisfaction.

EMC Consultant's Tool-Kit
Jerry Meyerhoff
JDM Labs LLC, USA

The Seven Habits of Highly Successful EMC Consultants
Kenneth Wyatt
Wyatt Technical Services LLC, USA

Lessons from a Recent EMC Consulting Startup
Michael J. Schutten
Schutten Technical Consulting LLC, USA

Professional Consulting
Patrick André
André Consulting, Inc., USA

Acquiring Test Equipment & Developing a Low-Cost EMC Troubleshooting Kit
Patrick André[1], Kenneth Wyatt[2]
[1]Andre Consulting, Inc., USA; [2]Wyatt Technical Services LLC, USA

WORKSHOP & TUTORIALS WT-WED-4

INTRODUCTION TO EMI MODELING TECHNIQUES

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

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 (FDTD) Technique
Bruce Archambeault, *Missouri University of Science and Technology, USA*

Introduction to the Finite Element Method
Chuck Bunting
Oklahoma State University, USA

Modeling with the Method of Moments
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 USA; [3]IBM Corporation, USA*

Introduction to the (PEEC) Partial Element Equivalent Circuit Approach Applied to EMC + SIPI
Albert E. Ruehli[1], Giulio Antonini[2], Lijun Jiang[3]
[1]Missouri University of Science and Technology, USA; [2]Università degli Studi dell'Aquila, Italy; [3]The University of Hong Kong, Hong Kong

Hybrid Modeling Approaches
Karen Burnham
Electro Magnetic Applications, Inc., USA

The Importance of Validation for All Simulations
Scott Piper
General Motors Corporation, USA

ASK THE EXPERTS

WEDNESDAY, 4 AUGUST
1:30 – 2:30 PM EDT

MILITARY EMC

- Frank Leferink, Professor EMC, *University of Twente & Technical Authority EMC, THALES Nederland, Enschede, The Netherlands (Moderator)*
- Fred Heather, *US Navy, USA*
- Greg Hiltz, *Quality Engineering Test Establishment, Department of National Defence, Ottawa, Canada*

Achieving electromagnetic compatibility with military equipment, systems, and platforms requires significant effort. EMC of military systems must be considered at all lifecycle stages and involves first characterizing the operational electromagnetic environment (EME) and then design/testing military systems at various stages of production, assembly and integration. Our panelists are available to share their expertise in Military EMC measurements and testing, including electromagnetic pulse, hazards of electromagnetic radiation to ordnance, personnel and fuel, co-site interference, electromagnetic vulnerability, conducted/radiated emissions and much more.

WORKSHOP & TUTORIALS WT-WED-5A

NEAR FIELD METHODS FOR EMISSIONS AND IMMUNITY ANALYSIS

Chair: David Pommerenke, *Technische Universitat Graz, Graz, Austria*

Near-field methods are tools for design and troubleshooting. They can be applied to emission and immunity problems. The most common, near-field scanning, is used to visualize fields above an IC or PCB. The real challenge, however, is how to use the data. This can be as simple as comparing A to B or visually searching for unexpected fields, but can also involve complex source reconstruction or far-field prediction. Still, one may ask, is the near field the information we want to know? Here, the workshop will address post-processing and other near-field methods. Source reconstruction will be explained. It uses the scanned data in order These sources can be imported into simulations to simulate coupling, for example. A related method, emission source microscopy, visualizes only the radiating sources, but at a cost: resolution is limited. The method is explained and contrasted with near-field scanning. For near-field scanning and emission source microscopy, there are a variety of methods to reduce scan time. They range from pre-scan to self-learning algorithms and will be addressed in the workshop. Having a local probe over a PCB can also be used for susceptibility analysis, such as determining the local response to an ESD-like pulse coupled across the field. This leads to a system-level ESD design and debugging tool for soft failures. The presentation will explain the methodology and its limitations. Once an ESD hits a system, for example at a USB port, the current propagates throughout the system. This current propagation can be visualized with picosecond resolution to show expected and surprising current paths via ESD current propagation measurements Other analysis methods based on local probing show the structural resonance of a PCB or module by measuring the frequency-dependent Q-factor of structures at different locations. Another topic treats source discrimination methods. In many electronic devices, emissions are generated by multiple uncorrelated sources, such as switching power supplies, digital clocks, etc. Traditional sampling methods provide total fields generated by all sources simultaneously, making it difficult to identify sources and estimate their contributions. Source contributions to the total field can be estimated using source separation methods. However, in this case the measurement setup becomes more complicated - additional probes are needed and the phase of the field must be determined. All near-field methods require probes. The ideal probe measures the desired field component and has no cross-field sensitivity and no cable. However, real probes cannot do this. The workshop explains the undesirable probe behavior and shows how to critically characterize probes.

Overview: Near Field Methods for Emissions and Immunity Analysis
David Pommerenke
Technische Universität Graz, Austria

Microwave Imaging Methods for EMC
Victor Khilkevich
Missouri University of Science and Technology, USA

WORKSHOP & TUTORIALS WT-WED-6

EMC FOR EMERGENT WIRELESS SYSTEMS

Chair: Tim Claeys, *Katholieke Universiteit Leuven, Brugge, Belgium*
Co-Chair: Marco Rossi, *Fraunhofer-Institut fur Elektronische Nanosysteme ENAS Abteilung Advanced System Engineering ASE, Berlin, Germany*

The EEWISE project (EMC for Emergent Wireless Systems) is funded under the combined national and regional programme for Collective Research for the benefits of SMEs (see https://www.cornet.online). The project is a collaboration between the University of Paderborn and Fraunhofer IZM in Germany and KU Leuven in Belgium. The EEWISE project started on Oct 1 2018 and will end on March 31 2021. The EEWISE project is supported by an industrial user-committee comprising more than 30 companies in Germany and Belgium. The EEWISE project aims at finding solutions to the electromagnetic interference (EMI) problems associated with interconnected wireless systems (IWSs). These IWSs are at the very heart of the industries involved in Industry 4.0, the Internet of Things (IoT), and 5G telecommunications, and increasingly important in applications involving, amongst others, smart devices, autonomous vehicles, and healthcare. It is likely that the EU will have 40% of the global IoT market. The total number of wirelessly interconnected devices worldwide is expected to reach 20.4 billion by 2020. The relevance of the EEWISE project and its technological ambitions is clear from the combined size and importance of the market for IWSs. Electromagnetic interference (EMI) is one of the major hidden challenges for IWSs. Unsurprisingly, the members of the EEWISE consortium are being inundated with an increasing number of questions from industry, especially from SMEs, about how to make their current and future IWSs - often components in applications with stringent reliability and safety requirements - compliant with the requirements set forward by the electromagnetic compatibility (EMC) and Radio Equipment Directives (RED) in a cheaper and more cost-effective way. The companies have made it abundantly clear that they need breakthrough solutions when it comes to estimating, improving and validating the EMC behaviour of their interconnected systems, especially given the much higher frequencies at which these systems will operate. The EEWISE project will raise the level of knowledge and effectively deploy this knowledge within the SMEs to design more reliable, safer and smarter IWSs more quickly and at competitive prices, meaning that the international competitiveness of the European companies covered by the project will be improved, thereby increasing job opportunities within Europe. The scientific and technological work is organized along 4 research tracks covering, on the one hand, the 3 main steps within a Design-for-EMC/RED approach (characterization and identification of (un)intentional radiating sources, application of dedicated mitigation techniques and measures, and validation and certification of the final product) and, on the other hand, application of this as part of case studies.

EMC for Emergent Wireless SystEms
Davy Pissoort
Katholieke Universiteit Leuven, Belgium

Simulation-Based Assessment of Antenna Performance in Internet-of-Things (IoT) Modules
M. Rossi, S. Al-Magazachi, C. Brockmann, U. Maaß, H. Pötter, N. Ndip
Fraunhofer IZM, Germany

How Near Field Measurements can support the Design and Assessment of IoT Devices
Dominik Schröder[1], Sven Lange[2]
[1]Universität Paderborn, Germany;
[2]Fraunhofer ENAS, Germany

EMC for Radio Products
Tim Claeys, Filip Vanhee, Klaas Pluvier
Katholieke Universiteit Leuven, Belgium

Bluetooth Low Energy Reliability and Improvement
Bozheng Pang, Tim Claeys, Hans Hallez, Jeroen Boydens
Katholieke Universiteit Leuven, Belgium

WORKSHOP & TUTORIALS WT-WED-7

WIRELESS COEXISTENCE TESTING PER ANSI C63.27: BASICS AND PRACTICAL APPLICATIONS

STANDARDS

Chair: Mohamad Omar Al Kalaa, *US Food and Drug Administration, Silver Spring, MD, USA*
Co-Chair: Jason Coder, *National Institute of Standards and Technology, Boulder, CO, USA*

This tutorial will review the scientific foundation of wireless coexistence, the unique challenges it raises, and discuss the practical implementation of coexistence testing as specified in IEEE/ANSI C63.27 standard for evaluation of wireless coexistence. This topic is relevant to many industries including medical devices and automotive. For example, wireless coexistence evaluation is recommended in the FDA Guidance document on radio frequency wireless technology in medical devices. FDA recognizes the IEEE/ANSI C63.27 standard and it is often incorporated in the evaluation framework. The speakers include experts who are actively involved in using, writing, maintaining and assessing the use of the standard. Attendees will also learn about the recent revisions being implemented in the standard and what to expect in the new edition, as well as ongoing research in the area of wireless coexistence.

Wireless Coexistence Measurements and Challenges: What is Coexistence?
Jason Coder
National Institute of Standards and Technology, USA

Medical Device Wireless Coexistence Evaluation Framework
Mohamad Omar Al Kalaa
US Food and Drug Administration, USA

Wireless Coexistence: Practical and Regulatory Challenges
Gregory Bowden
Medtronic Inc., USA

Verifying Coexistence Performance – A Review of Coexistence Test Methods and Environments
James Young
ETS-Lindgren, USA

Coexistence, an Automotive Measurement
Garth D'Abreu
ETS-Lindgren, USA

WORKSHOP & TUTORIALS WT-WED-8

GROUNDING AND BONDING

Chair: Daryl Beetner, *Missouri University of Science and Technology, Rolla, MO, USA*
Co-Chair: William Wantz, *IV, Spira Manufacturing, San Fernando, CA, USA*

This tutorial will provide an overview of the topics engineers must consider when performing grounding and bonding in their electronic products or systems. Presentations will cover fundamental concepts common to all grounding and bonding issues, as well as considerations when grounding for safety and lightning, when grounding for low-frequency interference, when grounding for high-frequency emissions/immunity, and when working in the transportation/military industries. The objective is to provide working engineers with a strong basis for tackling their grounding and bonding problems in a more comprehensive fashion than is possible in a shorter tutorial session. This session will be useful to those new to the field, as well as those who wish to brush up on the fundamentals.

Grounding Fundamentals
Todd H. Hubing
LearnEMC, LLC, USA

The Rights, Wrongs, and the "It Depends" of Bonding and Safety Connections in Transportation Systems
Mark Steffka
University of Detroit Mercy, USA

Low Frequency Signal Integrity and "Ground"
Lee Hill[1,2]
[1]SILENT Solutions LLC & GmbH, USA;
[2]Worcester Polytechnic Institute, USA

Grounding for Electrical Safety and Lightning Protection
Mike McInerney
Mac and Ernie, USA

WORKSHOP & TUTORIALS
WT-WED-5B

EMC DESIGN ISSUES FOR POWER ELECTRONIC CONVERTERS

Chair: Ilknur Colak, *Maschinenfabrik Reinhausen, Regensburg, Bavaria, Germany*

This tutorial is intended to address the EMC problems in the high power medium voltage converters and explain the related EMC design steps based on IEC standards. It describes how EMC applies to systems and installations, and also explains proven best EMC practices (implementation of EMC zones, bonding, earthing, when to use filter or shielding, cable layout and cable segregation, preventing grounding loop, routing within the system) in design, assembly and installation to optimize the essential reduction and conform to the standards of electromagnetic compatibility. The tutorial also covers the mechanical instructions when developing new converter design or evaluating existing solutions. The scope of the lecture would be very valuable to those power electronics engineers, mechanical engineers and researchers who are confronted with the practical problems of implementing EMC requirements in their applications and who need a guide to the methods that can be used immediately without performing complex mathematics.

EMC Design Issues for Power Electronics Converters

Ilknur Colak
Maschinenfabrik Reinhausen, Germany

WORKSHOP & TUTORIALS WT-THU-1

ADVANCES IN AUTOMOTIVE EMC AND CONNECTED CAR MEASUREMENTS

AUTOMOTIVE

Chair: Martin A.K. Wiles, *Albatross Projects GmbH, Nattheim, United Kingdom*
Co-Chair: Achim Gerstner, *Gerstner, Rohde & Schwarz USA, Inc., Dallas, TX, USA*

The automotive industry has for some time been going though a period of intense technological change driven by various regulatory, environmental and safety pressures. This workshop has been designed to provide an informative overview of some of the most current and key development areas and the measurement topics associated with them from key industry experts. The session will start by looking at the Electric Vehicle which is seeing huge growth and is predicted to continue for the next 5 -10 years "EMI compliance and analysis measurements with an FFT-based measuring receiver" looks at how automotive EMI testing is complex and time consuming with an increasing number of potential interferes in an EV. The FFT-based Time Domain Scan increases measurement speed of the EMI receiver. Additionally, it offers functions to find and analyse interferences in the vehicle. The talk presents FFT theory and applies it with practical examples. Regulatory changes with EMC standards in CISPR 25 and ISO 11452-2 have led to EMC EV motor testing becoming increasingly necessary for many Automotive OEMs. The variety of e motors available requires different solutions as well as addressing the different applications required of EV motors. Test facilities that work with electric vehicles (EV) or their high voltage (HV) modules should have a HV safety program to keep personnel safe. This workshop will discuss how to develop a HV safety program for testing EVs and their HV modules. The recommended HV safety program will focus on training, safety assessments and internal audits. Training is required to ensure personnel have the competence to perform HV activities; safety assessments are used determine the risk of being shocked, electrocuted, or experiencing an arc flash; and internal audits are used to confirm the test facility is compliant with its HV safety program. Workshop attendees will be given enough information and examples to help them create a HV safety program for their own test facility. In parallel the connected car with its plethoral of associated technologies including ADAS continues to advance the autonomous driving experience. " Radar + EMC" will look at Radar immunity and the challenges in testing automotive radar under stress and finally "ADAS + EME" will look at Electro Magnetic Environment (EME) scenario testing including the recording of RF signals in the environment, replay of recorded signals in the lab and the challenge of leveling, amplifier protection, PAPR, signal library and signal handling.

EV Motor Testing to CISPR 25
Martin Wiles
Albatross Projects GmbH, United Kingdom

Creating a High Voltage Safety Program for Testing Electric Vehicles and their Modules
Matt Jackson
DENSO International America, Inc., USA

EMI Compliance and Analysis Measurements with an FFT-Based Measuring Receiver
Tobias Groß
Rohde & Schwarz GmbH & Co. KG, Germany

Full Vehicle Electromagnetic Susceptibility Testing of Automotive Radar
Holger Gryska
Rohde & Schwarz, Germany

Safety of ADAS in Vehicles under EME Influences
Albert Lee
Rohde & Schwarz Asia Pte Ltd, Singapore

WORKSHOP & TUTORIALS WT-THU-2

EMC TESTING BASICS – PART 2

EMC EDUCATION

Chair: Janet O'Neil, *ETS-Lindgren, Cedar Park, TX, USA*
Co-Chair: Dan Hoolihan, *Hoolihan EMC Consulting, Lindstrom, MN, USA*

Due to the popularity of this tutorial when it was presented for the first time at the 2020 IEEE EMC+SIPI Virtual Symposium, we have brought it back with the original speakers and topics (updated for 2021)! This tutorial will cover basic topics in EMC testing – from designing a new laboratory or test capability to achieving accreditation. Presentations will provide practical information and real-world knowledge that can be immediately implemented. 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 assessing EMC test facilities. Attendees will quickly learn the best practices in each topic area. Join us and you'll see why this tutorial was included in the top five highest attended workshop/tutorial sessions at the 2020 IEEE EMC+SIPI Virtual Symposium. NOTE: This tutorial is designed as a two-part session. For a complete discussion of the topic, attendees should hear the presentations in EMC Testing Basics - Part 1 tutorial.

Calibration of EMC Test Equipment
Doug Kramer, *ETS-Lindgren Inc., USA*

Radiated Emissions Measurement Instrumentation Uncertainty Budget
Bob DeLisi, *UL LLC, USA*

Selecting External EMC Testing Labs
Daniel D. Hoolihan,
Hoolihan EMC Consulting, USA

Bench-Top EMC Testing
Jerry Meyerhoff, *JDM Labs LLC, USA*

What are EMC Tests Actually Measuring?
Todd H. Hubing, *LearnEMC, LLC, USA*

ASK THE EXPERTS

THURSDAY, 5 AUGUST
1:30 – 2:30 PM EDT

INPUT/OUTPUT BUFFER INFORMATION SPECIFICATION (IBIS)

- Randy Wolff, *Chair IBIS Open Forum, Micron Technology, Boise, ID, USA (Moderator)*
- Bob Ross, *Treasurer IBIS Open Forum, Teraspeed Labs, Portland, OR, USA*
- Lance Wang, *Vice-Chair IBIS Open Forum, Zuken, Boston, MA, USA*
- Wei-hsing Huang, *Principal R&D Engineer, ANSYS, Vancouver, WA, USA*

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 "Ask the Experts" panelists consists active members of the IBIS Open Forum and represents a diversity of integrated circuit manufacturers.

WORKSHOP & TUTORIALS WT-THU-3

HPEM EFFECTS ON ELECTRONIC SYSTEMS

EMP/IEMI

Chair: Frank Sabath, *Bundeswehr Research Institute for Protective Technologies and NBC Protection, Garstedt, Germany*

Intentional EMI is becoming more and more a threat to modern society because the availability of I-EMI is increasing, while modern electronic systems are becoming more vulnerable. Due to the widespread use of wireless systems this risk is increasingly important. Our civil infrastructures depend on the use of modern communication systems, and several research projects have been recently been carried out. In this tutorial we will give an overview of high-power and low-power I-EMI threats, the risks to civil infrastuctures and preventive actions.

High-Power Electromagnetic (HPEM) Environments
D.V. Giri[1,2]
[1]Pro-Tech, USA; [2]University of New Mexico, USA

HPEM Effects Mechanism
Frank Sabath[1,2]
[1]Bundeswehr Research Institute for Protective Technologies and NBC Protection, Germany; [2]Leibniz Universität Hannover, Germany

HPEM Testing and Protection
Richard Hoad
QinetiQ, United Kingdom

WORKSHOP & TUTORIALS WT-THU-4

ACHIEVING ESD ROBUSTNESS THROUGH SYSTEM EFFICIENT ESD DESIGN SIMULATION

Chair: David Pommerenke, *Technische Universitat Graz, Graz, Austria*

Traditionally, TVS components have been selected based on data sheet specifications. However, the maximum voltage levels that I/Os can handle have been reduced and the design window for high-speed I/O is very narrow such that a data sheet based approach may fail. Voltage margins are often less than 3 V and maximum currents are less than 2A. This must be achieved while ensuring SI up to 20GHz and avoiding harmonics in the RF range. To overcome this, and to be able to use TVS also to reduce soft-failures, a simulation-based approach is required. The Industry Council for ESD Target Levels has named this process “System Efficient ESD Design SEED.” It is based on characterizing the three main influencing components in a system: - Passive interconnect - IC and its internal ESD protection These models can be used to simulate the interaction of the components for different stimuli, e.g. contact mode ESD, cable discharge or slower rising air discharge at higher voltages. The tutorial will explain this method in detail and provide examples. This will allow engineers to- Understand the overall concept of SEED and its motivation. perform and understand TVS characterization - understand the capabilities and limitations of models - understand the complex interactions between snap-back components Three lectures will cover TVS devices, characterization, modeling, and combined system-level simulation.

Achieving ESD Robustness through System Efficient ESD Design Simulation
David Pommerenke
Technische Universität Graz, Austria

WORKSHOP & TUTORIALS WT-THU-5

THEORY, TECHNIQUES AND APPLICATIONS OF EMI/EMC IN MODERN POWER ELECTRONICS

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

Applications of modern power electronics have become very popular in the last decades in the applications such as electrification of transportation, consumer electronic product, residential and industry applications, energy, and medical applications, etc. Almost all modern electronic products use power converters. A power electronics system generates significant electromagnetic interference (EMI) due to high current and high voltage switching. The EMI has been headache problems for both power electronics and EMC engineers. The trial-and-error method, which is inefficient and time-consuming, is usually employed in the EMI debugging and suppression in power electronics and EMC industries. As a result, the EMI reduction is costly and the EMI filters are bulky and heavy. To help power electronics and EMC engineers understand EMI/EMC in power electronics systems, and based on the popular hot application topics, we submit a tutorial proposal based on 6 tutorial presentations (presenters are from both academia and industry) across two big tutorial sessions.

Pulse-Width-Modulation: With Freedom to Optimize EMI
Dong Jiang
Huazhong University of Science and Technology, China

Networks with High Penetration of Power-Electronics Converters: EMC Issues and Upcoming Standardization
Luca Dalessandro[1], Dominique Roggo[2]
[1]ETIX, Switzerland; Hes-so Valais Wallis, Switzerland

Differential Mode and Common Mode Active EMI Filter Modeling, Design and Control for AC/DC, DC/DC and DC/AC Power Converters
Shuo Wang
University of Florida, USA

Model-Based EMI Prediction for Power Electronics and use Cases in IC Design
Zheng Luo
Monolithic Power Systems, USA

WORKSHOP & TUTORIALS WT-THU-6

EMERGING TECHNOLOGIES: THE IMPACT OF MODERN ROBOTICS, DATA ANALYSIS, AND CEM SIMULATION ON ANTENNA AND EMC MEASUREMENTS IN 2021 AND BEYOND!

Chair: Dennis Lewis, *The Boeing Company, Seattle, WA, USA*
Co-Chair: Zhong Chen, *ETS-Lindgren, Cedar Park, TX, USA*

Today's EMC and Antenna Pattern Measurements are increasingly complicated and time consuming to perform. From small wireless devices such as cell phones to large devices such as full vehicles and airplanes, accurate and precise measurements are essential to confirm products perform as intended and comply with industry standards as well as regulations. These product examples are increasingly sophisticated with their widespread use of sensors and wireless technologies, often in an increasingly smaller footprint of the overall product. This tutorial presents these challenges and reviews a real-world solution. We start with a review of the complexity and challenges presented by testing modern passenger aircraft outfitted with hundreds of antennas that facilitate wireless connectivity, among other applications. A solution to address these test challenges will be reviewed in the form of a novel, robotic test system. 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. We'll provide an overview of this approach for an antenna measurement test range were model based systems engineering and development approaches can be employed to dramatically reduce the time, effort, and cost associated with the test development and validation phases of a given program. Next, we'll investigate the challenge of calibrating antennas. It is difficult to calibrate antennas in an anechoic chamber down to the VHF frequency range because absorbers do not perform adequately at these frequencies. A study will be shared on calibrating broadband biconical antennas from 75 MHz to 2 GHz in a chamber designed for above 1 GHz measurements. The tutorial will conclude with a discussion on how model-based systems engineering improves the design and optimization of antenna measurement and calibration systems. Through complementary numerical techniques such as the finite element method (FEM), integral equations (IE), finite element boundary integral (FEBI), as well as shooting and bouncing rays (SBR), one can gain significant insight on performance even before the measurement facility is constructed or the system fully configured. This new type of testing may be applied to EMC and 5G test applications as well.

Simplifying Time-Consuming Measurements to Improve Efficiency and Accuracy
Dennis Lewis
The Boeing Company, USA

Traditional to Modern Antenna Test Environments: Overview of a New Dual Multi-Axis Robotic Antenna Test System Highlighting the Impact of Modern Robotics and CEM Simulation
Stuart Gregson
Next Phase Measurements, USA

Extending the Usable Low Frequency Range of an Anechoic Chamber for Antenna Calibrations using a Time Domain Deconvolution Filter
Zhong Chen
ETS-Lindgren, USA

An Overview of Hybrid Computational Techniques for Antenna Measurement System Design
Jason Bommer
ANSYS, Inc., USA

WORKSHOP & TUTORIALS WT-THU-7

APPLICATION OF REVERBERATION CHAMBERS

Chair: Vignesh Rajamani, *Exponent Inc, Phoenix, AZ, USA*

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
Vignesh Rajamani[1], Gus Freyer[2]
[1]Exponent Inc., USA; [2] Consultant, USA

Absorbing Materials – Reverberation Chamber Assessments
Chuck Bunting
Oklahoma State University, USA

Electromagnetic Probability-of-Effect Assessment Tool (EMPAT) for High-Power HERO/EMV Test and Evaluation
Carl Hager IV
Naval Surface Warfare Center, USA

Application of Reverb Chambers
Garth D'Abreu
ETS-Lindgren, USA

Flexible Testing: Shaken, not Stirred
Frank Leferink[1,2]
[1]University of Twente, The Netherlands; [2]Thales Nederland B.V., The Netherlands

WORKSHOP & TUTORIALS WT-THU-8

OVERVIEW OF THE P2716 WG – IEEE GUIDE FOR THE CHARACTERIZATION OF THE SHIELDING EFFECTIVENESS OF BOARD LEVEL SHIELDING

STANDARDS

Chair: Davy Pissoort, *Katholieke Universiteit Leuven, Bruges, Belgium*
Co-Chair: John F. Dawson, *University of York, York, United Kingdom*

This tutorial wants to disseminate the results obtained so far by the IEEE P2716 working group to a broad audience. As a reminder we repeat the scope and purpose of IEEE P2716 below: Scope: The scope of this guide is to provide manufacturers and users of board level shielding with appropriate methods for the characterization of the shielding effectiveness of the board level shields themselves as well as the way they are mounted on the printed circuit board. This document will guide the user in the selection of the appropriate test method in order to determine the level of shielding provided in the intended application. Purpose: To supplement the work done in e.g IEEE 299, IEEE 299.1 which both cover stand-alone enclosures with dimensions larger than 10 cm. This document provides a standard set of methods and procedures for determining the shielding effectiveness of board-level shields.

Introduction to the IEEE P2716
Davy Pissoort
Katholieke Universiteit Leuven, Belgium

What makes Characterizing the SE of Board Levels Shields so Challenging?
Andy Marvin, John Dawson
University of York, United Kingdom

Nested Reverberation Room
L. Bastianelli, F. Moglie, V. Mariani Primiani
Università Politecnica delle Marche, Italy

Single Reverb Room
John Dawson[1], Andy Marvin[1], Brian She[2]
[1]University of York, United Kingdom; [2]Laird, USA

Double Reverb/VIRC
Robert Vogt-Ardatjew[1], Frank Leferink[1,2]
[1]University of Twente, The Netherlands; [2]Thales Nederland B.V., De Lutte, Netherlands

GTEM Cell
Dominic Härke, Cornelia Reschka, Heyno Garbe
Leibniz Universität Hannover, Germany

The Stripline Method for Characterizing Board Level Shields
Davy Pissoort, Tim Claeys, Johan Catrysse
Katholieke Universiteit Leuven, Belgium

IEEE P2716 Round Robin Overview
Davy Pissoort[1], John Dawson[2]
[1]Katholieke Universiteit Leuven, Belgium; [2]University of York, United Kingdom

WORKSHOP & TUTORIALS WT-FRI-1

MODERN AUTOMOTIVE EMC TECHNOLOGY – ENSURING SAFETY AND RELIABILITY

AUTOMOTIVE

Chair: Garth D'Abreu, *ETS-Lindgren, Cedar Park, TX, USA*
Co-Chair: Robert Kado, *Chrysler Group LLC, Auburn Hills, MI, USA*

Automotive EMC Technology continues to dramatically move forward with the growing acceptance of increasingly autonomous-operated vehicles. At the same time, there is growing concern about the safety of these vehicles with their sophisticated levels of advanced driver assistance systems (ADAS) capabilities. ADAS features, including adaptive cruise control, autonomous emergency breaking, lane departure warning systems, and blind spot warning, to name a few, are standard features drivers have come to expect. Some of these features are mandatory requirements for new production vehicles manufactured in Europe. Connectivity is also becoming a more prevalent component of the increasingly autonomous vehicle. Attendees of this tutorial will learn about the latest challenges facing automotive OEMs as well as those that design automotive EMC/Antenna Pattern Measurement (APM) test chambers, and those that offer commercial automotive EMC test services. Novel solutions to these challenges will be presented, including a discussion on utilizing software to complement automotive component EMC R&D. The tutorial presents different perspectives – both current and future - on modern Automotive EMC/APM Technology.

Low Frequency Electromagnetic Field Exposure in Automotive Environment
Nevin Altunyurt
Ford Motor Company, USA

Model-Based System-level Simulation for Automotive EMI/EMC
Dipanjan Gope[1,2]
[1]Indian Institute of Science, India; [2]Simyog Technology Pvt. Ltd.

EMC and SI Challenges with SerDes Camera Systems for Automotive Driver Assisted Technologies
Keith Frazier
Ford Motor Company, USA

Automotive Test Advances
Garth D'Abreu
ETS-Lindgren, USA

Automotive EMC Test Challenges and Solutions – A Commercial Test Lab's Perspective
Juan Carlos Soler
DEKRA, Germany

6 AUGUST • 10:00 - 10:30 AM

RE-IMAGINING 3D EM EXTRACTION WITH CLARITY 3D SOLVER

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WORKSHOP & TUTORIALS WT-FRI-2

LEARN EMC NOW! FOR THE SELF-LEARNER OR THE CLASSROOM

EMC EDUCATION

Chair: Keith Armstrong, *Cherry Clough Consultants Ltd, Stafford, United Kingdom*

Every year a new generation of engineers start work for the first time. they have received any education relating to the EMC their work will – these days – require them to deal with, the chances are that it dealt more with electromagnetic theory (i.e. mathematics), than with anything practical or relevant to their work. Experienced design engineers may also require vocational training in EMC, because the continually increasing EMC requirements in all aspects of modern electronic engineering mean they must now deal with EMC as part of their 'day job', instead of leaving it to a couple of EMC specialists in an EMC test lab at the end of the project. Where employers are unable or unwilling to themselves provide the necessary vocational training in EMC, these engineers must learn on-the-job. Unfortunately, this can have highly variable results, and can even cause costly delays to project timescales (at least). This tutorial provides many well-proven and free (or at least low-cost) resources to help these engineers get up to speed with the EMC requirements of their work as quickly and easily as possible. It also details some very cost/time-effective low-cost EMC bench testing techniques that have long been used by EMC specialists, that can be easily learned by any practicing engineer and used to help de-risk EMC during all stages of design and development projects. These resources are eminently suitable for use by:

- Individual engineers, for self-training
- Employers, in their in-house EMC training programs
- Educational and training establishments of any type:
  - As parts of academic engineering courses
  - In vocational 'continuing education' courses intended to up-skill their local engineering communities of engineers and employers.

Resources for EMC Fundamentals
Keith Armstrong
Cherry Clough Consultants Ltd., United Kingdom

Developing and using a Low-Cost EMC Probe Kit Suitable for Personal/Workplace Use
Keith Armstrong
Cherry Clough Consultants Ltd., United Kingdom

Teaching EMC using an EMC Demonstration Unit
A. Degraeve[2], T. Claeys[1], F. Vanhee[1], J. Peuteman[1], D. Pissoort[1], K. Armstrong[2]
[1]Katholieke Universiteit Leuven, Belgium; [2]Cherry Clough Consultants Ltd., United Kingdom

Quick turnaround PCBs
Louann Mlekodaj
Shure, Inc., USA

Demonstrations of EMC Concepts using a Learning Kit from the EMC Society
Kris M Hatashita
Department of National Defence and the Canadian Armed Forces, Canada

WORKSHOP & TUTORIALS WT-FRI-3

RECENT ADVANCEMENTS IN HEMP, EMP, AND IEMI PROTECTION – A GLOBAL PERSPECTIVE

EMP/IEMI

Chair: Joel Kellogg, *ETS-Lindgren, Austin, TX, USA*
Co-Chair: D. V. Giri, Ph.D., *Pro-Tech and University of New Mexico, USA*

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 EMP and IEMI and to identify cost effective yet viable protection solutions to EMP and IEMI threats. 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, academia, and government, who will discuss their respective R&D activity on EMP/HEMP/IEMI currently underway in China, Europe, and the Middle East.

EMP and IEMI Mitigation Strategies
Joel Kellogg
ETS-Lindgren, USA

EMP Mitigation for Electrical Substations
Eric Easton
CenterPoint Energy, USA

Transient SPICE Model of Gas Discharge Tube based on Experimental Data
Xie Yanzhao, Li Zetong
Xi'an Jiaotong University, China

Early-Time HEMP Conducted Environment
Nicolas Mora[1], Farhad Rachidi[2]
[1]Technology Innovation Institute, United Arab Emirates; [2]Swiss Federal Institute of Technology, Switzerland

Tolerance Values and Confidence Level of HEMP System Tests
Frank Sabath
Bundeswehr Research Institute for Protective Technologies and NBC Protection, Germany

WORKSHOP & TUTORIALS WT-FRI-4

LESSONS LEARNED CREATING RELIABLE COMPUTATIONAL MODELS FOR SI AND EMC APPLICATIONS

Chair: Colin Brench, *IEEE, Stow, MA, USA*
Co-Chair: Bruce Archambeault, *International Business Machines Corp, Four Oaks, NC, USA*

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 then 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
Bruce Archambeault
Missouri University of Science and Technology, USA

What I Wish I Knew about EMC Simulation when I First Started
Scott Piper
General Motors Corporation, USA

Lessons Learned while Studying the ESD Behavior and Shielding Performance of IT Equipment
Samuel Connor, Jacob Dixon
IBM Corporation, USA

Current Jumping Reference Planes: Exploring Physics and Engineering Design through EM Modeling
Yifan Ding[1], Harsh Shrivastav[2], Siqi Bai[3], Zach Legenzoff[4], Bruce Archambeault[5], Richard Zai[6], Baolong Li[7], James L. Drewniak[5]
[1]Cisco Systems, Inc., USA; [2]ANSYS, Inc., USA; [3]Facebook, Inc., USA; [4]National Nuclear Security Administration, USA; [5]Missouri University of Science and Technology, USA; [6]PacketMicro, Inc., USA; [7]Cadence Design Systems, Inc., USA

Aircraft Lightning Testing and Simulation: Lessons Learned about Validation
Cody Weber
University of Colorado Boulder, USA

11:00 - 13:00 EDT

WORKSHOP & TUTORIALS
WT-FRI-5A

THEORY, TECHNIQUES AND APPLICATIONS OF EMI/EMC IN MODERN POWER ELECTRONICS

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

Applications of modern power electronics have become very popular in the last decades in the applications such as electrification of transportation, consumer electronic product, residential and industry applications, energy, and medical applications, etc. Almost all modern electronic products use power converters. A power electronics system generates significant electromagnetic interference (EMI) due to high current and high voltage switching. The EMI has been headache problems for both power electronics and EMC engineers. The trial-and-error method, which is inefficient and time-consuming, is usually employed in the EMI debugging and suppression in power electronics and EMC industries. As a result, the EMI reduction is costly and the EMI filters are bulky and heavy. To help power electronics and EMC engineers understand EMI/EMC in power electronics systems, and based on the popular hot application topics, we submit a tutorial proposal based on 6 tutorial presentations (presenters are from both academia and industry) across two big tutorial sessions.

Wide Band Gap Devices and its related EMC Issues in Power Electronics
Wenjie Chen
Xi'an Jiaotong University, China

EMI Diagnostics – A Solution not a Problem
Mark Scott
Miami University, USA

11:00 - 15:30 EDT

WORKSHOP & TUTORIALS
WT-FRI-6

MMWAVE DEVICES: 5G TEST CHALLENGES AND SOLUTIONS

Chair: James Young, *ETS-Lindgren, Cedar Park, TX, USA*
Co-Chair: Clive Bax, *Bureau Veritas, Santa Clara, CA, USA*

As the wireless industry continues to work towards development and deployment of 5G new radio technology, the wireless test and measurement industry is working to develop the required test and measurement capabilities to ensure that these products perform as intended. In order to develop the optimal test and measurement methodology, it is helpful to have an understanding of mmWave antennas, how they are designed and function, as well how/if their performance is impacted by various usage and/or test environments. We begin the tutorial with a presentation on the mmWave antennas themselves to understand the complexity and nuances of this influential component of wireless devices. The impact of the antenna on end-user products will be discussed. Are you aware of the impact the clothes you're wearing may have on your cell phone performance? The materials used for your home or office building may also impact the use of your 5G FR2 device. We will discuss the impact of clothes and other common everyday materials on real-world mmWave performance. Another often overlooked factor that may influence testing of mmWave devices is the actual positioning equipment used. We'll review the impact of positioning equipment and support structures during the testing of wireless devices for performance verification. The tutorial will conclude with a review of the current activity underway in the mmWave Task Group of ANSI C63. Attendees will learn why this group was formed, the FCC KDB guidance that was published in parallel and based on the work of this group, and gain an understanding of how this group collaborates with industry, test labs, TCBs, and regulators (FCC in the US and ISED in Canada).

Challenges and Solutions in Designing mmWave Antennas
Katerina Galitskaya, Jari Van Wonterghem
Radientum, Finland

The Impact of Everyday Materials on mmWave Performance
Jari Vikstedt, Cindy Xie
ETS-Lindgren, USA

Minimizing the Impact of Positioning Equipment and Support Structure on 5G mmWave Device Testing
Michael D. Foegelle
ETS-Lindgren, USA

mmWave Joint Task Group Work within ANSI C63
Robert Paxman
Intel Corporation, USA

WORKSHOP & TUTORIALS WT-FRI-7

UPDATE ON KEY ANSI C63 STANDARDS ON EMC – A TRIBUTE TO DON HEIRMAN'S CONTRIBUTIONS TO ANSI C63.4

STANDARDS

Chair: Janet O'Neil, *ETS-Lindgren, Cedar Park, TX, USA*
Co-Chair: Dan Hoolihan, *Hoolihan EMC Consulting, Lindstrom, MN, USA*

This tutorial will cover several key EMC Testing Standards as well as three fundamental Wireless Testing Standards. Presenters will be EMC Engineers heavily involved in the development of the standards. We begin with a review of the seminal ANSI/IEEE C63.4 "Test Methods for Low-Voltage Equipment". This will be discussed from two perspectives; first, the history of the C63.4 Standard will be outlined with a review of the decades of contributions to the standard by the late Don Heirman. Second, the current on-going revision of the standard will be discussed by the working group chair. We will also address the seminal EMC Antenna Standard ANSI/IEEE C63.5. This standard is currently undergoing a revision as well; the chair of the working group responsible for this "antenna calibration standard" will be the technically competent lecturer. The Wireless Testing part of the tutorial will being with ANSI/IEEE C63.10 (Unlicensed Wireless Devices); this recently published standard will be analyzed by the chair of the working group that developed the standard which is being transmitted to the Federal Communications Commission with a recommendation to incorporate it into the FCC Rules. The second major wireless standard to be discussed is ANSI/IEEE C63.26 (Licensed Wireless Devices). The 2015 version of the standard will be highlighted as well as proposed changes being discussed for the current revision of the standard. Finally, the NEW wireless standard ANSI/IEEE C63.30 will be reviewed and explained by the chair of the working group that developed the standard.

Update on Key ANSI C63 Standards on EMC – A Tribute to Don Heirman's Contributions to C63.4
Daniel David Hoolihan
Hoolihan EMC Consulting, USA

ANSI C63.5-2017
Doug Kramer
ETS-Lindgren Inc., USA

ANSI/IEEE C63.10: Procedures for Compliance Testing of Unlicensed Wireless Devices
Jason Nixon
The Certification and Engineering Bureau of Innovation, Science and Economic Development Canada, Canada

Overview of C63.26 -American National Standard for Compliance Testing of Transmitters Used in Licensed Radio Services
Bob DeLisi
UL LLC, USA

WPT, Emerging Applications, & ANSI C63.30
Travis M. Thul
ANSI C63.30 Working Group, USA

Draft ANSI C63.4:202? A Review
Andy Griffin
Cisco Systems Inc., USA

WORKSHOP & TUTORIALS WT-FRI-8A

EMC TESTING AND EMI MITIGATION FOR SAFETY CRITICAL AEROSPACE SYSTEMS

Chair: Reinaldo Perez, *NASA, Jet Propulsion Laboratory, Denver, CO, USA*
Co-Chair: Irfan Majid, *Institute of Space Technology, Islamabad, ICT, Pakistan*

Functionally Airborne Electronics Hardware is divided into five categories according to safety criticality of function it performs. Systems whose failure would prevent the continued safe flight of aircraft are categorized as flight critical (Level "A") and their failure conditions are termed as Catastrophic. Electromagnetic Compliance (EMC) testing methodology, especially for High Intensity Radiated Fields (HIRF) and lightning protection certifications, follows a different methodology as compared to other electrical / electronic systems on board an aircraft. This tutorial will cover the recommended HIRF & Lightning Certification methodology in accordance with SAE ARP-5583 & FAA AC 20-158A recommended practices. Fly-by-Wire flight control system will be considered as representative safety critical system. Main focus will be on Low Level Coupling tests as they simplify the measurement set ups and are much more economical, though this comes at the cost of increased computational complexities to determine test levels. Carrying out these computations analytically and through simulations will be covered comprehensively. Finally, guidelines for better EMI protection in flight critical systems that help avoid failures in EMC certification, will be presented. Contents Effect of EMI in flight critical Systems Overview of Fly-by-Wire Flight Control System Aircraft Electromagnetic Environment Review of ARP-5583 and AC 20-158A HIRF Certification methodology for Level "A" systems Low Level Coupling (LLC) tests for HIRF Certification Computation/Simulations for test levels for LLC tests EMI protection guidelines for Flight Critical Systems.

EMC Testing and EMI Mitigation for Safety Critical Aerospace Systems
Reinaldo J. Perez[1], Irfan Majid[2]
[1]NASA Jet Propulsion Laboratory, USA; [2]Institute of Space Technology, Pakistan

EMC Testing and EMI Mitigation for Safety Critical Aerospace Systems
Irfan Majid[1], Reinaldo Perez[2]
[1]Institute of Space Technology, Pakistan; [2]NASA Jet Propulsion Laboratory, USA

WORKSHOP & TUTORIALS
WT-FRI-9

EMC COMPLIANCE TECHNIQUES FOR SILICON CARBIDE (SIC) POWER CONVERTERS

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

This tutorial is a comprehensive guide to provide engineers with the fundamental understanding of electromagnetic compatibility (EMC) issues associated with the use of Silicon Carbide (SiC) power semiconductors in switch-mode applications. Practical design techniques are presented that help the attendees understand the real-world issues and high frequency techniques necessary to successfully meet the EMI requirements. The seminar provides the necessary EMI theory for SiC power electronics, a new "SOLVE" EMC design flow for SiC power converters, and practical design, construction, and measurement techniques. Practical lessons provide a blueprint for successfully meeting EMI with SiC power converter products. The first section presents the necessary EMI fundamentals for SiC power converter design. Measurement techniques for common-mode (CM) and differential mode (DM) currents, and the circuitry to perform the critical CM/DM separation measurements. The concept of impedance mismatch is presented as a basis for understanding filtering concepts. Practical filter layout methods are presented with measured results demonstrating the advantages of a well-constructed design. The EMI impact of using SiC power semiconductors is compared with the use of traditional Silicon (Si) power semiconductors. The second segment focuses on a comprehensive 5-step EMC design flow for SiC power converters: "SOLVE". This design flow begins with considerations on electing proper architectures based upon system ratings and EMC specifications. The next steps develop techniques for obtaining component parasitics and layout for the system EMI model. Setting of different filter design aspects include magnetic material selection, structure, and practical filter performance. The last step presents techniques and principles for packaging enhancement. The third section provides examples from practical design techniques and lessons learned for SiC power converter product development. Characterization and importance of parasitics associated with some commonly used passive components are presented and correlated with typical power conversion packaging. These EMC techniques have been successfully used to meet critical EMC requirements for kW to MW applications.

EMC Compliance Techniques for Silicon Carbide (SiC) Power Converters
Michael Schutten[1], Cong Li[2], Predrag Hadzibabic[2]
[1]Schutten Technical Consulting LLC, USA; [2]General Electric, USA

"SOLVE" EMC Design Flow for SiC Power Converters
Cong Li
GE Global Research, USA

Practical Design Techniques and Lessons Learned for SiC Power Converter Product Development
Predrag Hadzibabic
GE Aviation Systems, USA

WORKSHOP & TUTORIALS
WT-FRI-8B

EMC TEST AND DESIGN FOR CABLES AND CONNECTORS

Chair: Huadong Li, *Molex LLC, Naperville, IL, USA*
Co-Chair: Charles Jullien, *Safran Electrical and Power, Blagnac, France*

This workshop will give a general introduction to cable construction, termination and grounding for product EMC. A new test vehicle is proposed for cable and connector assembly EMC testing. Common existing EMC characterization methods for cable and connector shielding will be generalized. Examples of using EMC simulation to control connector radiated emissions and help on harness EMC design will be demonstrated. Approaches of using various cable connector parameters in simulations tools to facilitate cable and connector design for effects such as lightning and HEMP will be described. The tutorial is divided into topics as: Proper Cable Construction and Shielding Termination Techniques; A New Vehicle for Cable and Connector Assembly EMC Testing; EMC Design for an I/O Connector; Using Simulation Tools to Facilitate Cable and Connector Design; Harness EMC Design by Simulation and Validation by Experiment. The workshop will help the audience to properly test and design cables, connectors and their assemblies for product EMC.

Prediction of Interference Coupling into Victim Circuits via the Cable/Connector Assembly
John G. Kraemer
Collins Aerospace, USA

SCHEDULE AT A GLANCE

WEEK 3: AUGUST 9 - 13

MONDAY, 9 AUGUST

10:00 AM- 11:00 AM	Sponsored Technical Presentation by AR RF/Microwave Instrumentation (Ends at 10:30 AM)			TC12 - EMC for Emerging Wireless Technologies		SC1 - Special Committee on Smart Grid		SC5 - Power Electronics EMC
10:30 AM - 11:00 AM	Advanced Test Equipment Rental Break Session							
11:00 AM- 1:00 PM	Keynote - On-Site Measurements of Terrestrial Navigation and Radar Signals Using Drones and A Research Aircraft by Thorsten Schrader							
		TP-MON-2B	TP-MON-3B	TP- MON- 4B	TP-MON-5B	TP-MON-6B	TP-MON-7B	TP-MON-8B	
1:30 PM- 3:30 PM		EMC Management – EMC Effects	Electromagnetic Environments isn Safety Critical Situations	Testing Techniques and Shielding Principles of Systems	Machine Learning/Cloud Computing 1	Computational Electromagnetics I	Printed Circuit Board Technology and SI Design 2	Power Electronics EMI Control via Optimal Modulation and Driving Schemes	

TUESDAY, 10 AUGUST

10:00 AM - 12:30 PM	Sponsored Technical Presentation by AR RF/Microwave Instrumentation (Ends at 10:30 AM)					TC 7 - Low Frequency EMC		TC 10 - Signal and Power Integrity	
10:30 AM - 11:00 AM	PMM-L3HARRIS-NARDA Break Session								
	TP-TUE-1A	TP-TUE-2A		TP-TUE-4A	TP-TUE-5A	TP-TUE-6A	TP-TUE-7A	TP-TUE-8A	SS-TUE-A
11:00 AM - 1:00 PM	Emissions	Calibration		Space EMC	IEMI Generators and Modeling	Power Integrity Analysis and Design 2	Power Electronics EMI Modeling and Measurement II	Passive Component Modeling & Measurement Techniques	EMC Diagnostics of Complex Systems
1:00 PM- 1:30 PM	AR RF/Microwave Instrumentation Break Session								
	TP-TUE-1B	TP-TUE-2B	TP-TUE-3B	TP-TUE-4B	TP-TUE-5B	TP-TUE-6B	WT-TUE-7B	TP-TUE-8B	SS-TUE-B
1:30 PM- 3:30 PM	Cables and LISN	Electromagnetic Environments in Mobile and Transportation	Conducted Emissions	Testing and EMC Application of Composite Materials	Coexistence of Wireless Systems	SI/PI/EMC Co-Simulation and Co-Design	Active and Passive EMI Filter Techniques	Jitter/Noise Modeling and Analysis	EMC Diagnostics of Complex Systems

WEDNESDAY, 11 AUGUST

10:00 AM- 11:00 AM	Sponsored Technical Presentation by EMC Partner (Ends at 10:30 AM)					TC 9 - Computational Electromagnetics		TC 11 - Nanotechnology and Advanced Materials	
10:30 AM- 11:00 AM	EMC Partner Break Session								
		TP-WED-2A	TP-WED-3A		TP-WED-5A	TP-WED-6A	TP-WED-7A	TP-WED-8A	SS-WED-A
11:00 AM - 1:00 PM		Reverberation	Measurement and Characterization of Electromagnetic Environments		Near Field Systems for Evaluation of Wireless Systems	Numerical Modeling and Simulation Techniques 2	Power Electronics EMI Modeling and Measurement I	High-Speed Link/Bus Design 2	Advanced Methods to Model, Evaluate, and Measure Electromagnetic Interference at Low Frequency in Transportation and Renewable Energy Systems
	TP-WED-1B	TP-WED-2B	TP-WED-3B	TP-WED-4B	TP-WED-5B	TP-WED-6B	TP-WED-7B	TP-WED-8B	SS-WED-B
1:30 PM- 3:30 PM	Antennas and Analysis	Chambers	2.5D/3D/Exotic ICs/Packing and Emerging Technologies	Cables and Connectors Considerations and Testing	Intentional EMI and HEMP	Power Integrity Analysis and Design 3	EMI Issues in Electric Vehicle Charging	Numerical Modeling and Simulation Techniques 1	Advanced Methods to Model, Evaluate, and Measure Electromagnetic Interference at Low Frequency in Transportation and Renewable Energy Systems

THURSDAY, 12 AUGUST

9:00 AM- 10:00 AM	Women in Engineering - EMCS								
10:00 AM- 10:30 AM	Sponsored Technical Presentation by AR RF/Microwave Instrumentation								
10:30 AM- 11:00 AM	Wurth Elektronik eiSos GmbH & Co. KG Break Session								
	TP-THU-1A	TP-THU-2A	TP-THU-3A	TP-THU-4A	TP-THU-5A	TP-THU-6A	TP-THU-7A	TP-THU-8A	SS-THU-A
11:00 AM - 1:00 PM	Power Systems	Automotive	Advanced Methods to Model, Evaluate, and Measure Electromagnetic Interference at Low Frequency in Transportation and Renewable Energy Systems	Transportation EMC	EM Information Leakage and Lightning	Computational Electromagnetics II	Machine Learning/Cloud Computing 2	Evaluation and Simulation of EMI in Wireless Systems	Risk-Based EMC
11:00 AM- 3:00 PM	IBIS Summit								
	TP-THU-1B		TP-THU-3B		TP-THU-5B	TP-THU-6B	TP-THU-7B	TP-THU-8B	SS-THU-B
1:30 PM- 3:30 PM	Immunity		Low-Frequency EMC Issues		ESD and Smart Grid IEMI	Aerospace/Automotive Computational	High-Speed Link/Bus Design 1	Aeronautics and Space EMC	Risk-Based EMC
3:30 PM- 4:30 PM	Whisky Appreciation Session								

FRIDAY, 13 AUGUST

9:00 AM - 10:30 AM	IEEE Young Professionals Meeting - Trivia Event								
10:00 AM - 11:00 AM	Sponsored Technical Presentation by AR RF/Microwave Instrumentation (Ends at 10:30 AM)					Experiments & Demos Live Q&A Session (Ends at 10:45 AM)		TC 3 - Electromagnetic Environment	
10:30 AM- 11:00 AM	Schlegel Electronic Materials, Inc. Break Session								
	TP-FRI-1A	TP-FRI-2A	TP-FRI-3A	TP-FRI-5A	TP-FRI-6A	TP-FRI-7A	TP-FRI-8A		SS-FRI-A
11:00 AM - 1:00 PM	Noise, Jitter and Communications	Shielding	Risk-Based EMC	Evaluation and Characterization	Computational Electromagnetics III	Power Integrity Analysis and Design 1	Printed Circuit Board Technology and SI Design 1		Robust Design for System Level ESD: Device, PCB and System Level
	TP-FRI-1B	TP-FRI-3B	TP-FRI-4B	TP-FRI-5B	TP-FRI-6B	TP-FRI-7B	TP-FRI-8B		SS-FRI-B
1:30 PM- 3:30 PM	Near Field Measurements	Risk-Based EMC	4B Circuit EMC Analysis, Testing and Considerations	Radiated EMI Modeling and Reduction for Power Conversion Systems	Transmission Line Computational Electromagnetics	High-Speed Link/Bus Design 3	IBIS based Power Integrity Modeling		Robust Design for System Level ESD: Device, PCB and System Level

VIRTUAL EXHIBIT HALL HOURS

2-6 & 9-13 AUGUST
11:00 AM – 3:30 PM EDT

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KEYNOTE SPEAKER PRESENTATION

MONDAY, 9 AUGUST, 11:00 AM EDT

ON-SITE MEASUREMENTS OF TERRESTRIAL NAVIGATION AND RADAR SIGNALS USING DRONES AND A RESEARCH AIRCRAFT

By Dr. Thorsten Schrader, *Director and Professor, Head of Division Mechanics and Acoustics, Physikalisch-Technische Bundesanstalt (PTB), The National Metrology Institute of Germany*
With contributions from Jochen Bredemeyer, Thomas Kleine-Ostmann, Jens Werner, Jens Wellhausen, and Heyno Garbe

In order to validate the functionality of terrestrial navigation aids and radars as well as their signal integrity in airspace, on-site measurements of these signals are essential. In particular, the question of whether and to what extent wind turbines alter the signals and thus lead to a safety risk has gained great importance due to the expansion of wind turbines in recent years.This question was investigated in the WERAN and WERAN PLUS projects for a number of navigation and radar systems between 500 kHz and 9.3 GHz. Drones were used to measure signals of airport surveillance radars, air surveillance radars and weather radars, localizer and glide path of instrument landing systems as well as very high frequency omnidirectional radio range (VOR). Horizontal beamwidths, side lobe suppression, front-to-back ratio, and near-ground radar coverage can be readily acquired and studied using drones. The flight measurement platforms (FMP) in use are RC octocopters with a flight range of 1 km, an RC hybrid variant copter/airplane (VTOL) with a range of about 100 km, and a Touring Motor Glider research aircraft with a range of over 1000 km. All the necessary data from RF frontends and flight position is synchronized in time and recorded on a SSD.

The measurements in the airspace represent the electromagnetic fields present at a distinct location and their signal structure. This measurement data can be compared well with, for example, numerical full-wave simulations of the fields and signals of VOR, since the same physical quantity is recorded here. A post-processing of this data on a mainframe computer allows one to calculate the target quantity (here the bearing angle error).

The FMP were calibrated on the reference open area test site (OATS) of PTB in Braunschweig using a reflector dipole antenna. Its simulated radiation pattern was measured in several virtual planes at increasing distances with the octocopter. At a distance of 2 km from the OATS and at an altitude of 600 m, it was thus possible to calibrate "real" aircraft or to validate their antenna pattern. Another goal was to develop a simple prediction method for the bearing angle error of Doppler-VOR caused by wind turbines, which runs on a simple PC and delivers the result in a few minutes. This prediction is backed up and validated by on-site measurements and full-wave simulations. *Examples of the available data will be shown and discussed*

ABOUT THE KEYNOTE SPEAKER

ABOUT THORSTEN SCHRADER

Thorsten Schrader (SM'11) was born in Braunschweig, Germany, in 1967. He received the Dipl.-Ing. and Dr.-Ing. Degrees in electrical engineering from the Technical University of Braunschweig, Braunschweig, in 1992 and 1997, respectively. In 1998, he was with EMC Test Systems, L.P., Austin, Texas (now ETS-Lindgren, Cedar Park, Texas). In 1999, Dr. Schrader joined the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, Germany. He started in the working group "High Frequency Measurement Techniques". In 2000, he served the Presidential Staff Office. In 2004, he became head of the working group "Electromagnetic Fields and Electromagnetic Compatibility";. From 2006 to 2011, he was responsible for the Working Group "Antenna Measuring Techniques". In 2019, he became head of the working group "Non-Linear High-Frequency Metrology for Digitalization". Between 2005 and 2020 he directed the department "High Frequency and Electromagnetic Fields". Since May 2020, he is head of the division "Mechanics and Acoustics".

Dr. Schrader has supervised 19 externally funded research projects since 2006. He currently holds six patents in the area of high frequency measurements and communications. In 2015, he received the IEEE Transactions on the THz Science and Technology Best Paper Award of the Microwave Theory and Techniques Society for the contribution "Field Exposure and Dosimetry in the THz Frequency Range," Vol. 4, No.1, pp. 12-25, January 2014.

The Physikalisch-Technische Bundesanstalt, Germany's national metrology institute, is a scientific and technical higher federal authority falling under the competence of the Federal Ministry for Economic Affairs and Energy. It is Germany's highest authority when it comes to correct and reliable measurements.

Founded in 1887, PTB was the first metrology institute worldwide. With its almost 2000 staff members, it is the largest institute in Europe and one of the fifth largest of this type worldwide. Research and development work amounts to 70% of PTB's activities.

Nearly all sectors of Physics are covered to support the International System of Units (realization and dissemination of the physical units), legal metrology, and measurement science. PTB is also providing calibration services for industry to help traceability (several thousand calibrations per year).

TECHNICAL PAPERS TP-MON-2B

EMC MANAGEMENT – EMC EFFECTS

(SPONSORED BY TC-1)

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

13:30 Proposals for Change in Automotive EMC Standardization and Engineering Practices
Alastair R. Ruddle, Anthony J.M. Martin, Mark Emery
HORIBA MIRA Ltd., United Kingdom
Abstract: Current automotive EMC engineering practices have served the industry well over many decades. In more recent years, however, the nature of vehicle electronic systems has begun to develop in ways that are leading to fundamental changes in the nature of road vehicles. The speed and nature of these changes are now becoming such that traditional assurance approaches based on prescriptive standards are beginning to struggle to keep pace with emerging technological changes. It is considered that moving towards the goal-based assurance and risk-based engineering approaches that are already used in other aspects of the engineering of complex systems would provide the basis of more sustainable assurance and engineering processes for automotive EMC engineering in the future.

13:55 Selection Methodology of Risk Assessment Techniques for Electromagnetic Resilience
Acássio Matheus Roque1, Carlos Antonio França Sartori[1,2]
[1]University of São Paulo, Brazil; [2]Pontifícia Universidade Católica de São Paulo, Brazil
Abstract: The growing use of electrical and electronic technologies has intensified the electromagnetic environment at the same time as new technologies tend to be more susceptible to electromagnetic interference (EMI). This is a major concern for the application of electrical and electronic equipment in safetyrelated systems since faults and malfunctioning caused by EMI can affect human and environmental safety. In this context, the achievement of functional safety regarding electromagnetic disturbances, known as electromagnetic resilience, is mandatory to prevent the occurrence of incidents and accidents. The process to reach electromagnetic resilience is based on many steps, in which the risk assessment is one of high importance. Although many risk assessment techniques have been studied and general rules for their selection have been developed, little effort has been done to establish a method to evaluate the suitability of risk assessment techniques for electromagnetic resilience. This paper introduces a proposal for a framework to select risk assessment techniques suitable for electromagnetic resilience. The definition of criteria is based on the literature research concerning the fundamental difficulties encountered in the electromagnetic resilience field. The formulation of the selection problem and the comparison analysis between the selected risk assessment are performed using the Analytical Network Process (ANP) method. To illustrate the methodology, it is performed an application comparing two well-known risk assessment methods: failure mode and effect analysis (FMEA) and failure tree analysis (FTA).

TECHNICAL PAPERS TP-MON-3B

ELECTROMAGNETIC ENVIRONMENTS IN SAFETY CRITICAL SITUATIONS

(SPONSORED BY TC-3)

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

13:30 Near Field Exposure Conditions of UHF-RFID Systems in Smart Healthcare Environments
Silvia Miguel-Bilbao[1], Jose A. Hernandez[2], Oscar J. Suarez[3], Pablo Marina[1], Victor M. Febles[2], Luis E. Rabassa[2], Samuel Suarez[2], Jolanta Karpowicz[4], Patryk Zradzinski[4], Krzysztof Gryz[4], Erik Aguirre[5], Victoria Ramos[1]
[1]Instituto de Salud Carlos III, Spain; [2]Hospital Universitario de Canarias, Spain; [3]Secretaría de Estado de Telecomunicaciones e Infraestructuras Digitales, Spain; [4]National Research Institute, Poland; [5]Universidad Pública de Navarra, Spain
Abstract: Short range wireless RFID technology has many applications in socialcare and healthcare environments, having to coexist with other sources of electromagnetic (EM) radiation and even with patients' implanted devices. This work provides an overview of exposure conditions in near EM field conditions and evaluates this exposure. The near EM field conditions by RFID reader is discussed based on the results of measurements inside an anechoic chamber under strict experimental conditions, and numerical modelling with simulation software. The obtained results were considered with respect to the human EM exposure evaluation principles and exposure limitations provided by the relevant international guidelines and regulations. In areas close to the RFID reader, the local exposure to EM radiation has the near field nature, i.e. the impedance of EM field significantly differs from the far field (free space). Evaluating human exposure requires measurements of the electric and magnetic field strength, or even the numerical modelling of Specific Energy Absorption Rate (SAR). It was found that a near field nature of EM radiation near an RFID reader ranges several times longer when the operator is present nearby, compared to the same emitting device considered alone in the empty space. This is of significance when evaluating EM exposure of humans (patients or health care personnel, especially users of medical implants) if, for any reason, they are less than 50 cm away from an RFID reader, especially when emission from it exceed 2 W.

13:55 Research on Emergency Call System Adaptability to Actual Electromagnetic Environment
Yue Zhang, Yifu Ding, Xu Zhang
China Automotive Technology and Research Center Co., Ltd., China
Abstract: Research on the performance of emergency call system in the actual electromagnetic environment is of great significance to ensure the reliable operation of the system. Based on the analysis of the emergency call system connectivity and communication quality, the actual electromagnetic environment signal collection and playback are carried out, and the connectivity and communication quality of the emergency call system in actual electromagnetic environment are tested and verified. The test results show that some performance indicators of the emergency call system will be affected by the actual electromagnetic environment signal, which provides a reference for the electromagnetic compatibility quality assessment of emergency call system and the formulation of relevant standards.

TECHNICAL PAPERS
TP-MON-4B

TESTING TECHNIQUES AND SHIELDING PRINCIPLES OF SYSTEMS

(SPONSORED BY TC-4)

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

13:30 Imaging Distributed Sources with Sparse ESM Technique and Gaussian Process Regression
Jiangshuai Li, Victor Khilkevich, Ruijie He, Yuanzhuo Liu, Jiahao Zhou
Missouri University of Science and Technology, USA
Abstract: Emission source microscopy (ESM) technique can be utilized for the localization of electromagnetic interference sources in complex and large systems. In this work, a Gaussian process regression (GPR) method is applied in real-time to select sampling points for the sparse ESM imaging. The Gaussian process regression is used to estimate the complex amplitude of the scanned field and its uncertainty allowing to select the most relevant areas for scanning. Compared with the random selection of samples the proposed method allows to reduce the number of samples needed to achieve a certain dynamic range of the image, reducing the overall scanning time. Results for simulated and measured 2D scans for multiple and distributed emission source are presented.

13:55 Magnetic Field Leakage Reduction and Efficiency Enhancement of Wireless Power Transfer by using Side-Positioned Coil Array
Zhiyuan Gu[1], Liping Yan[1], Xiangyong Mou[2], Xiang Zhao[1], Richard Xian-Ke Gao[3]
*[1]Sichuan University, China; [2]Chengdu University of Information Technology, China; [3]A*STAR, Singapore*
Abstract: A side-positioned coil array printed on a PCB slab effectively suppressing the magnetic field leakage of a magnetic resonant wireless power transfer (WPT) system while preserving good transfer efficiency is presented in this paper. Based on a basic two-coil WPT system working at 6.78 MHz, a slab with four coils printed on both sides is proposed and fabricated. The effect of the slab on the magnetic field shielding and power transfer efficiency is investigated through physical experiment, when the slab is placed at the side of the WPT system. The magnetic fields around the WPT with and without the slab are measured by a magnetic probe under the control of a 3D scanning system. The measured results show that the proposed coil array reduces the magnetic field leakage by an average of 6.42 dB without degrading the transfer efficiency, instead it improves the efficiency of the WPT system at an average of about 27%.

14:20 Common Mode Mitigation by Applying Absorber with Genetic-Algorithm Optimized Cross-Section to Microstrip Pair
Ruijie He1, Xu Wang[1], Victor Khilkevich[1], Paul Dixon[2], Onyekachi Eloagu[2]
[1]Missouri University of Science and Technology, USA; [2]Laird Performance Materials, USA
Abstract: At the post-design stage, applying absorber to transmission lines is a cost-effective and efficient way to improve the EMI behavior of a product. This work presents an optimized shape of absorber that can be applied to a microstrip pair. The presented shape is an outcome of Genetic-Algorithm Optimization. It mitigates EMI by increasing common mode insertion loss of the microstrip pair while maintaining the differential mode signal integrity. Measurements are conducted to prove the superiority of the optimized shape of absorber.

14:45 VO2 Thin Film as a Temperature Activated Electromagnetic Shield
Quentin Tricas[1], Philippe Besnier[2], Xavier Castel[1], Claire Le Paven[1], Patrice Foutrel[3]
[1]Université de Rennes 1, France; [2]INSA Rennes, France; [3]Safran Electronics and Defense, France
Abstract: This communication presents the fabrication, characterization and performance of a vanadium dioxide (VO2) thin film deposited on a c-cut sapphire substrate, and used as an electromagnetic screen whose shielding effectiveness is controlled through heating/cooling. The film is first deposited at high temperature on the substrate using a radiofrequency magnetron sputtering technique, and is then annealed in-situ in pure dioxygen atmosphere, to obtain the required oxide stoichiometry. The screen shielding effectiveness is measured using the nested reverberation chamber method at room temperature and at 75°C. At 65°C, VO2 undergoes an insulator to metal transition and the material conductivity drastically increases, resulting in a significant shielding effect of the VO2 layer at microwaves (2 – 34 GHz). The experimental results are in accordance with theoretical values predicted by an analytical model. The VO2- based electromagnetic shield is therefore a promising solution to protect sensitive electronics from high intensity radiated field by using the temperature rise as the trigger to rapidly improve the shielding effectiveness of the screen. On the contrary, cooling down the screen is possible if shielding is no longer necessary.

TECHNICAL PAPERS
TP-MON-5B

MACHINE LEARNING/CLOUD COMPUTING 1

(SPONSORED BY TC-9 AND TC-10)

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

13:30 Machine Learning-Based Verilog-A Modeling for Supply Induced Jitter Sensitivity of High-Speed Memory Interface: Two Layer PCB Case Study
Michael Chang
HTC Corporation, Taiwan
Abstract: With the ever-increasing demand for both highperformance and high-integrated chips, it is becoming more and more difficult to meet the power distribution network (PDN)- related target specifications. This paper provides the Verilog-A model of supply-induced jitter-aware sensitivity for analyzing supply noise induced timing jitter in DDR high speed interface integrated in cost-effective two-layer circuit board to perform the jitter generated by the supply noise in the time domain compared to present general analysis methods. During design phase, the effort of power distribution network optimization takes place very first to define the floor plan of die, package and circuit board. We propose a Verilog-A model with the skill of vector fitting and neural network for the efficient methodology of timing budget calculation when double data rate (DDR) interface works simultaneously in highly integrated system at early design stage. The goal is to provide adequate performance for cost-effective and system solution and achieving on system-level success.

13:55 Optimization of Joint Equalization of High-Speed Signals using Bayesian Machine Learning
N. Dikhaminjia[1], G. Tsintsadze[1], Z. Kiguradze[2], J. He[2], M. Tsiklauri[2], J. Drewniak[2], A. Chada[3], B. Mutnury[3]
[1]Ilia State University, Georgia; [2]Missouri University of Science and Technology, USA; [3]Dell Inc., USA
Abstract: The paper elaborates an efficient algorithm for optimization of joint Feed-Forward Equalization (FFE) and Decision Feedback Equalization (DFE) for non-return-to-zero (NRZ) and 4 level pulse amplitude modulation (PAM-4) signals using Bayesian Machine Learning approach previously introduced for NRZ by authors and expanded for PAM-4. A new optimal covariant function and hyper-parameters has been selected for the Bayesian optimization. Cost function for the Bayesian optimization is chosen based on eye height. The proposed method was compared to the conventional Least Mean Square (LMS) method and showed significant improvement. Test cases were performed for several data rates of NRZ and PAM-4 signals with crosstalk and injected jitter. Test results show that the proposed algorithm is the more effective the higher data rates are considered.

14:20 Distributed Data Processing for Large-Scale Simulations on Cloud
Tianjian Lu, Stephan Hoyer, Qing Wang, Lily Hu, Yi-Fan Chen
Google, USA
Abstract: The computational challenges encountered in the large-scale simulations are accompanied by those from dataintensive computing. In this work, we proposed a distributed data pipeline for large-scale simulations by using libraries and frameworks available on Cloud services. The building blocks of the proposed data pipeline such as Apache Beam and Zarr are commonly used in the data science and machine learning community. Our contribution is to apply the data-science approaches to handle large-scale simulation data for the hardware design community. The data pipeline is designed with careful considerations for the characteristics of the simulation data in order to achieve high parallel efficiency. The performance of the data pipeline is analyzed with two examples. In the first example, the proposed data pipeline is used to process electric potential obtained with a Poisson solver. In the second example, the data pipeline is used to process thermal and fluid data obtained with a computational fluid dynamic solver. Both solvers are in-house developed and finite-difference based, running in parallel on Tensor Processing Unit (TPU) clusters and serving the purpose of data generation. It is worth mentioning that in this work, the focus is on data processing instead of data generation. The proposed data pipeline is designed in a general manner and is suitable for other types of data generators such as fullwave electromagnetic and multiphysics solvers. The performance analysis demonstrates good storage and computational efficiency of the proposed data pipeline. As a reference, it takes 5 hours and 14 mins to convert simulation data of size 7.8 TB into Zarr format and the maximum total parallelism is chosen as 10,000.

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TECHNICAL PAPERS
TP-MON-6B

COMPUTATIONAL ELECTROMAGNETICS I

(SPONSORED BY TC-9)

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

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

Chanjong Lee[1], Sangyeong Jeong[1], Jingook Kim[1], Jun-Bae Kim[2], Jeong Don Ihm[2]
[1]Ulsan National Institute of Science and Technology, Korea; [2]Samsung Electronics Co. Ltd., Korea
Abstract: The reinforcement learning (RL) is applied to the optimization of decoupling capacitors on power distribution network (PDN) for reduction of radiated emissions (REs). A small-size parallel-plates PDN structure containing two ICs is modeled as equivalent lumped-circuits, and far-field REs due to the structure are calculated using closed-form expressions. The closed-form expressions are validated with the full-wave simulation results. The environment with a proper reward system for RL is proposed by using the closed-form REs expressions. The proposed RL environment is tested with two design examples for Q-learning and deep reinforcement learning (DRL). The learning results are converged to optimal policies very efficiently, which satisfy the RE regulation with minimum number of decaps for the given PDN structures.
BEST EMC STUDENT PAPER FINALIST

13:55 A Deep Learning based Macro Circuit Modeling for Black-Box EMC Problems

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

TECHNICAL PAPERS
TP-MON-7B

PRINTED CIRCUIT BOARD TECHNOLOGY AND SI DESIGN 2

(SPONSORED BY TC-10)

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

13:30 Single Pair Ethernet for the Industrial Internet of Things: Accurate Line Modeling

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

13:55 Linear Periodic Time Varying Filtering of Cyclostationary Signals in Transmission Lines

Yuriy Kuznetsov[1], Andrey Baev[1], Maxim Konovalyuk[1], Anastasia Gorbunova[1], Johannes A. Russer[2]
[1]Moscow Aviation Institute, Russian Federation; [2]Technical University of Munich, Germany
Abstract: Theoretical and experimental evaluation of the cyclostationary random data transferring process corrupted by the individually and jointly cyclostationary crosstalk interference added by stationary noise with possible deterministic component of the synchronizing clock signal is presented. The interference and the message signals were measured by the real time digital oscilloscope and autocorrelation functions were evaluated by synchronous cyclic averaging procedure. The analyzed periodic two-dimensional impulse response of the time-varying filter allows to obtain the output random process with the same cyclic frequency at the output of the filter by separation of orthogonal stationary waveforms constituting the input cyclostationary random process (CSRP). The filtering of the observed measured random process was implemented by cyclic Wiener filter, estimating the message from the measured random signal. The evaluation of two-dimensional autocorrelation function and eye diagrams at the output of the cyclic filter showed significant reduction of the independent interference components in the estimated message signal.

14:20 An Optimized Transition Structure for Solving Reference Ground Discontinuities in SIW Filter Integration

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

TECHNICAL PAPERS
TP-MON-8B

POWER ELECTRONICS EMI CONTROL VIA OPTIMAL MODULATION AND DRIVING SCHEMES

(SPONSORED BY SC-5)

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

13:30 **A VSFPWM Method of Three-Phase CSI for EMI Mitigation based on DC Current Ripple Prediction**
Ruodong Wang, Kang Liu, Dong Jiang
Huazhong University of Science and Technology, China
Abstract: Pulse-width-modulation (PWM) is one of the main reasons of electromagnetic interference (EMI) in switching power converter. The level jump, high di/dt and dv/dt of output square-wave voltages or currents caused by the switching process of active components like IGBT or MOSFET lead to the increase in harmonics near switching frequency, its multiples and even higher. And frequency variation is an effective method to mitigate EMI. A variable switching frequency pulse-widthmodulation (VSFPWM) method for three-phase current source inverter (CSI) is introduced in this paper. Based on the ripple prediction of DC current, switching frequency is designed to be updated in DSP in every interruption period to keep the ripple current of DC inductor constant. Both simulation and experiment results show that the application of VSFPWM in CSI can significantly reduce switching losses and suppress differential mode (DM) EMI noises.

13:55 **A Novel Common-Mode Voltage Reduction Method of MMC: Pulse Sequential Connection Carrier Phase-Shifted SPWM**
Jiaxin Wang[1], Hong Li[1], Zuoxing Wang[1], Zhaoyi Chu[1], Bo Zhang[2]
[1]Beijing Jiaotong University, China; [2]South China University of Technology, China
Abstract: The switching of the sub-modules (SMs) of modular multilevel converter (MMC) causes a common mode (CM) voltage to ground at the neutral point of the AC side of the MMC, which will affect the normal operation of the system. For instance, the CM voltage in MMC will damage the motor bearing and cause the conducted electromagnetic interference (EMI) problem seriously. In order to reduce the CM voltage in MMC, this paper proposes a novel modulation method of pulse sequential connection (PSC) carrier phase-shifted sinusoidal pulse width modulation (CPS-SPWM), under which the CM voltage of the MMC is zero theoretically. The correctness and effectiveness of the reduction method are validated by the 5- level MMC simulation platform.

14:20 **A Critical Assessment of Open-Loop Active Gate Drivers under Variable Operating Conditions**
Erica Raviola, Franco Fiori
Politecnico di Torino, Italy
Abstract: Active gate drivers have been investigated in power circuits to reduce unwanted over-voltages and over-currents, whilst keeping the transients fast. Indeed, the use of such a kind of driver avoids the triggering of oscillations related to high frequency parasitic resonant circuits, which affect adversely the electro-magnetic interference delivered by power modules. However, in the case of fast power switches, the driver is working in an open-loop manner, and the modulation pattern is fixed. This paper assesses the effects of different operating conditions on the switching waveforms of an AGD-driven power transistor. More precisely, load current, input voltage and temperature variations were investigated on an open-loop active gate driver comprised in a Buck converter. Experimental results suggest that the AGD is no longer effective in damping the unwanted oscillations under a significant change of the operating conditions.

14:45 **Frequency-Selective Reduction of Power Electronic Switching Noise by Applying Synthesized Gate Signals**
Caroline Krause, Andreas Bendicks, Stephan Frei
Technische Universität Dortmund, Germany
Abstract: The high-frequency switching of power transistors in electronic systems can be a significant source of electromagnetic emissions (EMI). Simple measures like reducing the high-frequency disturbances by introducing an additional gate resistor lead to an increase of the switching losses. This creates a conflict of interests between the reduction of disturbances and high system efficiency. More complex active gate drivers offers improved compromises between EMI and efficiency. Avoiding steep switching slopes, overshoots or sharp edges are typical measures. The whole spectrum is modified this way and efficiency is still affected. In many cases, only a narrow banded modification of the spectrum might be needed to avoid the excitation of critical system resonances. This can be reached by a target signal-oriented control of the gate of the transistors. In the target signal the critical RF components should be reduced. Maximum control of the target signal is possible with fully synthesized gate signals. The reduction of some harmonics in the switching spectrum may lead to overshoots in time domain due to the Gibbs phenomenon. These overshoots may violate the physical limits of a transistor and cannot be realized. In this work, a method is presented to determine the target signal considering all physical limits. The found approach is applied in simulation to the signal of the drain-source voltage of a boost converter to reduce the harmonics in the FM broadcasting range. The gate control signal is determined for this application.
BEST EMC PAPER FINALIST

TECHNICAL PAPERS TP-TUE-1A

EMISSIONS

(SPONSORED BY TC-2)

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

11:00 Prediction of Radiated Emissions by Applying Multipole-Network Theory to a Measurement Setup
Alexander Engeln, Kai-Uwe Rathjen, Stefan Dickmann
Helmut-Schmidt-Universität, Germany
Abstract: A CISPR 25 radiation measurement setup is decomposed into the device under test itself and its surroundings including the antenna. The latter part is described by scattering parameters relating the connecting ports of the device to the antenna. In this way the antenna voltage can be predicted knowing the internal behaviour of the device. It can be shown that the method is applicable for devices including linear networks.

11:25 Methods for Investigating Influence Parameters in the Measurement Setup for Radiated Emissions according to CISPR 25
Jan Schabel[1], Michael Zerrer[2], Martin Kull[2], Michael Beltle[1], Stefan Tenbohlen[1]
[1]Universität Stuttgart, Germany; [2]mk-messtechnik GmbH, Germany
Abstract: This work examines methods to evaluate the impact of different measurement setups on the radiated emissions measurement according to CISPR 25. Besides using a real device under test, swept measurements with a vector network analyzer and the artificial excitation of the wiring harness with a broadband impulse are discussed. The investigations evaluate the reproducibility of measurements using CISPR 25 setup. This paper concludes that of the methods investigated, the most suitable is the one in which the wiring harness is excited with a broadband impulse.

11:50 Auto Focus for Far Field Source Localization using Emission Source Microscopy
Ling Zhang, Shaohui Yong, Yuanzhuo Liu, Victor Khilkevich
Missouri University of Science and Technology, USA
Abstract: Emission source microscopy (ESM) is a useful technique to locate emission sources contributing to far-field radiation. The focusing distance can affect image qualities and confuse the localization of radiation sources. This paper adopts the autofocus method in image processing to calculate the optimal focusing distance with the best image quality. The proposed methodology was verified using a numerical simulation as well as a measurement. Also, calculating the contrast of a local source region shows better noise immunity. This autofocus algorithm in ESM can easily obtain the exact distance between the radiation sources and the scanning plane and can be used to localize sources in 3D space.
BEST EMC PAPER FINALIST

12:15 Radiated Emission Tests for High-Frequency Router Systems in Class A: Discussion and Improvement
Wei Zhang, Zhekun Peng, Xu Wang, DongHyun Kim, James Drewniak
Missouri University of Science and Technology, USA
Abstract: The standards for radiated emissions (RE) test in FCC Part 15 and CISPR 32, and the related literature concerning the limit line extrapolation, testing methods and challenges in the RE test are reviewed herein. In particular, factors to be considered during the RE test for the equipment in Class A operating above 10 GHz are discussed including: 1) possibilities to miss the maximal electric field (Emax); 2) specifications of the 2 dB rule; 3) falloff factors in the conversion between the measured electric (E) field at closer distances (1 m or 3 m) to 10 m. Methods that might be considered for improvement are proposed to increase the confidence of the multi-modular systems in passing/failing the RE standard and compliance with other devices in terms of: 1) according to 2 dB rule, 63.1% of the optical modules are proposed to represent the radiation of the fully loaded router system; 2) statistical falloff factors are needed in converting the E field at 1 m/3 m to 10 m at high frequencies (> 10 GHz); and, 3) specific limit lines are preferred at high frequencies for router/multi-modular systems.
BEST EMC STUDENT PAPER FINALIST

TECHNICAL PAPERS TP-TUE-2A

CALIBRATION

(SPONSORED BY TC-2)

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

11:00 Design of High-Frequency Differential Line for Ex Probe Calibration
Yu Tian, Yu Du, Zi-Jian Zhou, Tian-Hao Song, Ze-kai Hu, Xing-Chang Wei
Zhejiang University, China
Abstract: This paper describes a new design of high-frequency differential line for Ex/Hz probe calibration. Both simulation and measurement results show that it can generate a pure transverse electromagnetic field up to 30GHz.

11:25 Application of a Calibration Procedure for EMC Analysis with an Open Directional Coupler
Teresa Tumbrägel, Hanno Rabe
Volkswagen AG, Germany
Abstract: Automotive tests concerning electromagnetic compatibility are usually performed as hardware tests in late development stages. Because the electromagnetic environment in vehicles becomes increasingly complex, changes in these late development stages become more time consuming and financially challenging. In this paper a general calibration method for contactless electromagnetic compatibility analysis is applied with a new type of open wave coupler for the frequency range of 300 kHz to 300 MHz. It is found that the procedure lacks accuracy in the determination of phase information. An additional calibration step is proposed in order to gain the correct phase information.

11:50 Spectral Response of Electromagnetic Field Sensor Calibration Setups
Fernando Albarracin-Vargas, David Martinez, Gideon N. Appiah, Juan Galvis, Chaouki Kasmi, Nicolas Mora
Technology Innovation Institute, United Arab Emirates
Abstract: This work presents a comparative analysis on the spectral response of two versions of the cone and ground plane calibration setups-for electromagnetic field sensors.

12:15 Research on an EMC High and Low Voltage Coupling Test Method
Junjie Ma, Zhe Xu, Dengyu Zhang, Haipeng Li
China Automotive Technology and Research Center Co., Ltd., China
Abstract: At present, the electromagnetic compatibility(EMC) high and low voltage coupling network test for automotive electrical sub-assembly(ESA) in the standard only requires the use of an adapter to connect the network and the test sample, in other words, the impedance matching is not considered. In practice, if the impedance does not match, accuracy and consistency of test results cannot be guaranteed. But it is difficult to achieve impedance matching in the whole frequency band. In view of the above problem, this paper proposes an impedance matching method for high-low voltage coupling test, by isolating indirectly contact between the test system and the sample, which reduces test errors and improves the accuracy of test data caused by impedance mismatch. The experimental results prove that this method can effectively solve the shortcomings of the existing high and low voltage coupling EMC test technology of electric vehicle ESA, and provide a reasonable test idea for accurately testing the electric vehicle ESA high and low voltage coupling network test method.

TECHNICAL PAPERS TP-TUE-4A

SPACE EMC

(SPONSORED BY TC-8)

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

11:00 Statistical Field Model for Performance of Localized RF Absorption Blankets in a Payload Fairing
P.G. Bremner[1], M. Bahadorzadeh[2], J.C. West[2], C.F. Bunting[2], S. Kabiri[2]
[1]Robust Physics, USA; [2]Oklahoma State University, USA
Abstract: In the space community, there is increasing interest in adaption and augmentation of launch fairing thermal-acoustic blankets, to also control electromagnetic environment threats. This paper reports on the development of simulation methods to both optimize blanket materials for RF absorption and to provide quantitative guidance on their minimal spatial deployment inside the fairing. A stochastic power-balance model with multiple connected sub-cavities is used to map the reverberant electric field in the fairing when RF absorbing blankets are applied only locally – ie only partial coverage of the fairing wall. The sub-cavity Q factors resulting from different RF absorption blanket materials is calculated from published reflection loss data and a field incidence correction factor. Comparison with model-scale test data, verifies that the model correctly predicts the electric field attenuation of different absorber materials. The model also correctly predicts the spatial distribution of the field and the improvement in shielding effectiveness.
Best EMC Paper Finalist

11:25 Design and Fabrication of a Model Launch Fairing for EMC Measurements
Shabir Kabiri[1], Mehdi Bahadorzadeh[1], James C. West[1], Charles Bunting[1], Paul G. Bremner[2]
[1]Oklahoma State University, USA; [2]Sonelite, Inc., USA
Abstract: A launch vehicle payload fairing scale model has been designed, fabricated, and tested to investigate the reverberant electromagnetic fields within launch vehicle fairings. The fairing scale model uses a mechanical stirrer to attain statistically uniform fields within the fairing cavity. A removable payload model and payload adapter model are included in the fairing to study the interactions of fields with these structures. The layering of the fairing walls, use of shielding gaskets, and field probes to measure the cavity fields are described. The quality factor is measured when the fairing cavity is empty and when the surrogate payload and payload adapter models are added. The quality factor of the empty fairing measured from about 32 dB at 1 GHz to 41 dB at 6 GHz. The Q values dropped approximately 2 dB across the band when the payload and payload adapter models were placed in the fairing cavity. Measurements of Q at different probe positions within the fairing yielded similar results.

11:50 Electric Field Excited in a Model Spacecraft Fairing through Internal and External Source Excitation
Mehdi Bahadorzadeh[1], Charles F. Bunting[1], James C. West[1], Shabir Kabiri[1], Paul G. Bremner[2]
[1]Oklahoma State University, USA; [2]Robust Physics, USA
Abstract: The electric field levels established at various points within a modeled rocket fairing under different excitations are measured. Both interior sources placed within different fairing sub cavities and exterior excitation was used. The effect of the addition of different absorbers on the electric field level in different sub cavities was investigated as well. The shielding effectiveness of the fairing within the different fairing sub cavities was considered. The relation between the total surface of absorber and the electric field level studied. In addition, the electric field level excited inside the fairing under external illumination was numerically simulated. The laboratory measurements were verified through comparison with the simulation results.

TECHNICAL PAPERS TP-TUE-5A

IEMI GENERATORS AND MODELING

(SPONSORED BY TC-5)

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

11:00 A Lightweight, Compact, High Voltage Hyperband Antenna for IEMI Testing
John F. Dawson[1], Richard Hoad[2], Barney Petit[2], Tim Rees[2], Martin Robinson1, Simon Bale[1], Mark Hough[1], Linda Dawson[1], Andy Marvin[1], Iain Will[1]
[1]University of York, United Kingdom; [2]QinetiQ, United Kingdom
Abstract: A robust lightweight antenna for testing immunity of equipment to intentional electromagnetic interference (IEMI), based on a planar Vivaldi design, is described, along with simulated and measured test results.

11:25 A 1.3GHz, High Voltage Mesoband Dipole Antenna Antenna for IEMI Testing
John F. Dawson[1], Tim Rees[2], Barney Petit[2], Richard Hoad[2], Simon Bale1, Mark Hough[1], Linda Dawson[1], Martin Robinson[1], Andy Marvin[1], Iain Will1, S.J. Porter[1]
[1]University of York, United Kingdom; [2]QinetiQ, United Kingdom
Abstract: A resonant dipole antenna for testing immunity of equipment to intentional electromagnetic interference (IEMI) is described, along with simulated and measured test results which are in good agreement and demonstrate the high voltage operation.

11:50 A 150MHz, High Voltage Mesoband Dipole Antenna for IEMI Testing
Simon Bale[1], Richard Hoad[2], Barney Petit[2], Tim Rees[2], Martin Robinson[1], Mark Hough[1], Stuart Porter[1], Linda Dawson[1], Andy Marvin[1], John F. Dawson[1], Iain Will[1]
1University of York, United Kingdom; [2]QinetiQ, United Kingdom
Abstract: An antenna for testing immunity of equipment to intentional electromagnetic interference (IEMI) is described, along with simulated and measured test results which show a good agreement and demonstrate the high-voltage operation.

12:15 The Method of Modal Parameters for the Single and Double Segments of the Wires with Symmetrical Geometry and the Singularity Expansion Method
Sergey V. Tkachenko, Felix Middelstaedt, Ralf Vick
Otto-von-Guericke-Universität Magdeburg, Germany
Abstract: The previously developed Method of Modal Parameters (MoMP) was applied to calculate the Singularity Expansion Method (SEM) poles of the single and double wire segments with symmetrical geometry: straight wire, circular wire, and helix wire, which are important for EMC practice. The symmetry leads to the simplification of the conesponding formulas for matrix elements and allows to obtain SEM poles of the first, second and third layers, which conespond both to the known analytical results and numerical data. Moreover, for the first layer of the poles one can use a simplified variant of the method taking into account only diagonal elements of the p.u.l. impedance matrix.

TECHNICAL PAPERS
TP-TUE-6A

POWER INTEGRITY ANALYSIS AND DESIGN 2

(SPONSORED BY TC-10)

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

11:00 Gauss-Newton Method for Fast Analysis of PDNs with Arbitrarily Shaped Power-Ground Plane Pairs
Ihsan Erdin, *Celestica Inc., Canada*
Abstract: A Gauss-Newton (G-N) based method is developed for the analysis of power delivery networks (PDN) with arbitrarily shaped parallel-plate power/ground plane pairs. The proposed method allows for power integrity (PI) assessment in a few iteration steps, providing significant speed-up in comparison to alternative methods. The proposed method is tested on a practical example which includes a 16-pin ball-grid array (BGA) device and the results are observed in good agreement with those obtained from a numerical electromagnetic (EM) simulator.

11:25 VRM Modeling for Platform FastPI upon SPIM
Xingjian Kinger Cai, Wei Qian, Chi-te Chen, Kundan Chand, *Intel Corporation, USA*
Abstract: The formula of Lvr and Rvr is 1st time derived in industry for a VRM with Adaptive Voltage Positioning (AVP)[1]. The simulation is elaborated with a largely dependent CPU power delivery network (PDN) for holistic platform FastPI upon SPIM, to facilitate platform PI design flexibility, and review & sign-off.

11:50 Optimal Power Distribution Network Design for High-Performance Solid-State-Drive based on Novel Target-Impedance Extraction Method
Jinwook Song, Chunghyun Ryu, Sangho Park, Donggon Jung, Jaeyoung Shin, Youngmin Ku
Samsung Electronics Co., Ltd., Korea
Abstract: In this paper, we proposed a novel methodology to offer power distribution network (PDN) design guide for PCB power integrity (PI) design for high performance solid-statedrive (SSD). Compared with conventional target-impedance (Z) formulated by current profile of a chip power model (CPM), the proposed methodology utilizes a measurement based current spectrum and a hierarchical PDN-Z model. In order to solve the fundamental limitations of the narrow-banded CPM current model, we successfully measured the PCB-level current of memory packages consisting of the SSD device and converted the measured current values to the chip-level current values using Y-matrix of the hierarchical PDN-Z model consisting of a PCB, a test interposer, a package, and a chip. High-capacity SSD devices are too expensive to make PCBs for design of experiments to test device performance with current measurement. Therefore, we made a test interposer to measure cost-efficiently a current spectrum for each specific powerdomain of a unit package such as a DRAM, a NAND, and a SSD controller that all consisting of a SSD device without disturbing SSD's normal operations.
BEST SIPI PAPER FINALIST

12:15 Novel Methodology for Validating SIMPLIS based VR Models for Server Platform Power Delivery Prediction
Judy Amanor-Boadu[1], Hannah Homer[1], Daniel Mauricio Garcia Mora[2], Pavan Kumar[1], Tammie Bard[3]
[1]Intel Corporation, USA; [2]Intel Corporation, Mexico[3]Infineon Technologies Americas Corp., USA
Abstract: Voltage Regulators (VR) use non-linear features to mitigate large transient droops and overshoots, to enable high server processor performance. VR behavior due to non-linear features is complex, and can no longer be modeled using simple linear modeling methods. Accurately modeling VR behavior in conjunction with Power Delivery Networks (PDN) in server platforms is becoming a necessity to predict, optimize, explore, and identify performance impacts when changes are made to design parameters, such as processor current (Iccmax), decoupling capacitor solutions, and VR components. Inaccurate VR models can potentially lead to inaccurate predictions which in turn lead to increased design time, board spins, and either performance degradation or oversized and costly decoupling capacitor solutions. Thus, it is imperative to be confident in determining whether a VR model is accurate before it is used for design and prediction purposes. This paper presents a detailed methodology to validate and qualify VR models to be able to accurately model the VR behavior even after changes are made to the design parameters. The method can be used along with various platform PDNs ranging from a complex processor network to a simple Point of Load (POL) VR. The methodology pioneered in this paper has been successfully applied to qualify over 20 VR models, ensuring correlation between experimental measurements and simulations using SIMulation of Piecewise LInear Systems (SIMPLIS) circuit simulator. Correlation results are presented from four case studies to demonstrate the effectiveness of the proposed methodology.

TECHNICAL PAPERS
TP-TUE-7A

POWER ELECTRONICS EMI MODELING AND MEASUREMENT II

(SPONSORED BY SC-5)

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

11:00 A Bias Tee for Broadband Measurement of Power Electronic Components
Michael Fuchs, Christoph Maier, David Pommerenke, *Technische Universität Graz, Austria*
Abstract: Bias tees are an important tool for many applications including vector network analysis. When trying to measure power electronic components with large DC currents and voltages at low frequencies, however, one quickly encounters the limits of the devices of common manufacturers. As accurate understanding and modeling of power electronic components becomes increasingly important for the study of their electromagnetic emissions, so do broadband measurements with bias tees. This paper describes the composition of such a special bias tee in terms of the necessary geometries and circuitry. Measurements of the characteristics of the presented tee show good results in a frequency range from 9 kHz to 500MHz at DC currents up to 10A (30A for a short time) and voltages up to 500V. Vector network analysis of passive filter structures under load thus also becomes possible for power electronic components in a broad frequency range.
BEST EMC PAPER FINALIST

11:25 Analysis on Common to Differential Mode Conversion within Automotive Communication Systems
Carina Austermann, Stephan Frei, *Technische Universität Dortmund, Germany*
Abstract: Communication systems with high data rates like CAN FD and Automotive Ethernet are increasingly used in automobiles. New safety-critical driving assistance functions can be realized with the help of these bus systems, but data transmission has to be very reliable. Road vehicles are a challenging electromagnetic environment because of the high density of electric and electronic devices. Power electronic systems can be very close to communication systems. The typical cable type for automotive communication systems is the unshielded twisted wire pair. Common mode disturbances cannot be reduced by this cable type. Due to unavoidable asymmetry in the communication system electromagnetic coupling can also induce critical differential mode voltages. For this reason, the immunity of communication systems to electromagnetic interferences has to be investigated in detail. In this paper, simulation models are presented and validated by measurements to quantify cable coupling to CAN FD and 100BASE-T1 Automotive Ethernet. Both, common and differential mode voltages caused by cable coupling are investigated. Based on measurements and simulations critical influencing parameters on mode conversion are discussed.

11:50 Noise-Source Parameter Identification Considering Switching Fluctuation of DC-DC Converter
Shuqi Zhang, Taishi Uematsu, Kengo Iokibe, Yoshitaka Toyota, *Okayama University, Japan*
Abstract: This paper proposes noise-source parameter identification of the noise-source equivalent-circuit model for predicting conducted noise while considering the switching fluctuation of a DC/DC converter. We decomposed measured conducted noise into ripple noise, turn-on spike noise, and turnoff spike noise to prevent the accuracy degradation in the parameter identification. The predicted conducted noise spectra show the error with the measurement was within 3 dB up to 200 MHz, which is more accurate than that in our previous study.

12:15 An Immunity Estimation Technique for In-Vehicle CAN-FD
Miyuki Mizoguchi, Takeshi Yoneyama, Yoshiroh Hirata, *Soken, Inc., Japan*
Abstract: It is a well-known fact that a lot of Electronic Control Units (ECUs) and high-speed communication Local Area Networks (LANs) are necessary for Advanced Driver Assistance System (ADAS). Original equipment manufacturers (OEM) are interested in introducing CAN-FD on vehicles for its high data rate and low data arbitration phase. Meanwhile, ensuring immunity performance is one of the main issues in the CAN-FD using differential signals. In this paper, we define a CAN-FD Transceiver ICs' immunity criterion and their selection method.

TECHNICAL PAPERS
TP-TUE-8A

PASSIVE COMPONENT MODELING AND MEASUREMENT TECHNIQUES

(SPONSORED BY TC-10)

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

11:00 **Time Domain Reflectometry Accuracy Control for via Characterizations in High Speed Links**
Tao Wang, Brian Brecht
Teradyne Inc., USA
Abstract: The time domain reflectometry (TDR) is a very popular tool for high speed link characterizations. However, its modeling and simulations for vias constantly face accuracy challenges due to vias' small dimension and fast rise time. While many existing papers discussed discontinuity analysis of transmission lines, in this paper, we focus on the accuracy control methods in TDR modeling and analysis for vias in PCBs for high speed signal integrity (SI). There are many practical factors affecting the via impedance result in TDR, such as frequency domain simulation setups, TDR window selections, rise time, bandwidth, etc. Based on the principal analysis, we propose a practical calculation flow for a via's TDR modeling process, and provide a TDR interpretation approach by jointly using different window functions to justify the correct locations and impedance values of the via structures. Highly oscillatory TDR responses are also discussed to guide the real TDR practice. According to our search, there is very little in literature describing similar techniques to solve a via's TDR analysis accuracy issues. The proposed method can also be used on other small feature's TDR analyses.

11:25 **Electric Property Analysis and Wire Placement Optimization of Automotive Wire Harness**
Tadatoshi Sekine, Takumi Ito, Shin Usuki, Kenjiro T. Miura
Shizuoka University, Japan
Abstract: This paper describes an analysis and optimization technique for understanding and effective design of an automotive wire harness. In the analysis phase, the multiple linear regression analysis is used to reveal the relationship between an electric property of the wire harness and its cross-sectional shape. Subsequently, we perform coarse and fine optimization processes with the knowledge obtained in the prior analysis phase to efficiently determine the optimal placements of the wires so that a crosstalk voltage is reduced. The proposed technique and knowledge obtained from results will contribute the future automotive EMC/SIPI design.

11:50 **Li-Ion Cell Impedance Measurement using Open/Short/Load Compensation for De-Embedding**
Herbert Hackl[1,2], Martin Ibel[1,2], Thomas F. Landinger[3], David Pommerenke[1,3], Bernhard Auinger[1,2]
[1]Silicon Austria Labs GmbH, Austria; [2]Technische Universität Graz, Austria; [3]Infineon Technologies AG, Germany;
Abstract: Knowledge of battery cell impedance is crucial for the design of many modern applications, as well as for predicting their electromagnetic compliance. For detailed 3D simulation of battery packs, single cells are commonly replaced with simplified bodies enhanced by internal impedance data obtained from measurement on real cells. Thereby it is necessary to exclude all influence of the measurement setup, i.e. to de-embed the cell impedance from exterior properties. In this work, two approaches are presented to extract the impedance of an 18650 Lithium-ion (Li-ion) cell from within a battery holder on a printed circuit board (PCB), using Open/Short/Load compensation (OSLC) and a copper cylinder as reference. By adding components in series and parallel to the cell, it is verified that the extraction result is not impacted by PCB circuitry, and also that the cell's impedance is load-independent. Eventually, the test setup including Li-ion cell is replicated as electromagnetic (EM) simulation project. Two measurement-based methods to model the cell are compared, suitable for both 3D or circuit simulation. The frequency range under consideration is from 9 kHz to 1 GHz, whereas the presented approach proves reliable up to 200 MHz.

12:15 **Lumped Circuit Model and VNA Measurement of the RF Impedance of a Bypass Network**
Federico Sordi, Lorenzo Capineri, Carlo Carobbi
Università degli Studi di Firenze, Italy
Abstract: In this work, a method is presented to predict the radiofrequency impedance of a practical implementation of a bypass network. Circuit models of both ceramic and electrolytic capacitors are introduced, whose parameters are derived from manufacturers' specifications. Mounting inductance of capacitors is accounted for through estimates of vias and microstrips inductance. Predictions are confirmed by vector network analyzer (VNA) measurements through an incremental process of comparisons in which the number of parallel capacitances of the bypass network is progressively increased. A simple technique to remove the residual (after VNA calibration) series inductance introduced by the radiofrequency connectors used to connect the VNA ports to the printed circuit board hosting the bypass network is presented. An insight into the low-frequency behavior of ceramic capacitors of large capacitance (in the tens of microfarad range) is also offered. Measurements confirm the reliability of the lumped circuit model of the bypass network up to about 400 MHz for a printed circuit board (PCB) sized 15 cm x 11.3 cm. Above this frequency distributed phenomena and radiation cause measurements to significantly deviate from predictions. The bypass network impedance behavior is essentially described, up to the frequency limit of validity of the lumped model, by a simple but effective series circuit consisting in a large capacitance of the order of 1 mF , an inductance of the order of 0.07 nH and a resistance of the order of 0.5 m .

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TECHNICAL PAPERS
SS-TUE-A

EMC DIAGNOSTICS OF COMPLEX SYSTEMS

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

11:00 Frequency-Independent Asymptotes of System Parameters of Urban Cellular Communications at Multipath Propagation of Radio Waves
Vladimir Mordachev
Belorusskiy Gosudarstvennyy Universitet Informatiki I Radioelektroniki, Belarus
Abstract: Frequency-independent relationships for estimating a following number of system parameters of cellular communications under the conditions of multipath propagation of radio waves in urban canyons and the presence of intrasystem interference are obtained: the required equivalent isotropic radiated power (EIRP) of subscriber stations, the maximum data transmission capacity of the uplink radio channel, the maximum distance of qualitative communication, and also the permissible level of intranetwork radio interference at given requirements for communication range and data transfer rate of uplink radio channel taking into account the accepted restrictions on EIRP of subscriber radio equipment. Together with the frequencyindependent component of the electromagnetic background near the earth's surface, created by electromagnetic radiations of subscriber stations located outside the breakpoint vicinity of the observation point, these dependencies form a family of asymptotes that provide ample opportunities for system analysis and diagnostics of solutions and scenarios for the implementation of 4G/5G/6G systems and services in various conditions, taking into account the quality of frequency-spatial planning and the intra-system EMC design of radio networks of cellular (mobile) communications.

11:25 Fast EMC Diagnostics of Complex On-Board Radio Systems with use of Experimentally Refined Worst-Case and Conditionally Worst-Case Models of "Transmitter-to-Receiver" Interactions
Eugene Sinkevich[1], Vladimir Mordachev[1], Alexey Galenko[1], Yauhen Kharasheuski[2], Mikalai Panchanka2, Viktar Bobra[2]
[1]Belorusskiy Gosudarstvennyy Universitet Informatiki I Radioelektroniki, Belarus; [2]Research Institute of Automation Facilities, Belarus
Abstract: An improved computationally efficient technique for EMC diagnostics of radio equipment of complex on-board radio-electronic systems is presented. The first improvement is based on the use of worst-case and conditionally worst-case mathematical models to describe unwanted electromagnetic (EM) interactions between transmitters and receivers of the system, which allows to detect all potentially dangerous interactions rapidly and avoid second-type errors when assessing the danger of these interactions. The second improvement concerns the iterative refinement of worst-case and conditionally worst-case models of potentially dangerous interactions (including models of transmitter radiation spectra, receivers susceptibility characteristics, amplitude-frequency characteristics of decoupling antenna filters and EM spurious couplings between antennas of on-board system) by the use of both numerical simulation methods and measurements to improve the accuracy of EMC diagnostics. The third improvement is associated with the use of an extremely effective technique of discrete nonlinear behavior simulation of radio receivers' operation in a severe EM environment formed by a set of powerful EM radiations from radio transmitters of the analyzed on-board system and a variety of external EM fields generated by various radio systems of different services.

11:50 Analysis of EMC between Medical Short-Range Devices and Equipment of Wireless Systems
Aliaksandr Svistunou[1], Vladimir Mordachev[1], Eugene Sinkevich1, Ming Ye[2], Arthur Dubovik[1]
[1]*Belorusskiy Gosudarstvennyy Universitet Informatiki I Radioelektroniki, Belarus;* [2]*Huawei Technologies Sweden AB, Sweden*
Abstract: The analysis of EMC between medical short range devices of body area network system, capsule endoscopy system, active implant system and wireless equipment of mobile stations of cellular communications (LTE and 5G), RLAN equipment, NB IoT sensors operating inside a hospital building is performed. The integrated interference margin is used as a criterion of EMC. Results of the analysis show the following: 1) the equipment of wireless systems can create the interference to all considered types of medical short range devices (as well as medical short range devices can create the interference to receivers of the wireless systems) in case of allocation of emitters and receptors inside the same room or in neighboring rooms; 2) in order to ensure EMC of considered systems, it is advised to set more stringent requirements on characteristics of susceptibility of the medical equipment to radiofrequency electromagnetic fields created by wireless equipment of 4G/5G networks as well as on spurious emissions of transmitters of wireless systems. The results can be used in diagnostics of intersystem EMC in order to ensure safety of use of mobile wireless telecommunication equipment regarding medical vital devices in conditions of mass distribution of 4G/5G wireless information services in hospitals.

12:15 Experimental Studies of Spectrum Masks of 5G Base Station Transmitter operating in DSS Mode to estimate Feasibility of Accommodation of 5G Network within 4G Frequency Channels
Valery Tikhvinskiy[1], Victor Koval[2], Pavel Korchagin[2], Altay Aitmagambetov[3]
[1]*University of Communications and Informatics, Russian Federation;* [2]*Geyser-Telecom Ltd., Russian Federation;* [3]*The International Information Technology University, Kazakhstan*
Abstract: One of the most attractive ways to quickly deploy 5G networks when new frequency bands are not yet available to local operators is to do it on the basis of Dynamic Spectrum Sharing (DSS) solution. The DSS mode provides 5G network with access to 4G spectrum resource and the use of a single-frequency broadcast network in which one part of OFDM-signal resource blocks is used to transmit LTE (4G) resource blocks, and the other part is used to transmit 5G resource blocks. Bearing in mind that 4G operator has a relevant spectrum license to transmit LTE signals, it is necessary to show that the spectrum mask of the combined frequency channel accommodating both 4G and 5G OFDM-signal resource blocks does not exceed authorized bandwidth and ensures EMC between LTE and 5G networks. Thus, the aim of the authors was to conduct experimental studies of spectrum masks of the combined 4G/5G frequency channel for different LTE channel bandwidths in real operating conditions of 5G base stations operating in the DSS mode and demonstrate that EMC is feasible.

TECHNICAL PAPERS
TP-TUE-1B

CABLES AND LISN

(SPONSORED BY TC-2)

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

13:30 **Validity of Mains Cable Termination by VHF-LISN for Radiated Emission Measurement Compared with the Conventional Test Condition**
Kunihiro Osabe[1], Nobuo Kuwabara[2], Hidenori Muramatsu[1]
[1]VCCI Council, Japan; [2]Kyushu Institute of Technology, Japan
Abstract: In this article, we introduce an alternative terminating condition for the AC mains cable of Equipment Under Test (EUT) with appropriate common mode impedance by VHF-LISN in radiated emission measurements at test sites. In Round Robin Testing (RRT) conducted by CISPR SC-A/I joint ad hoc group 6 (JAHG6), inter-laboratory reproducibility was significantly improved by setting terminating conditions for the AC mains cable of EUT, thus, reflecting the same results as those of previous RRT conducted by CISPR/SC-I. However, since only a conventional comb generator was employed, differences in radiated emission of EUT with and without AC mains cable termination by VHF-LISN were not clear. In this RRT, we performed actual product measurement (prepared by ten participating laboratories) and compared the accumulative probability distributions of radiated emissions by using two types of VHF-LISN of different termination impedances and without a termination device (deemed as the actual operating condition). From the investigation results, mains cable termination with VHF-LISN of a specific common mode impedance was deemed to be valid for radiated emission measurement.

13:55 **Coupling Analysis Under Lightning Indirect Effects for Cable Bundles with Different Ground Plates in Unmanned Aerial Vehicles**
David Ramos Somolinos[1], Carolina Morales Blanco[2], Daniel López Sanz[1], Borja Plaza Gallardo[1], David Poyatos Martínez[1]
[1]Instituto Nacional de Técnica Aeroespacial, Spain; [2]Procesia, Spain
Abstract: It is increasingly common in aerospace industries to take advantage of novel composite materials in their manufacturing processes to improve performance and reduce costs. Obtaining the electromagnetic (EM) characterization of these materials or a combination of them is essential to ensure safety and EM compatibility. In this paper, a laminate of the central fuselage of an aircraft developed at INTA is recreated. This aircraft is called MILANO and it is mostly made of Carbon Fiber Composite (CFC). The same material is used for the laminate. Besides, another metallic plate is built in order to compare the performance of the former one with respect to a Perfect Electric Conductor (PEC). The main goal of this work is studying the coupling between the cable bundles embedded in the MILANO and how is this affected by the different materials of the ground plate (metal and CFC). Two kind of tests are carried out: S-parameters measurents and injection of Lightning Indirect Effect (LIE) waveforms. Sparameters results are then obtained through simulation too and compared with both the metallic and the CFC sample.

TECHNICAL PAPERS
TP-TUE-2B

ELECTROMAGNETIC ENVIRONMENTS IN MOBILE AND TRANSPORTATION

(SPONSORED BY TC-3)

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

13:30 **Simulation and Measurement of Multi-Source Electromagnetic Environment of Urban Rail Transit Communication Room**
Jiaqi Wang[1], Yinghong Wen[1,2], Wenxuan Wei[1], Jie Ren[1]
[1]Beijing Jiaotong University, China; [2]Beijing Engineering Research Center of EMC and GNSS Technology for Rail Transportation, China
Abstract: The safety of the equipment in the communication room is the basis to ensure the reliable operation of the urban rail transit. Therefore, it is of great significance to investigate the complex electromagnetic field distribution and radiation level in the communication room. On the basis of investigation, the typical interference sources and their transmission routes are explored first. The influence of each interference source on the internal electromagnetic environment is simulated and analyzed, which shows good consistency with the measured.

13:55 **Approaching User Exposure Assessment using Broadband versus Frequency-Selective Methods: IEEE 802.11ax Mobile Device Emitted Field**
Annamaria Sârbu[1], Simona Miclăuș[1], Emil Șorecău[2], Paul Bechet[1]
[1]Nicolae Bălcescu Land Forces Military Academy, Romania; [2]Technical University of Cluj Napoca, Romania
Abstract: We have approached user exposure to EMF originated from an IEEE 802.11ax client (mobile phone) by using both broadband and frequency selective measurement instrumentation. All the measured field strengths were situated below the ICNIRP and IEEE reference levels for public safe exposure. Higher field levels were observed during file upload followed by file download and then video streaming. Following, we propose an original algorithm for similarity evaluation of the two measurement system readings based on cross-correlation and dynamic time warping (DTW) algorithm. We observed clear differences between probes in general, and between their ability to correctly follow the field strengths amplitude time dynamic. The proposed algorithm offers a series of advantages compared to traditional response time investigation. While the temporal response of the used broadband field probe appears to be adequate for 802.11ax signals, the amplitude resolution exhibits a serious drawback for measuring low field levels associated with some Wi-Fi applications like video streaming.

14:20 **Improvement of EM Diffusion Performance of Checkerboard Structure in 28 GHz Band**
Yasutaka Murakami, Jerdvisanop Chakarothai, Katsumi Fujii
National Institute of Information and Communications Technology, Japan
Abstract: Recently, 5G wireless communications system has been deployed in 28 GHz band. Due to high propagation loss of EM waves, there are few paths which can reach receiving antenna when a blockage exists. In order to increase number of propagation paths and increase EM coverage for the system, checkerboard structures for diffusing EM waves emitted from transmitting antenna has been designed. The EM diffusion performance for different number of scattering elements was numerically evaluated and it was found that EM diffusion performance can be significantly improved by inverting the reflection phase of one element in the checkerboard pattern.

TECHNICAL PAPERS TP-TUE-3B

CONDUCTED EMISSIONS

(SPONSORED BY TC-7)

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

13:30 Electromagnetically Interfered Energy Metering Resulting from Droop of Current Transducers
Bas Ten Have, Niek Moonen, Frank Leferink, *University of Twente, The Netherlands*
Abstract: Non-linear equipment is increasingly being used in household situations to increase the efficiency of the power consumption of equipment. This results in conducted electromagnetic interference problems due to the switching of the equipment, which draws pulsed currents with high peak values and fast rising slopes. Accordingly, static energy meters, used to measure the energy consumption in households, show misreadings in conjunction with such pulsed currents. Therefore, a control meter is under construction which is used to validate the readings of an installed static energy meter. When validating the control meter, energy metering errors were found resulting from current droop of the current transducers. The droop in the current response multiplied with the voltage resulted in large energy metering errors of 38%. While no issues where found for linear, resistive, loads. This shows the need for pulsed immunity tests to validate energy measurement systems, because linear tests have not shown to be problematic.
BEST EMC PAPER FINALIST

13:55 Power Converter Impedance and Emission Characterization Below 150 kHz
Per Thaastrup Jensen[1], Pooya Davari[2]
[1]Force Technology, Denmark; [2]Aalborg University, Denmark
Abstract: IEC standardization is preparing general conducted emission limits for grid connected power converters in the frequency range between 2 kHz and 150 kHz, which has until recent years only been regulated for some categories of equipment. With the necessity of analyzing and estimating power converter behavior, this paper proposes a black-box modeling approach suitable for this new frequency range of interest. A method for measuring the dynamic power converter impedance when powered and in operation has been developed and proven in practice by superposition of a multi-tone signal onto the AC input voltage to the power converter under different load conditions. Later, through extraction of the noise source, an equivalent circuit diagram of the power converter is developed which can be used for emission estimation and further analysis such as EMI filter designing. The provided experimental results showed high accuracy of the proposed method and its suitability in estimating EMI

14:20 Reduction of Mode Conversion of Differential-Mode Noise to Common-Mode Noise by Printed Circuit Board Modification for Unbalanced EMI Filter Network
Srinath Penugonda[1], Zhifei Xu[1], Yuandong Guo[1], Muqi Ouyang[1], Minho Kim[2], Junesang Lee[2], Jungrae Ha[2], Hyewon Lee[2], Sangwon Yun[2], Jun Fan[1], Hongseok Kim[1]
[1]Missouri University of Science and Technology, USA; [2]Mando Corporation, Korea
Abstract: This paper presents a method for the reduction of mode conversion from differential-mode (DM) noise to common-mode (CM) noise in an unbalanced EMI filter. The unbalanced nature in the EMI filter is a result of not incorporating all the required filter components due to space and cost constraints or due to the parasitic impedances of a printed circuit board (PCB). It is demonstrated that the reduction of mode conversion from DM noise to CM noise can be achieved by modifying the current path on the ground (GND) layer of the PCB of the unbalanced EMI filter. The currents on the GND layer are guided to take a longer route by introducing a “cutout” to the ground plane in the PCB, which increases the impedance of the current path on the GND layer. This approach does not require additional components to the EMI filter for the reduction of CM noise due to the mode conversion. Simulations show that the cutout decreases the CM noise converted from the DM noise by at least 4 dB in the AM radio frequency band (530 kHz – 1.8 MHz).

14:45 Near Field Considerations for Modeling Harness in Low Frequencies
Anargyros T. Baklezos[1,2], Theodoros N. Kapetanakis[1], Ioannis O. Vardiambasis[1], Christos N. Capsalis[2], Christos D. Nikolopoulos[1]
[1]Hellenic Mediterranean University, Greece; [2]National Technical University of Athens, Greece
Abstract: Limited knowledge regarding modeling cables in extremely low frequency (ELF) regime can be found in literature. This work aims to provide insights for accurate modeling of harness routing, as required in various ESA’s studies for space science missions regarding electromagnetic cleanliness considerations. More precisely, this work considers a straight cable path as an infinitesimal dipole source when modeled in the ELF region and studying the implications on the resulting electric field in close proximity to the source.

TECHNICAL PAPERS TP-TUE-4B

TESTING AND EMC APPLICATION OF COMPOSITE MATERIALS

(SPONSORED BY TC-4)

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

13:30 3D Printed Electromagnetic Absorber Built with Conductive Carbon-Filled Filament
Rui Mi[1], Wei Zhang[1], Kaustav Ghosh[2], Sameer Walunj[2], Qian Liu[2], Jacques Rollin[2], Philippe Sochoux[2], David Pommerenke[3], Victor Khilkevich[1]
[1]Missouri University of Science and Technology, USA; [2]Juniper Networks Inc., USA; [3]Technische Universität Graz, Austria;
Abstract: This article presents a method for manufacturing a frequency selective surface (FSS) using the 3D printing technology, including material characterization, design, fabrication, and evaluation. The FSS design is based on a three-layer structure. The first layer is a 3D printed lossy material, the second layer is an air gap, and the third layer is a ground plane. By changing the geometrical parameters of the 3D printed layer, it is possible to tune the frequency of the absorption band of the FSS.
BEST EMC PAPER FINALIST

13:55 Literal Solutions for Optimal Design of Microwave Absorbing Composites
Alessandro G. D’Aloia, Marcello D’Amore, Maria Sabrina Sarto, *Sapienza University of Rome, Italy*
Abstract: This paper proposes a new approach for the optimal design of microwave absorbing composites backed by a PEC layer and characterized by frequency dependent permeability and permittivity. The reflection coefficient is expressed as a function of the difference between the absorber hyperbolic input impedance and the free space wave impedance, considering an impinging plane wave with either normal or oblique incidence angle. The impedance matching condition for the selected frequency and incidence angle is solved in terms of literal expression of the optimal thickness, which is compared with the one quarter wavelength thickness given by a new accurate expression. The optimal thickness is used for the design of microwave absorbers made by dielectric-magnetic and dielectric composite materials. The frequency spectra of the absorber input impedances and reflection coefficients are computed in the frequency range from 2 GHz up to 18 GHz and for an incidence angle ranging between 0° and 30°. The obtained results prove the validity of the literal expression of the composite optimal thickness which explicitly shows the crucial parameters for the absorbing performances, obscured in common numerical procedures.

14:20 Analysis of EMI Shielding Effectiveness for Plastic Fiber Composites in the 5G Sub-6 GHz Band
P.A. Martinez[1], J. Victoria[2], J. Torres[1], A. Suarez[1], A. Alcarria[2], A. Amaro1, B. Galindo-Galiana[3], C. Losada-Fernandez[3], V. Ramirez-Monsell[3], B. Lopez-Rius[3]
[1]Universitat de Valencia, Spain; [2]Würth Elektronik eiSos GmbH & Co. KG, Germany; [3]Plastics Technology Centre AIMPLAS, Spain
Abstract: The study and modeling of EMC are becoming more critical than ever due to the ubiquitous presence of electronic circuits in all aspects of our lives. Specifically, it is crucial to extend these studies to the new frequencies that, in a few years, will be a reality in modern telecommunications systems, such as 5G and its derived technologies. A specific critical field where the proper EMI shielding has been ensured to avoid EMC problems is the electric autonomous vehicles (EAVs). The huge number of electronics systems in new vehicles will dramatically extend the demands on the EMI shielding solutions used to attenuate the radiated emissions that could affect circuits in the vehicle. Metals or metal alloys are the most common EMI shielding materials since they demonstrate adequate shielding capacity against EMI. However, polymers have become up-and-coming materials for EMI shielding with the characteristics of lightweight, flexibility, cost-effective, easy processing, and resistance to corrosion. Consequently, it is necessary to develop EMI shielding materials based on polymers, plastic materials, and fiber composites that ensure compliance with the different standards that regulate 5G and the proper operation of possible systems susceptible to the intentional and unintended signals generated by this new technology. This contribution focuses on characterizing different composite structures’ performance based on fibers combined with conductive materials in terms of shielding effectiveness, covering the 5G sub-6 GHz frequency range.

14:45 SE and HEMP Testing a Conductive Concrete Shielded Enclosure
Lim Nguyen[1], Matthew Bergstrom[2], David McGaw[3]
[1]University of Nebraska-Lincoln, USA; [2]Omni-Threat Structures, USA; [3]American Business Continuity Group, USA
Abstract: This paper reports shielding effectiveness (SE) and high-altitude electromagnetic pulse (HEMP) testing of a conductive concrete shielded enclosure. Test results demonstrate that the concrete structure can provide substantial pulse attenuation below the susceptibility levels of electronic equipment.

TECHNICAL PAPERS TP-TUE-5B

COEXISTENCE OF WIRELESS SYSTEMS

(SPONSORED BY TC-12)

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

13:30 Analysis on EMC influencing Factors of Electric Vehicle Wireless Charging System
Li Jiang, Haiming Liu, Xu Zhang
China Automotive Technology and Research Center, China
Abstract: This paper analyzes the structure of the electric vehicle wireless charging system, and uses actual samples to illustrate the severity of its EMC performance. Based on radiation emission test, the reference test set-up is given. Then, the coil offset, output power and other factors analyzing the EMC performance of the wireless charging system are verified based on actual product, which illustrate the necessity of prescan test.

13:55 Near Field Scanning based Characterization for Wireless Coexistence
Qiaolei Huang, Johns George, Chen Chen, Duck Ho Bae
Amazon Lab126, USA
Abstract: In this paper, a near field scanning based method is utilized to characterize wireless coexistence issues in design of a practical electronic device. This device supports multiple wireless communication radios. Based on near field, the radiation at the intermodulation frequency when two different radios both operate are evaluated. Reduction of scanned near field is proved to be an effective method to predict far field reduction.

TECHNICAL PAPERS TP-TUE-6B

SI/PI/EMC CO-SIMULATION AND CO-DESIGN

(SPONSORED BY TC-10)

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

13:30 SI Considerations in Flexible Channels on High-Speed Intra-Panel Interface for Large-Size Flat Panel Display Applications
Jinho Kim, Jihyun Lee, Seonha Lee, Jungsun Yoo, Sungwook Moon, Kil-Hoon Lee, Hyun-Wook Lim, Jaeyoul Lee
Samsung Electronics Co. Ltd., Korea
Abstract: In large-size flat panel display modules for TV applications, signaling channels designed on flexible printed circuit (FPC) cable or chip-on-film (COF) package are incomparably shorter than source PCBs, but they can play a significant role in determining overall signal integrity (SI) performance. This work analyzes interconnection designs on FPC cable and COF package in terms of impedance matching and crosstalk. It also provides channel design considerations and design guidelines for better SI performance in flexible channels on high-speed interface for large-size LCD TV applications.

13:55 Active EMI Noise-Canceling System
Mart Coenen
EMCMCC, The Netherlands
Abstract: With the increase of active power conversion using higher switching (PWM) frequencies, the need for filtering and shielding increases proportionally to minimize crosstalk and to adhere EMC compliance. As power conversion is often done without galvanic separation, every measure taken on either side; supply and/or load has an immediate impact on the other. Circuit optimization can be done for pre-defined EMI test environments which then often fails in prnctical installations. EMI noise reduction solutions need to be created which are adaptive and self-optimize to their environment. Additionally, compared to conventional filtering, active EMI noise cancellation can be compact, cheap, unconditional stable, power and crosstalk reduction efficient. As such, active EMI noise cancellation will eliminate the need for heavy stiff shielded cables, large and heavy inductances and capacitor banks, used in filter stages, and as such save weight and volume. This paper is the result of the ongoing research on an active EMI noise cancelling concept [1] as presented at EMC Europe 2018 in Amsterdam. This project has been carried out under the European Project H-2020, ESCEL, I-Mech which ran from 2017 and was successfully accomplished 2020 [10-11].

TECHNICAL PAPERS TP-TUE-7B

ACTIVE AND PASSIVE EMI FILTER TECHNIQUES

(SPONSORED BY SC-5)

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

13:30 Modeling and Stability Analysis of Digital EMI Filter
Junpeng Ji[1,2], Gang Li[1], Wenjie Chen[2], Fengjiao Cheng[1], Shuo Wang[3]
[1]Xi'an University of Technology, China; [2]Xi'an Jiaotong University, China; [3]University of Florida, USA
Abstract: Smaller size and lower loss are always the target of EMI filter which suppresses EMI emitted by power electronics converter. Digital EMI filter (DEF) is the best solution to suppress the conducted EMI in size and loss, especially for highpower converters. However, for current DEF model, it is not enough to describe the filtering ability. The model which can describe DEF stability is absent. To cope with these, this paper proposes a modeling technique about filter and stable behavior of DEF system. In proposed technique, the insertion gain model can accurately describe the filtering behavior, and the loop gain model can predict the stability of DEF system. Experimental testbed based on a Boost converter as EMI interference is built. Experimental results validate that the proposed model can successfully predict the stability and performance of DEF system.

13:55 Switching Noise Reduction of Synchronous DC-DC Buck Converter based on Smart Power Stages by Minimizing Parasitic Inductances
Lingling Zhao[1], Min Sun[1], Fei Xu[2], Qi Huang[1], Siming Pan[1]
[1]University of Electronic Science and Technology of China, China; [2]Chongqing University, China
Abstract: This paper introduces the smart power stage (SPS) chip for synchronous buck converter which has the feature of minimized parasitic inductances. Through analyzing the drain-source voltage of switching MOSFETs based on the parasitic inductances in one switching interval, the switching noise is obtained. Compared with the buck converter using discrete switching components, SPS built buck converters have greatly improved the voltage stress, eliminating false triggering pulses and increasing efficiency. Simulation results and experimental platforms of SPS-buck and DSC-buck were established to verify the correctness of the theory.

14:20 FPGA-based Adaptive Notch Filters for the Active Cancellation of Varying Electromagnetic Emissions of Power Electronic Inverter Systems
Tobias Dörlemann, Andreas Bendicks, Stephan Frei
Technische Universität Dortmund, Germany
Abstract: In many modern power electronic systems, fastswitching semiconductor devices are used to reduce switching losses. Due to steep switching waveforms and high switching frequencies, significant electromagnetic disturbances can be emitted. In contrast to conventional passive filter components, active cancellation methods are based on the controlled destructive interference between a noise signal and a corresponding anti-noise signal. Adaptive notch filters revealed themselves as a promising active EMI cancellation concept for periodic noise signals. In this work, adaptive notch filters are regarded in context of slowly time-varying periodic noise signals, e.g. pulse-width modulated signals as common in inverters. The corresponding noise signals consist of switching harmonics and adjacent sideband harmonics. Therefore, the notch filter's bandwidth comes into focus and an analytical approximation for the ideal adaptive notch filter's bandwidth is discussed. With help of this approximation, the adaptive notch filter can be parametrized specifically to a given noise spectrum and other requirements. The capability of the parametrization strategy and the adaptive notch filter itself are shown by simulation and measurement.

14:45 An EM-Circuit Co-Simulation Model to Predict Insertion Loss in a Busbar-PCB type EMI Filter
Kwangho Kim[1], Hwang Hee[2], Wansoo Nah[1]
[1]Sungkyunkwan University, Korea; [2]LS Automotive Corp., Korea
Abstract: Recently, a busbar-PCB structure for the installation of EMI filter has been used widely, especially in the automotive industry, which accommodates large current for driving electric motors. In this paper, an EM-circuit cosimulation model is proposed to efficiently estimate the insertion loss in a busbar-PCB type EMI filter. The developed cosimulation model was applied to a prototype busbar-PCB filter, and the predicted data proved to coincide very good to the measured insertion loss in common mode and differential mode up to 100 MHz, which confirms the validness of the proposed method.

TECHNICAL PAPERS TP-TUE-8B

JITTER/NOISE MODELING AND ANALYSIS

(SPONSORED BY TC-10)

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

13:30 Analysis of Power Supply Induced Jitter of High Speed Output Buffer with On-Die Low-Dropout Voltage Regulator
Yin Sun[1], Junho Joo[1], Jongjoo Lee[2], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]SK Hynix Inc., Korea
Abstract: In this paper, a methodology to analyze the power supply induced jitter (PSIJ) of high speed output buffer with on-die low-dropout (LDO) voltage regulator is presented. The approach relies on separate analysis of the LDO block and the buffer block. The total system level PSIJ analysis is achieved by combining the stand-alone results together. The AC analysis of power supply rejection ratio (PSRR) of LDO is performed. The loading effect of the buffer is also included. The PSIJ sensitivity analysis of the output buffer is obtained by transient analysis varying the frequency of sinusoidal power rail noise. The system PSIJ sensitivity analysis is completed by multiplying the LDO block PSRR response with the buffer block PSIJ sensitivity. This procedure allows designer to evaluate the system PSIJ with fewer and faster simulations. The contribution of different blocks can be clearly revealed. The proposed approach is validated through Hspice simulation of the entire system level circuit. Reasonably good accuracy has been achieved with the proposed analysis method.

13:55 Efficient Estimation of Noise Suppression Amount in Power Bus with Decoupling Capacitors using Lossy Resonator Filters
Sho Kanao, Kengo Iokibe, Yoshitaka Toyota
Okayama University, Japan
Abstract: To estimate the amount of noise suppressed by lossy resonator filters (LRFs) in a power bus with a decoupling capacitor, we used an equivalent circuit model considering the effect of the capacitor to know the suppression mechanism using the LRF. The discrepancy between the model and a full-wave simulation was approximately 2 dB.

14:20 Intended Electromagnetic Interference with Motion Detectors
Arne Pahl, Kai-Uwe Rathjen, Stefan Dickmann
Helmut Schmidt University, Germany
Abstract: Electromagnetic Interference with sensors has led to various problems in the past. In this work, two sensors, a gyroscope and an accelerometer are examined with respect to their susceptibility to interference. These sensors can be found in various electronic systems like drones, mobile phones, cars, etc.. The sensors are placed in a TEM cell and a signal generator excites a sine signal with the frequency between 5MHz and 1GHz. It is shown how susceptible to electrical fields the sensor system is. Finally, the analysis of the communication between the sensor and a controller over an I^2C bus shows how simple it is to disturb a sensor system.

14:45 Root Cause Analysis for the Phase Noise of the Clock Generator
Yuanzhuo Liu[1], Siqi Bai[1], Bo Pu[1], Zhifei Xu[1], Bichen Chen[2], Srinivas Venkataraman[2], Xu Wang[2], Jun Fan[1], DongHyun Kim[1]
[1]Missouri University of Science and Technology, USA; [2]Facebook, Inc., USA
Abstract: The performance of the high-speed links in the electronic system is highly dependent on the quality of the clock signal, which can be quantified by phase noise. The phase noise represents the instabilities of the signal in the frequency domain by measuring the power at various offsets from the carrier frequency. The root cause for the phase noise of the clock output at the resonance frequency is analyzed and identified in this paper. The power supply, the heat sink, and the external crystal are the main sources of the phase noise. Spurious occurs at the frequency of the power rail in the measured phase noise. The heat sink over the chip induces the conductive coupling noise to the clock. The low-frequency bump in the phase noise plot turns out to be induced by the external crystal design of the clock. More attention should be paid to the ground routing of the external crystal to ensure the quality of the clock output.

TECHNICAL PAPERS
SS-TUE-B

EMC DIAGNOSTICS OF COMPLEX SYSTEMS

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

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

Dzmitry Tsyanenka[1], Vladimir Mordachev[1], Eugene Sinkevich[1], Leanid Lynkou[1], Aleksander Prudnik[1], Alexey Galenko[1], Wen-Qing Guo[2], Xie Ma[2], Zhe Wang[2]
[1]Belorusskiy Gosudarstvennyy Universitet Informatiki I Radioelektroniki, Belarus; [2]China Electronics Technology Cyber Security Co., Ltd., China

Abstract: A wide set of shielding materials is used for protection of electronic systems and their critical components against the impact of Ultra Wideband Electromagnetic Pulses (UWB EMP). Widely known protection solutions are materials with polymer metalized films, the needle-punched and felt fabrics with conductive fillers, materials with ferromagnetic fillers, fabrics impregnated by electrolyte solutions such as regular water, NaCl and CaCl2 water solutions. In this paper, a technique for express in-situ measurement of UWB EMP shielding effectiveness of composite materials is developed. The shielding effectiveness of materials with complex structure is tested in framework of the developed technique by the use of Test System providing the generation of EMP with duration of 242324 ps (at half of maximum) and rise time of 139314 ps. The obtained value of shielding effectiveness for the EMP with the noted parameters is 15.5 dB for four layers of the needle-punched material with carbon additives impregnated by electrolyte solution, 13.9 dB for the two layers of felt fabric material with a layer of polymer metalized film, and about 12.5 dB for material with the metalized films.

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

Sergey Loyka, *University of Ottawa, Canada*

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

TECHNICAL PAPERS TP-WED-2A

REVERBERATION

(SPONSORED BY TC-2)

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

11:00 **Variability of the Mean Received Power from Several In-Band Antennas in Reverberation Chambers**
Gustav J. Freyer[1], Vignesh Rajamani[2]
[1]Consultant, USA; [2]Exponent Inc., Austria
Abstract: In-band antennas are used in reverberation chamber testing as receive antennas for several different functions including establishing a reference during chamber calibration and certification; establishing the desired test level and monitoring the test environment during the actual test. Historically there have been discussions about whether all in-band antennas will provide the same measured received power values in reverberation chambers or whether there will be significant differences in measured power from different antenna types. Attempts to address this issue have resulted in defining a range of antenna efficiencies with some included in compliance Standards. This paper provides test data on the measured received power from different antennas in two reverberation chambers over five different frequencies and highlights some of the differences and potential reasons for observed differences.

11:25 **Design of a Broadband Antenna for a Reverberation Chamber with Multiple Antenna Source Stirring**
A. De Leo, G. Cerri, P. Russo, V. Mariani Primiani
Università Politecnica delle Marche, Italy
Abstract: This paper presents the design of a broadband antenna to be used in a multiple antenna source stirring scenario. Usually, an array of monopole is placed onto the chamber's walls and the antennas are sequentially fed to perform the stirring action. But monopoles are intrinsically narrowband antennas: for this reason the use of a broadband antenna was investigated. The adopted structure is a helix antenna able to minimize the chamber volume reduction and to maximize the averaged power delivered to the chamber. Its performance was investigated by analyzing some typical RC performance indicators.

11:50 **Considerations on the Dwell Time for a Vibrating Intrinsic Reverberation Chamber**
Danilo Izzo[1,2], Robert Vogt-Ardatjew[2], Frank Leferink[1,2]
[1]Thales Nederland B.V., The Netherlands; [2]University of Twente, The Netherlands
Abstract: The dwell time is an important factor when conducting a radiated immunity test and shall be compatible with the response time of the device under investigation. In mode-stirred reverberation chambers, like the vibrating intrinsic reverberation chamber, the electromagnetic field is continuously stirred by the flexible, vibrating walls of the cavity and the time duration of high-strength interferences is generally unknown. Therefore, concerns have arisen regarding the proportion of time that the electromagnetic field level spends at or above the target level during the test. This study investigates, through empirical and simulated data, the expected value of this time interval, considering a threshold level equals to the quantile-80% of the field samples distribution. This information is useful for the user of the method, when considering a mode-stirred reverberation environment for devices with a well-known response time.

12:15 **Correlated Random Variables and Measurement Uncertainty in Reverberation Chambers**
Carlo Carobbi[1], Ramiro Serra[2]
[1]Universita degli Studi di Firenze, Italy; [2]Eindhoven University of Technology, The Netherlands
Abstract: We provide analytical expressions for the variance of the mean, variance, and Allan variance of a series of observations when taking correlation into account. Specific correlation models are adopted suitable for an insightful statistical analysis and for quantification of measurement uncertainty. An application to data measured in a reverberation chamber (RC) is also offered.

TECHNICAL PAPERS TP-WED-3A

MEASUREMENT AND CHARACTERIZATION OF ELECTROMAGNETIC ENVIRONMENTS

(SPONSORED BY TC-3)

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

11:00 **Estimation of Measurement Uncertainties in TEM-Cells based on Generalized Telegraphist's Equation**
Hoang Duc Pham[1], Katja Tüting[1], Heyno Garbe[1], Sven Fisahn[2]
[1]Leibniz Universität Hannover, Germany; [2]Bundeswehr Research Institute for Protective Technologies and NBC Protection, Germany
Abstract: This work examines the uncertainties of electric field measurements in coaxial TEM-cells with a circular cross-section. The TEM-cell can be used as a standardized field generator for probe calibration or EMC measurements. The main advantage of a coaxial TEM-cell with a circular cross-section is the inherent transverse cross-section, an enlarged frequency bandwidth, and the possibility of efficiently calculating its electromagnetic characteristics. Based on the generalized telegraphists equations, the electromagnetic fields and the TEM-cells resonance frequencies can be calculated. Using this approach, we can include various uncertainty factors into our mathematical model equation. We will derive all necessary equations for a complete uncertainty evaluation of a coaxial TEM-cell following the GUM.

11:25 **Wave Chaos in the Vibrating Intrinsic Reverberation Chamber**
Justin Geerarts, Ramiro Serra
Eindhoven University of Technology, The Netherlands
Abstract: In this work, we experimentally investigate the wave chaotic nature of the vibrating intrinsic reverberation chamber (VIRC).The measured normalized field intensity is confronted against different known probabilistic models in RCs, both traditional (e.g. the 22 distribution) and the distributions from wave chaos theory. A discussion on some limitations of applying the state-of-the-art chaotic models is introduced, in particular on the appropriate estimation of the modal overlap.

11:50 **Efficient Estimation of the Band-Ratio of HPEM Sources for IEME Classification**
Juan Galvis, David Martinez, Gideon N. Appiah, Fernando Albarracin-Vargas, Chaouki Kasmi, Nicolas Mora
Technology Innovation Institute, United Arab Emirates
Abstract: This work presents the development of an algorithm for the estimation of the band-ratio for discrete spectra. The proposed approach is compared with two additional methods in order to validate its efficiency.

11 AUGUST • 10:00 - 10:30 AM

AVIONIC / MIL-STD – IMPULSE TESTING UPDATE

EMC PARTNER

TECHNICAL PAPERS
TP-WED-5A

NEAR FIELD SYSTEMS FOR EVALUATION OF WIRELESS SYSTEMS

(SPONSORED BY TC-12)

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

11:00 **Improvement on the Accuracy of Near-Field Scanning using Tangential Electric Field Probe**
Wei Zhang[1], Shun Liu[1], Xin Yan[1], Takashi Enomoto[2], Hideki Shumiya[2], Kenji Araki[2], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]Sony Global Manufacturing and Operations Corporation, Japan
Abstract: This paper discussed the issues about the nearfield measurement with a differential electric (E) probe. Based on the physical understanding, a method to improve the accuracy of the measured E field is proposed by suppressing the common-mode noise and eliminating the unwanted magnetic (H) field coupling. By adding ferrites around the cables that connect to the differential E field probe, suppression of the commonmode (CM) noise in the outer shield of the probe is achieved. In addition, the probe factor for the unwanted H field coupling of the E field probe is calibrated, which can be used to eliminate the H field coupling during the E field measurement. The effectiveness of the proposed method has been demonstrated in experiments. This paper provides a practical method to obtain accurate E-field measurement with a tangential E field probe, especially in the cases where the detected signal of the unwanted coupling is comparable to the wanted coupling.

11:25 **Radiated Noise Source Characterization based on Magnitude-Only Near Field**
Ze Sun[1], Yansheng Wang[2], Warren Lee[2], Ken Wu[2], DongHyun Kim[1]
[1]Missouri University of Science and Technology, USA; [2]Google Inc., USA
Abstract: Accurate noise source characterization is critical in increasing the accuracy of desense simulations. However, characterization of the emission sources in full-wave simulations often lacks accuracy. In this paper, a fast and accurate method to extract equivalent dipole moments of radiated noise sources is proposed. The proposed method uses the genetic algorithm to optimize the position and type of dipoles, and it also uses a back-and-forth iteration algorithm to retrieve phase based on the magnitude information of two observation planes with different heights. Compared with the traditional equivalent dipole extraction algorithms, this method can minimize the number of reconstructed dipoles and avoid the complicated and timeconsuming phase measurement. This method is verified by comparing the measurement and simulation of coupled noise from an image sensor to a nearby cellular antenna.

11:50 **Analysis of Compensation Networks for a Transcutaneous WPT System to Achieve Compliance with ICNIRP Basic Restrictions**
S. Cruciani[1], T. Campi[2], F. Maradei1, M. Feliziani[2]
[1]Sapienza University of Rome, Italy; [2]University of Aquila, L'Aquila, Italy
Abstract: The paper deals with the application of the wireless power transfer (WPT) technology, based on near field inductive coupling, in implantable medical devices (IMDs). A transcutaneous WPT system is considered here to transfer a power of over 10 watts. The selection of the most adequate topology of the compensation network is a key point to mitigate the variation of physical quantities inside the human body, such as internal electric field E and specific absorption rate (SAR). An investigation is here provided to demonstrate the different behavior of each compensation topology in order to obtain compliance with ICNIRP limits in biological tissues.

12:15 **Long-Term Evolution Uplink Impacts on Aeronautical Mobile Telemetry**
Duncan A. McGillivray, Jack G. Sklar, M. Keith Forsyth
National Institute of Standards and Technology, USA
Abstract: The National Advanced Spectrum Communications Test Network conducted a test campaign to evaluate impacts of advanced wireless services - 3 long-term evolution uplink (1755 MHz - 1780 MHz) signals on adjacent Lband (1780 MHz – 1850 MHz) aeronautical mobile telemetry air to ground links. The test campaign applied a host of field and laboratory-collected long-term evolution uplink waveforms to an aeronautical mobile telemetry system in a highly automated, cabled testbed. We showcase the test methodology and lessons learned of a susceptibility study in the adjacent band as applied to a telemetry receiver under test.

TECHNICAL PAPERS
TP-WED-6A

NUMERICAL MODELING AND SIMULATION TECHNIQUES 2

(SPONSORED BY TC-10)

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

11:00 **Order Determination of the Multiple Edge Response Method for Nonlinear Links**
Yuhuan Luo, Xiuqin Chu, Jun Wang, Yan Rong, Feng Wu, Wenting Guo
Xidian University, China
Abstract: As data rates of high-speed links increase, the impact of nonlinearity is becoming more and more prominent. To capture the effect of nonlinear behaviors on the system response, the multiple edge response (MER) method was proposed for nonlinear systems. High order MER can capture sufficient nonlinearity and achieve accurate results. However, it is quite time-consuming to obtain a large amount of edge responses for the higher order MER. Therefore, it is necessary to study the minimum required order of MER to estimate the system performance. In this work, a simple and efficient method based on multiple pulse responses is proposed to estimate the minimum required order of MER. The accuracy of the proposed method is validated by simulation for a nonlinear high-speed link.

11:25 **Uncertainty Quantification of a CMOS Oscillator using Stochastic Collocation Techniques**
Aksh Chordia, Jai Narayan Tripathi
Indian Institute of Technology Jodhpur, India
Abstract: In recent years, stochastic techniques have emerged as computationally superior techniques for Uncertainty Quantification (UQ). This paper focuses on the application of different stochastic techniques based on Stochastic Collocation (SC) for UQ. Here, the performance of different SC approaches like interpolation, regression and pseudo-spectral projection is assessed for an illustrative example of a 2:4 GHz CMOS LC oscillator. The application of these approaches for the oscillator circuit is investigated by performing the UQ of its phase noise output. The approaches are further compared with the traditional Monte Carlo simulations. The advantages and disadvantages of each of the methods clearly emerge from our study that helps in choosing the appropriate technique for modeling the uncertainty for any given similar oscillator circuit.

11:50 **Modeling of Power Supply Noise Associated with Package Parasitics in an On-Chip LDO Regulator**
Junho Joo[1], Yin Sun[1], Jongjoo Lee[2], Sunkyu Kong[2], Soonku Kang[2], Inmyung Song[2], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]SK hynix Inc., Korea
Abstract: In this paper, the power supply noise associated with package parasitics in an on-chip low-dropout (LDO) regulator is investigated. The on-chip LDO regulator with off-chip decoupling capacitors has power supply rail noise typically in the frequency range of few hundreds of MHz, which is related to the inductive package interconnects and the parasitic capacitance of the pass transistor. An equivalent circuit is proposed to model the power supply noise and understand the effect of inductive package interconnects. Based on the proposed equivalent circuit, the mitigation of the power supply noise from a package design perspective is discussed.

12:15 **Simplified De-Embedding for Return Loss Estimation**
Syed Bokhari, *Fidus Systems Incorporated, Canada*
Abstract: The work presented in this paper addresses two important Signal Integrity applications. First, s-parameter measurements of a DUT (denoted by D) invariably involve a Test fixture (denoted by F). De-embedding requires the sparameters of the test fixture, and an s-parameter simulator. In a second application, it is desirable to know the return loss of a link comprising several parts which again requires an sparameter simulator. During a channel system architecture phase, quick estimates are needed. These are easy to do with insertion loss, but not with return loss, and this work presents a simple approximation useful in both cases.

TECHNICAL PAPERS TP-WED-7A

POWER ELECTRONICS EMI MODELING AND MEASUREMENT I

(SPONSORED BY SC-5)

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

11:00 **Evaluating EMI of Unshielded Cables in High Frequency GaN Inverter Application**
Julian Dobusch[1], Daniel Kuebrich[1], Thomas Duerbaum[1], Fabian Diepold[2]
[1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany; [2]Siemens AG, Germany
Abstract: Inverters in VSDs represent a common source of EMI. The steep voltage slopes of modern power electronics with their high frequency share can cause radiated emissions. Therefore, shielded motor cables are used to minimize these emissions. However, in order to reduce costs, unshielded cables are an attractive option. This paper analyses an inverter setup with different motor cables. A measurement setup is presented in order to investigate the proper PE connection for complying with the standards.

11:25 **Common-Mode and Differential-Mode Prediction in a Drive System by Transmission-Line Theory**
Andrea Zingariello, Vefa Karakasli, Gerd Griepentrog, *Technische Universität Darmstadt, Germany*
Abstract: In drive systems, high-frequency leakage currents with frequencies up to several 10 MHz are likely to occur due to the switching operation of power electronic systems. Those leakage currents can unintentionally affect other components such as circuit breaker or residual current breaker and are hard to predict in most applications. A new model for the evaluation of the leakage current associated with each component in a three-phase system is proposed. The simulation model is easily adjustable according to the associated frequency range and it can evaluate both common mode and differential mode current. The proposed model result demonstrates a good agreement with the measurements up to 10 MHz

11:50 **Experimental Formulation to Estimate the Power Density in the Near Field of a Linear Transmitting Antenna**
Luis Fernando Destro, Benjamim Galvão
IBBX Innovation, Brazil
Abstract: In order to find an estimation of the Near Field power density in the space between two half-wave dipole antennas, an empirical formulation was developed to achieve the reduced gain of the dipoles in the Fresnel region. The power density is calculated by taking the values of the wave impedance at each point in the space, which were found through the measurement results. The obtained results are helpful to the project designer prior to laboratory testing, saving time and costs. In the design of an antenna for a RF Harvesting System, once the effective area of the receiving antenna is known, the estimation of the captured energy is found in the particular case presented herein.

12:15 **Online Input Impedance Extraction of SMPS with Different Impedance of Two Power Lines to Ground**
Junpeng Ji[1], Tuo Li[1], Jingjie Lu[1], Peng Luo[2]
[1]Xi'an University of Technology, China; [2]Suzhou Veichi Electric Co., Ltd., China
Abstract: It is important to acquire the impedance of switched-mode power supply (SMPS) under its operating condition for designing electromagnetic interference (EMI) filter. The online impedance extraction technique has become a research hot topic. However, the result of current online measurement technique is inaccurate due to ignorance of the different impedance of two power lines to ground of SMPS. To cope with this, an online impedance extraction technique is proposed in this paper. Considering the practical characteristics of impedance of two power lines to ground, the extraction principle and method is developed based on the established measurement models. Finally, the measurement platform with SMPS and measurement device under operating condition is built. Experimental results validate that the proposed technique can extract the differential mode (DM) and the impedance of two power lines to ground.

TECHNICAL PAPERS TP-WED-8A

HIGH-SPEED LINK/BUS DESIGN 2

(SPONSORED BY TC-10)

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

11:00 **Convolutional Neural Network-based Design of EBG Structures in High-Speed Packages and PCBs**
Seongbo Sim, Myunghoi Kim
Hankyong National University, Korea
Abstract: We propose a method of predicting a cutoff frequency band(Stopband) of electromagnetic band gap(EBG) structure that reduces noise using Convolutional Neural Network(CNN). The stopband is predicted by using the structures of ResNet and DenseNet, which are known CNN models. This is compared and analyzed with the results of the existing method.

11:25 **An Investigation on Multiple Reflections and Group Delay Behavior in High-Speed System Designs**
Muqi Ouyang[1], Bo Pu[1], Kevin Cai2, Anna Gao[2], Srinath Penugonda[1], Liang Liu[1], Bidyut Sen[2], DongHyun Kim[1]
[1]Missouri University of Science and Technology, USA; [2]Cisco Systems, Inc., USA
Abstract: In this study, the analytical solution for the group delay of a high-speed system with large impedance mismatch is derived. The accuracy and applicability of the solution are validated by comparing the calculated results between the analytical formulation and commercial tool results. Causal frequency-dependent stripline model is used in the formulation, and the derivation of analytical formulation is based on the transmissions and reflections of wave components in the highspeed channel. Therefore, the causality of the system can be ensured, and the number of transmissions and reflections considered in the calculation can be specified in the formulation. The derived analytical results indicate that multiple reflections in a system with impedance mismatch will contribute to oscillations in the group delay curve, but the minimum group delay at the valleys of the oscillations does not appear to be the minimum propagation delay of the system. The benefits of having analytical results play a critical role in identifying channel impairments in high-speed designs.

11:50 **Automated Full-Board SI Scan for High-Speed Applications up to 112Gb/s and Beyond**
Kevin Cai[1], Anna Gao[1], Bidyut Sen[1], Joshua Wan[2], Feng Ling[2]
[1]Cisco Systems Inc., USA; [2]Xpeedic Technology, Inc., USA
Abstract: With the signal speeds doubling for every generation, PCB design is becoming more and more challenging. The high-speed signal is getting more sensitive to the board layout impairments due to the dense placement of components. Therefore, a comprehensive scan including geometry, crosstalk, and noise coupling is necessary to ensure a quality eye at the receiver end for the concerned high-speed nets at 56Gb/s and beyond. In this paper, we offer a complete and automated full-board SI scan methodology. With such a methodology, subtle board layout defects are quickly pinpointed, including ground coverage, via stub length, trace necking, power via to signal via/trace spacing, and ground via to signal via distance, etc. Moreover, high-speed return loss and crosstalk scan in connector and ASIC pin fields are also implemented in an automated way with the help of the fast EM solver technology. As a result, the goal to have a confident PCB sign-off for the high-speed signals is achieved.

TECHNICAL PAPERS
SS-WED-A

ADVANCED METHODS TO MODEL, EVALUATE, AND MEASURE ELECTROMAGNETIC INTERFERENCE AT LOW FREQUENCY IN TRANSPORTATION AND RENEWABLE ENERGY SYSTEMS

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

11:00 **The Effect of Stray Capacitance to the Common Mode Current on Three-Phase System**
Muhammad S. Alamsyah[1], Francinei L. Vieira[1], Heyno Garbe[1], Sebastian Koj[2]
[1]Leibniz Universitat Hannover, Germany; [2]IAV GmbH, Germany
Abstract: The common-mode (CM) current phenomena is one of many problems in the EMC world due to the radiated magnetic field caused by it. A power transmission line with a delta-connection both generator and load normally do not have a connection to ground to establish a line for the return current. To determine the CM current, finding the stray capacitances to the ground is highly important because they are used as the return path for the CM current. In this paper, the investigation of predicting the CM current flowing through the stray capacitances will be done at a three-phase equivalent system of a wind turbine (WT). The wind turbine body is the place where the CM current flows, due to the stray capacitances between the power cables and the WT body around it. The CM current can be determined using the current magnitudes in a pointer-image method, which has a good agreement for CM current prediction and it might become a very useful tool applicable to measurements.

11:25 **Electromagnetic Fields on 3-Phase Induction Motor using Finite Element Analysis**
Douglas Nascimento[1,2], Robert Smolenski[1], Hermes Loschi[1,2,3], Flavia Grassi[4], Lu Wan[4], Abduselam H. Beshir[4]
[1]University of Zielona Góra, Poland; [2]University of Twente, Poland; [3]University of Nottingham, United Kingdom; [4]Politecnico di Milano, Italy
Abstract: Electromagnetic fields of a 3-phase induction motor, i.e., electric and magnetic fields and current density, are highly influenced by its geometry, conductor material (conductivity, magnetic permeability, electric permittivity, and nonlinearity), and boundary conditions applied (interface between conductors and dielectrics). Through Finite Element Analysis (FEA), the behavior of electromagnetic fields can be predicted. Thus, favoring the electromagnetic interference mitigation techniques of the 3-phase induction motor. Therefore, this paper presents numerical modeling with FEA, based on COMSOL, as an early pre-compliance tool to investigate the current density distribution and electric and magnetic fields. The validation of the modeling approach will be presented and discussed considering a 3-phase induction motor. Furthermore, CISPR 25 will be considered to evaluate the interactions between electric and magnetic fields, current density distribution, and skin effect on an increasing frequency.

11:50 **Micro-Grid Inrush Current Stability Analysis**
Alexander Matthee, Niek Moonen, Frank Leferink
University of Twente, The Netherlands
Abstract: Transient currents can severely impact the operation of weak or islanded grids. Inrush current electromagnetic compatibility challenges, due to their unpredictable and intermittent nature, are very difficult to identify. Using multi-point synchronised measurements, analysis is performed on an inverter. The supply powers various loads that are observed during cold start as well as under load switching conditions. Inrush event triggered failure probability is linked to non linear and average load levels.

12:15 **The Effect of Spread Spectrum Modulation for a Buck Converter Coupled with a Single Wired Communication Link**
A. Pena-Quintal, K. Niewiadomski, V. Muneeswaran, S. Greedy, M. Sumner, D.W.P. Thomas
University of Nottingham, United Kingdom
Abstract: This paper explores the effect of using a Spread Spectrum modulation technique with a Buck Converter on a communication cable coupled at the input voltage. The EMI created by the switching of the power converter generates damped oscillations on the data cable that can have great impact on the quality of the communication channel. Frequency domain analysis shows lower EMI levels in the power cable when compared to the standard deterministic modulation. However, there is no real improvement to the actual communications as there in an increase in the measured Bit Error Rate when evaluated experimentally.

TECHNICAL PAPERS
TP-WED-1B

ANTENNAS AND ANALYSIS

(SPONSORED BY TC-2)

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

13:30 **Localized Time Rotation of the Electric Field Near the Boundary of the Reactive Near Field of a Dipolar Antenna**
James McLean, *TDK R&D Corp., USA*
Abstract: It is well known that in the reactive near electromagnetic field of a dipolar antenna such as a 1.4-m biconical antenna the electromagnetic field is predominantly electric in nature and that in some immunity measurements such as MIL- 461, RS 103, the DUT is located in this region. That the field is predominantly electric in nature is considered acceptable if the anticipated coupling mechanism into the DUT is electric. It is less widely noted that near the boundary of the reactive near field (the induction zone) and outside of the H-plane of the dipole, the near electric field vector undergoes time rotation. For the geometry of MIL-461 RS 103 with a DUT located 1 meter from a 1.4-m biconical dipole we show that in the vicinity of 100 MHz, in some portions of the uniform field area, the electric field appears to be pseudo-circularly polarized with two orthogonal equal-magnitude components in phase quadrature. A simple analytical model is used to confirm the electric field rotation for an isolated dipole. A numerical simulation is employed to compute the field of a more complex and practical 1.4-m biconical antenna and also to model the effects of ground. Preliminary experimental results confirm the simulation. Clearly, such a field would affect a DUT differently from the way a linearly-polarized electric field would and also very differently from the way a true circularly-polarized plane wave would.

13:55 **Assessment of the Antenna-Equivalence Approach to Common-Mode Input Impedance Modeling**
A. Hubrechsen, L.A. Bronckers, A. Roc'h
Eindhoven University of Technology, The Netherlands
Abstract: Analytical modeling of the common-mode input impedance of a motor along with its cable for various installation characteristics would allow designers to assess EMI levels and to evaluate in an early stage if adaptations are needed in their cable installation. Earlier work has shown that the input impedance over frequency of such a system is mostly dominated by the cable. A common assumption is that a cable can be approximated as a monopole antenna above a ground plane, which has an input impedance equivalent to that of a dipole with a correction factor. We compare the Hall´en and King & Middleton dipole models to a measurement setup which is designed to reproduce parastic effects from the installation, to assess the validity of the analytical model. We analyze these results for various distances between the cable and the groundplane. We show that large discrepancies occur due to paristics of the installation and the presence of the groundplane, but that for some applications such closed-form analytical models may suffice in assessing frequencies at which radiated emissions occur.

14:20 **Consistency Analysis of S-parameter Indirect Measurement for Improving Estimation Result**
Noboru Maeda[1], Kengo Fukunaga[1], Keishi Miwa[2], Soichiro Ota[2]
[1]*Soken, Inc., Japan;* [2]*Toyota Motor Corporation, Japan*
Abstract: A consistency analysis procedure for our previously proposed indirect measurement method for the S-parameters of a multiport reciprocal circuit (e.g. bundle of wires or PCB traces) is proposed. In the measurement method, half of the ports are connected with some known loads and the remaining ports are directly measured by changing the load values to estimate the whole S-matrix. Some linear relations in the transfer coefficient submatrices between the direct and indirect measured ports have been used in the method. Those relations are selected to analyze the consistencies of the method from the theoretical viewpoint. Then, the indirect measurement method is applied to an example target, fixtures to measure the characteristics of wireharness mounted in a vehicle, to evaluate the consistencies in the calculation process. Also, a method to obtain an improved estimation result using the consistency evaluation is provided. Index Terms—Circuit analysis, Measurement techniques, Estimation theory, Automotive electronics .

14:45 **Comparison of Extrapolation Methods for De-Embedding Truncated Measured Transfer Functions**
David Martinez, Fernando Albarracin-Vargas, Juan Galvis, Gideon N. Appiah, Felix Vega, Chaouki Kasmi, Nicolas Mora
Technology Innovation Institute, United Arab Emirates
Abstract: This paper presents a comparison of three extrapolation methods used to re-construct the missing parts of truncated transfer functions used to de-embed measured transient electromagnetic signals.

TECHNICAL PAPERS TP-WED-2B

CHAMBERS

(SPONSORED BY TC-2)

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

13:30 **GTEM Cell – An Alternative Immunity Test Environment for Automotive Components**
Nitin Aggarwal[1], Moawia Al-Hamid[1], Ralf Vick[1], Steffen Schulze[2]
[1]Otto-von-Guericke-Universität Magdeburg, Germany; [2]Würth Elektronik eiSos GmbH, Germany
Abstract: ALSE (Absorber Lined Shielded Enclosure), BCI (Bulk Current Injection), TEM (Transverse Electromagnetic) cell and stripline are some of the methods described by the ISO 11452-x standard series to test vehicle sub-components. Till today, the GTEM (Gigahertz Transverse Electromagnetic) cell was not considered for vehicle sub-component immunity testing. In this paper, the GTEM cell is assessed, using a simple EUT (Equipment Under Test) with an attached cable. Different cable layouts were tested in order to find the one with the worst case coupling of the external noise. Additionally, the GTEM cell's measurement result is compared with the standard immunity methods, based on the measured RF current on the EUT cable harness and required forward power of the power amplifier.

13:55 **Statistical Approach to Verification of Field Uniformity and Dominance of the Primary Field Component in the GTEM Cell**
Yevhenii Hubariev, Jan Sroka
Warsaw University of Technology, Poland
Abstract: Software capable to set electrical field strength in any point under interest in the GTEM cell is developed for setting uniform field area in set of points and for verification of the dominance of the primary field component over secondary field components as demanded in the standard IEC 61000-4- 20. Microsoft. NET programming platform is used. Uniformity is checked with statistical criteria. In the standard 75 % confidence level is required. This level is suitable for N = 5 total number of points. 75 % means 4 points. However by N = 6 this level gives in some circumstances erroneous verdict. The Author propose other suitable confidence levels. The application is validated with the GTEM 5317 cell from EMCO.
Best EMC Paper Finalist

14:20 **Investigation of the Workbench Faraday Cage Method, IEC 61967-5**
Morten Sørensen[1], Søren Kjærulff Christensen[2], Claus Vittarp[3], Hans Ebert[4]
[1]University of Southern Denmark, Denmark; [2]Terma A/S, Denmark; [3]DEIF A/S, Denmark; [4]Aalborg University, Denmark
Abstract: The Workbench Faraday Cage Method (WBFC), IEC 61967 Part 5, is a method to estimate common mode current radiated emission caused by integrated circuits either applied on a standardized test-board or on a final printed circuit board. The presented work analyzes the method with the help of simulations of a simple microstrip board with two attached cables connected to ground. The analysis shows that the theoretical foundation of the method is weak and that the WBFC method gives a poor prediction of the radiated emission.

14:45 **Analysis of the Impact of the Monitoring Equipment on the Common-Mode to Differential-Mode Conversion in Bulk Current Injection Tests**
Pablo J. Gardella[1], Eduardo Mariani[2]
[1]Instituto Tecnológico de Buenos Aires, Argentina; [2]Allegro Microsystems Argentina, Argentina
Abstract: In this paper, the common-mode to differentialmode conversion in a Bulk Current Injection (BCI) test setup is analyzed in the presence of an optical fiber transmitter. A modular-basis analysis based on S-parameters measurements and Electromagnetic simulations has been performed. It is shown that the loading effects can change the insertion losses from the RF amplifier to the Devices Under Test, even at frequencies as low as 10MHz by 2dB and up to 23dB at worst cases. The study has been undertaken with the substitution and closed-loop methods. Quantification of this problem as well as mitigation strategies are proposed, analyzed and evaluated with the aim of improving the accuracy of BCI simulations at early-design stages. Considering the significant cost of redesigning at an advanced point in the product development cycle, the presented work expects to raise awareness about how even small changes in the BCI setup can remarkably compromise the outcome.

TECHNICAL PAPERS TP-WED-3B

2.5D/3D/EXOTIC ICS/PACKING AND EMERGING TECHNOLOGIES

(SPONSORED BY TC-10)

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

13:30 **Signal Integrity Design Methodology for Package in Co-Packaged Optics based on Figure of Merit as Channel Operating Margin**
Bo Pu[1], Jiayi He[2], Aaron Harmon[3], Yuandong Guo[3], Yuanzhuo Liu[3], Qiangming Cai[4]
[1]DeTooLIC Technology Co. , Ltd., China; [2]Cisco Systems, Inc., USA; [3]Missouri University of Science and Technology, USA; [4]Southwest University of Science and Technology, China
Abstract: Optical engines co-packaged with switching Application-Specific Integrated Circuit (ASIC) can offer a solution for advancement in bandwidth requirement and are potentially the ultimate direction for the long-touted "optical integration" era. This paper prnposes a novel signal integrity (SI) design methodology for package of co-packaged optics (CPO) by using channel operating margin (COM) as a figure of merit (FOM) for the first time. The conventional design method of SI based on individual criteria, such as masks for loss, crnsstalk, jitter, eye width/height, impedance, etc., are no longer able to be satisfied at the same time for cul'l'ent high-speed signals up to S0Gbps and even over lO0Gbps. COM, combining most of the individual criteria into a single value of signal to noise ratio, prnvides the possibility to estimate the quality of the channel and achieve a balance between performance and design complexity in the early design stage. In this work, a design methodology in a format of a visible map using the most two significant factors, loss, and crnsstalk, to satisfy the required COM is discussed in detail. With this novel methodology, one can predict the SI performance of a package in the early design stage when the real layout has not generated yet for full-wave simulation and can avoid the costly iteration in the conventional design concept.
BEST SIPI PAPER FINALIST

13:55 **Design and Analysis of On-Package Inductor of an Integrated Voltage Regulator for High-Q Factor and EMI Shielding in Active Interposer based 2.5D/3D ICs**
Subin Kim, Seungtaek Jeong, Boogyo Sim, Seongsoo Lee, Hyunwook Park, Haeyeon Kim, Joungho Kim
Korea Advanced Institute of Science and Technology, Korea
Abstract: On-package inductor, a promising type of filter inductor for integrated voltage regulator (IVR) requires low loss and shielding structure for high IVR efficiency and vertical noise coupling. In this paper, we proposed a novel on-package inductor of an integrated voltage regulator for high-Q factor and EMI shielding in active interposer based 2.5D/3D ICs. The proposed on-package inductor is composed of 4 parallel spiral loops and a shielding loop. The proposed inductor is verified with simulation and measurement in frequency domain. It achieves both high-Q factor and high shielding effectiveness using the package re-distribution layers only. With its shielding structure, vertical magnetic noise coupling to a noise sensitive circuit block on active interposer is successfully suppressed by 25.5 dB and normal operation of circuit is ensured.
BEST SIPI PAPER AND BEST STUDENT PAPER FINALIST

14:20 **The Whole Solution Space based Pin Pattern Optimization in BGA Technology**
Tao Wang, *Missouri University of Science and Technology, USA*
Abstract: I/O pin counts have been able to increase significantly thanks to ball grid array (BGA) packages. The pogopin socket and elastomeric socket are developed to test BGA devices for quick device screening, device characterization and final production test. The cross talk issue introduced by using production test socket is inevitable due to the high density of speed I/Os. To mitigate the cross talk problem, this paper discusses the methodology to quickly generate pin patterns in a full solution space aiming to select the optimal pin patterns which will produce acceptable SI/PI performance in the chip design phase.

TECHNICAL PAPERS
TP-WED-4B

CABLES AND CONNECTORS CONSIDERATIONS AND TESTING

(SPONSORED BY TC-4)

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

13:30 Single Pair Ethernet for the Industrial Internet of Things: Accurate Line Measurements
Matthias Hampe, Thomas Müller, Alexander Stieler
Ostfalia Hochschule für angewandte Wissenschaften, Germany
Abstract: In this work accurate measurement setups have been developed in order to determine the per-unit-length parameters of Single Pair Ethernet (SPE) transmission lines in the frequency range 0Hz 1.0GHz. In particular, the frequency dependence of all per-unit-length parameters will be derived, which goes far beyond the information in conventional data sheets. Based on these measurement results, accurate simulations in the fields of Automotive Ethernet, Internet of Things (IOT) and Industrial Internet of Things (IIOT) can be performed in future.

13:55 Investigation of an Iterative Method for Finding of Currents, Voltages and Termination Impedances of PCB Traces based on Phase-Less Near-Field Data
Robert Nowak, Stephan Frei
Technische Universität Dortmund, Germany
Abstract: The evaluation of near-field data can be an effective way to analyze EMI sources. In contrast to antenna measurements, near-field techniques can determine the emitted field without special requirements on the measurement environment. Moreover, critical sources can be found when current distributions can be identified. Therefore, current reconstruction methods for PCB traces were developed. With additional voltage information the termination impedances of the traces can be found. The known phase-less approaches suffers from different limitations, e.g., non-unique reconstruction results. In this paper, the necessary conditions for a unique reconstruction are discussed by investigating simulated phase-less near-field data. Based on these findings, measured near-field data of a PCB trace is evaluated, and the successful retrieval of the phase information is shown. Additionally, reconstructed voltage distributions are presented and compared to measurement data.

14:20 EMI Investigation and Mitigation of Flexible Flat Cables and Connectors
Xin Yan[1], Chunyu Wu[1], Dave Zhang[2], Shuai Jin[2], Songping Wu[2], Jun Fan1, Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]Google Inc., USA
Abstract: In modern mobile devices, as a result of the increase in data rate, requirement for higher density signal and costeffective solution, the flexible flat cable (FFC) now plays an important role to connect separated printed circuit boards (PCBs). Due to the low-cost fabrication and varied shielding structure, FFC has been identified as a noise source for electromagnetic interference (EMI) and desense issues. In this paper, the common mode noise generated from FFC and related connectors is investigated. With the assistance of full wave and circuit simulation, main cause of the common mode noise has been identified as the ground discontinuity and the related voltage difference between the PCB ground and the FFC ground. By providing better shielding and improving ground continuity, 11 dB reduction of total radiation power (TRP) is observed at 5 GHz.

14:45 Meta-Networks: Reconfigurable Cable Network Topologies for Interference Control
Mubarack Ahmed, Gabriele Gradoni, Stephen Creagh, Gregor Tanner
University of Nottingham, United Kingdom
Abstract: The importance of filters in signal processing abound in real-life applications such as audio electronics and power distribution networks. We introduce an efficient concept of constructing reconfigurable cable networks for interference control. The method utilises quantum-graph formalisms on composite nodes to implement reconfigurable, compact, wideband filters. By using a cascade of loop networks as building blocks, we show that such meta-networks can provide a flexible way of suppressing unwanted signals thereby increasing the efficiency of the underlying networks. Numerical results show that microwave interference can be filtered to allow only specific narrow (or wide) band frequencies to be fully transmitted while suppressing the other frequency bands. For example, a wave of frequency 0 f 6 GHz can be filtered using a cascade of three-loop networks with cable lengths 0:0001 l 0:05 m. By tuning one of the constituent cables, we are able to achieve maximum power transmission on a specific set of frequencies while completely suppressing signals of unwanted frequencies. The present paper shows how to implement narrow-, medium- and wide-band bandpass filters by adopting a simple and easy-to-design cable topology for the reconfigurable filter. The proposed solution can be easily integrated with solutions, including varactor diode and phase-shifter based architectures, to achieve practical implementations.

TECHNICAL PAPERS
TP-WED-5B

INTENTIONAL EMI AND HEMP

(SPONSORED BY TC-5)

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

13:30 Investigation of Protection Effects using Transient Voltage Suppressor Diodes-Based Circuits under High Power Microwave Pulses
Xun Zeng, Liang Zhou, Chengrui Zhang
Shanghai Jiao Tong University, China
Abstract: This study demonstrates the protection effects using transient voltage suppressor (TVS) diodes-based circuits under high power microwave (HPM) pulses. Two types of TVS diodes were studied, and their dynamic resistances versus the input power were obtained. Five types of topology using these two TVS diodes-based circuits were designed and compared with their voltage-ampere characteristics. The dynamic resistances of each branch of two typical circuits were simulated and compared. These TVS diodes-based protection circuits were measured under HPM pulses with their protection effects recorded. The highest protection ratio of these circuits is approximately 17 to 20 dB when the input power of HPM pulses ranges from 50 to 62.5 dBm. The simulated and measured results show close correlations. This analysis is useful for further electromagnetic protections under HPM pulses.

13:55 Non-Invasive Optimal Coupling upon Detection of a Local Change of Impedance in a Cable Network
K. Brahima Yeo, Matthieu Davy, Philippe Besnier
Université de Rennes 1
Abstract: In this paper, we apply a novel wavefront shaping technique within a cable network. By manipulating an array of crosstalk sources at different locations of the network, we demonstrate experimentally a strong enhancement of the intensity at a specific wire end where an impedance change occurs. The optimal wavefront for maximal focusing is determined non-invasively using the generalized Wigner-Smith operator. Our approach relies on two successive measurements of the scattering matrix at the injection ports, before and after the change. The optimal wavefront then closely corresponds to the first eigenstate of the generalized Wigner-Smith operator. Thus, a maximum focused intensity is reached at a remote distance without cooperation of the target, opening up new perspectives in the context of electromagnetic aggressions or attacks (cybersecurity).
BEST EMC STUDENT PAPER FINALIST

14:20 Susceptibility of Sensors to IEMI Attacks
Louis Cesbron Lavau[1], Michael Suhrke[1], Peter Knott[2]
[1]Fraunhofer Institute for Technological Trend Analysis INT, Germany; [2]RWTH Aachen, Germany
Abstract: The use of sensors has grown dramatically in recent years and many devices rely on the information provided by them. The potential vulnerability of sensors to attacks that use Intentional Electromagnetic Interference (IEMI) needs to be investigated. These attacks can cause typical errors such as a forced restart of a system, capturing erroneous sensor data, data communication being impeded or even disrupted, as well as a complete freeze of all processes. In order to measure the susceptibility of sensors to IEMI, it is important to understand the internal mechanisms that lead to the undesired effect. This paper investigates the impact of IEMI on three separate sensors: a Barometer, a Magnetometer and Current Sense Sensor. Having full access to sensor ports and interface information may help to explain erroneous values and could lead to the development of protective measures in the future.

14:45 Conducted Electromagnetic Pulse Testing of Digital Protective Relay Circuits
Tyler Bowman[1], Ross Guttromson[1], Tim Minteer[2], Travis Mooney[2], Matt Halligan[3]
[1]Sandia National Laboratories, USA; [2]Schweitzer Engineering Laboratories Inc., USA; [3]The Boeing Company, USA
Abstract: The electric power grid is one of the most critical national infrastructures, and determining the susceptibility of power grid elements to external factors is of significant importance for ensuring grid resilience. Reliable energy is vital to the safety and security of society. One potential threat to the power grid comes in the form of strong electromagnetic field transients arising from high-altitude nuclear weapon detonation. The radiated EM fields from these can affect the operation of electronic components via direct field exposure or from the conducted transients that arise from coupling onto long cables. Vulnerability to these pulses for many electrical components on the grid is unknown. This research focuses on conducted pulse testing of digital protective relays in a power substation and their associated high-voltage circuit breaker circuit and instrumentation transformer circuits. The relays, yard cables, power supplies, and components representing yard equipment were assembled in a manner consistent with installation in a substation to represent the pulse's propagation in the components and wiring. Equipment was tested using pulsed injection into the yard cable. The results showed no equipment damage or undesired operations for insult levels below 180 kV peak open circuit voltage, which is significantly higher than the anticipated coupling to substation yard cables.

TECHNICAL PAPERS
TP-WED-6B

POWER INTEGRITY ANALYSIS AND DESIGN 3

(SPONSORED BY TC-10)

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

13:30 **Reinforcement Learning for the Optimization of Decoupling Capacitors in Power Delivery Networks**
Seunghyup Han, Osama Waqar Bhatti, Madhavan Swaminathan
Georgia Institute of Technology, USA
Abstract: This paper proposes an advantage actor–critic (A2C) reinforcement learning (RL)–based method for the optimization of decoupling capacitor (decap) design. Unlike the previous RL-based methods used for the selection of decap types or decap placements, the proposed method enables placement and the simultaneous selection of both decap types and their placements, thereby simplifying the design process. The results show that the proposed method can provide a larger number of optimized decap design solutions compared with previous methods, and can yield decap solutions even for multi-port optimization.

13:55 **Impact of Accuracy of Capacitor ESL Values in High-Speed Power Delivery Network Design**
Mengxuan Li[1], Siqi Bai[2], Tamar Makharashvili[2], Albert E. Ruehli[2], James L. Drewniak[2], Daryl Beetner[2]
[1]Zhejiang University, China; [2]Missouri University of Science and Technology, USA
Abstract: While the equivalent series inductance (ESL) of multi-layer ceramic capacitors is widely used for power integrity analysis, the definition of ESL is ambiguous. Its value depends on how the capacitor is mounted on the PCB and on coupling to the nearby pads, traces, vias, and return plane. A single value for ESL is not sufficient to quantify the behavior of a capacitor in a broad number of power distribution network (PDN) designs and will lead to errors in the simulated PDN impedance. The impact of errors in ESL is analyzed in the following paper using measurements and simulations. The dependence of ESL on the layout is demonstrated using fullwave simulations. Measurements of 0402 and 0201 capacitors show that using the datasheet ESL can lead to up to 47% overestimation of the value of the total connection inductance, Labove. Test PDN structures with various stackups were analyzed to quatify the error in the total impedance due to errors in ESL. Results show that errors in ESL can lead to a 26% overestimation in the overall PDN impedance in the studied examples. Overestimation of ESL may cause more capacitors to be put on the board than needed.

14:20 **Metaheuristic Optimization of Decoupling Capacitors in a Power Delivery Network**
Surendra Hemaram, Jai Narayan Tripathi
Indian Institute of Technology Jodhpur, India
Abstract: In VLSI circuits and systems, it is a common practice to reduce power supply noise in power delivery networks by decoupling capacitors. The optimal selection and placement of decoupling capacitors is crucial for maintaining power integrity efficiently. This paper presents a metaheuristic technique based generic framework for decoupling capacitor optimization in a practical power delivery network. The cumulative impedance of a power delivery network is minimized below the target impedance by optimal selection and placement of decoupling capacitors using state-of-the-art metaheuristic algorithms. A comparative analysis of the performance of these algorithms is presented with the insights of practical implementation.

TECHNICAL PAPERS
TP-WED-7B

EMI ISSUES IN ELECTRIC VEHICLE CHARGING

(SPONSORED BY SC-5)

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

13:30 **Interference Risks from Wireless Power Transfer for Electric Vehicles**
Karina Fors, Sara Linder, Peter Stenumgaard, Kia Wiklundh
Swedish Defence Research Agency, Sweden
Abstract: Wireless power transmission (WPT) for electrical vehicle (EV) charging is a relatively new application of wireless energy transfer and its potential electromagnetic (EM) interference impact on other systems has not been investigated in depth. The proposed frequencies for WPT-EV are also used by radio communication systems or services. WPT systems transfer high power and can cause out-of-band and spurious EM emissions. In the analysis, both current and proposed emission limits for WPT systems are considered.

13:55 **Susceptibility Analysis of Different Communication Technologies in Presence of High Power Charging Emissions**
S. Jeschke, M. Kleinen, M. Olbrich, J. Bärenfänger
EMC Test NRW GmbH, Germany
Abstract: In the context of the electrification of public and heavy duty transportation vehicles, large batteries are implemented providing driving distances of several hundred kilometers. With the increase of battery capacity also comes a significant increase of its recharge time. Thus, currently a working group deals with new specifications for Megawatt Charging Systems (MCS) to enable DC charging at power levels of a few megavolt-amperes. Apart from the intended energy flow, the power electronic systems generate unwanted broadband emissions due to switching operations of the converters. These, in return, are coupled onto the wired communication lines, routed in parallel to the DC lines inside the charging cable, causing a potential degradation of the system. Therefore, a communication technology providing a sufficient data rate while not being susceptible to the disturbances generated by the power electronics of the chargers, is mandatory. This work focusses on the comparison of Controller Area Network (CAN), 100Base-T1 and Power Line Communication (PLC) as wired communication systems regarding their suitability for this purpose. Initially, typical disturbances of DC charging stations are identified and an appropriate test setup is proposed to generate the typical disturbances. Subsequently, measurements are conducted and the impact on the communication systems at physical and transport layer are compared and evaluated, respectively.

14:20 **Methodology for Reduction of Noise Interference in Wireless Charging Implantable ECG Sensor**
Dawon Jeong[1], Jongwook Kim[1], Haerim Kim[1], Dongwook Kim[2], Jaehyoung Park[1], Seongho Woo[1], Sungmin Park[3], Seungyoung Ahn[1]
[1]Korea Advanced Institute of Science and Technology, Korea; [2]Yeungnam University, Korea; [3]Pohang University of Science and Technology, Korea
Abstract: According to commercialization of implantable medical devices (IMDs), wireless charging system is necessary to solve the problem of battery duration. However, magnetic field generated by the wireless charging system may cause magnetic interference to the IMDs, especially, implantable ECG sensor. Therefore, this paper proposes a methodology for reduction of the noise interference at the implantable ECG sensor with wireless charging system. The methodology is to design the pattern of the trace between the sensing electrodes of the sensor using the effect of canceling the magnetic vectors. By applying the methodology, reduction of the noise interference was verified through simulation and measurement.

TECHNICAL PAPERS
TP-WED-8B

NUMERICAL MODELING AND SIMULATION TECHNIQUES 1

(SPONSORED BY TC-10)

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

13:30 Simulation of Mode Division Multiplex Transmission Method in Shielded Four-Wire Cable
Tohlu Matsushima, Takuya Sato, Yuki Fukumoto, Nobuo Kuwabara
Kyushu Institute of Technology, Japan
Abstract: A mode division multiplex transmission system that assigns signals to the eigenmodes of a transmission line was proposed for a cable that is uniform in the longitudinal direction. The transmission characteristics when the proposed method is used in a 1m long shielded untwisted 4-wire cable were verified by circuit simulation. It is shown that the proposed method enables four-channel simultaneous transmission. In addition, the proposed method significantly improves the crosstalk compared to the differential and single-ended transmission methods.
BEST SIPI PAPER FINALIST

13:55 Time Domain Modeling Method for the Crosstalk Analysis of Multiple Parallel Microstrip Lines
Zhihong Ye, Mengzu Ru, Xiaolin Wu, Bei Tang, Yi Wang, Yifeng Yuan
Chongqing University of Posts and Telecommunications, China
Abstract: Based on a higher order finite-difference time-domain (FDTD(2,4)) method, and transmission line (TL) equations, an efficient time domain hybrid method is presented for the fast crosstalk analysis of multiple parallel microstrip lines. In this method, the per unit length (p.u.l) inductance and capacitance distribution parameters of multiple microstrip lines are solved by the empirical formulas firstly. Then, the crosstalk model of multiple parallel microstrip lines excited by lumped voltage source is established by the TL equations. Finally, the higher order FDTD (2,4) selecting large space step is utilized to discretize the TL equations to obtain the transient responses on these microstrip lines and terminal loads, which needs less mesh number and improves the computation efficiency without decreasing the calculation accuracy. A numerical example of three parallel microstrip lines excited by lumped voltage source is employed to verify the accuracy and efficiency of this presented method by comparing with the BLT equation and commercial software CST in terms of precision and time consumption. Moreover, the effects of length, height and thickness of microstrip lines on the crosstalk results are simulated and analyzed to master some valuable crosstalk principles.

14:20 Modelling, Simulation and Optimization of High Density Capacitance Solutions for HPC Applications
Sumant Srikant, Seungki Nam, Sungwook Moon
Samsung Electronics Co. Ltd., Korea
Abstract: Present day HPC (High Performance Computing) designs require a vast range of Power Integrity (PI) optimization techniques to help meet challenging specifications. In this work, we present the multiple high density capacitance options available to help achieve the target and go over the various aspects involved (modelling, system simulations and optimizations) to achieve a PI compliant HPC system PDN design

14:45 Basic Study on a Novel FDTD Method Implemented Frequency Dispersion of PCB
Taiki Kitazawa[1,2], Ren Kitahara[3], Taiki Yamagiwa[3], Jerdvisanop Chakarothai[4], Yuichi Hayashi[2], Takashi Kasuga[1]
[1]National Institute of Technology, Nagano College, Japan; [2]Nara Institute of Science and Technology, Japan; [3]The University of Electro-Communications, Japan; [4]National Institute of Information and Communications Technology, Japan
Abstract: Signal transmission degrades significantly in GHz band due to loss of substrates, which is generally frequency-dependent. In this paper, the purpose is to develop a novel FDTD algorithm which can incorporate frequency dispersion of FR-4 substrates. Complex relative permittivity is measured up to 26.5 GHz by balanced-type circular disk resonator and then used in the FDTD analyses. It is shown that numerical results are in a good agreement with measurement results using VNA over the broad frequency range, demonstrating validity of the method.

TECHNICAL PAPERS
SS-WED-B

ADVANCED METHODS TO MODEL, EVALUATE, AND MEASURE ELECTROMAGNETIC INTERFERENCE AT LOW FREQUENCY IN TRANSPORTATION AND RENEWABLE ENERGY SYSTEMS

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

13:30 Assessment of Validity Conditions for Black-Box EMI Modelling of DC/DC Converters
Lu Wan, Abduselam Beshir, Xinglong Wu, Xiaokang Liu, Flavia Grassi, Giordano Spadacini, Sergio Pignari
Politecnico di Milano, Italy
Abstract: Black-box modelling approaches, based on suitable sets of measurements at the output ports of the device, are often exploited for the modelling of power converters to predict their conducted emissions. However, these techniques can be effectively applied only if the device to be modelled can be approximately treated as a linear and time-invariant (LTI) system. This assumption is not necessarily satisfied by every power converter. In order to investigate suitable conditions assuring effectiveness of black-box modelling for a boost converter, this work investigates the role that the converter input capacitors and the functional inductor play in masking the inherent non-linear and time variant behavior of the switching modules, and their impact on the effectiveness of the proposed black-box model. It will be shown that preliminary measurements of the differential mode impedance of the converter can provide useful information on the feasibility of black-box modelling techniques, even in the absence of detailed information on the internal architecture of the converter.

13:55 Behavior of COTS-Based Equipment under Ship Mains Supply Frequency Tolerance Requirements
Muhammad Imam Sudrajat[1,2], Niek Moonen[1], Hans Bergsma[3], Frank Leferink[1,3]; 1University of Twente,
The Netherlands; [2]Indonesian Institute of Sciences, Indonesia; [3]Thales Nederland B.V., The Netherlands
Abstract: The use of commercial off the shelf (COTS) devices have become a preferred strategy in ship system developments. In this work, we investigated the behavior of an uninterruptible power supply (UPS) using COTS-based equipment on a ship's power distribution system. It focuses on the implementation of IEC 60092-101 and STANAG 1008 Ed. 9 frequency tolerance requirements. One of the important benefits of this work is that it can be used as a consideration for the electromagnetic risk of integrating COTS-based equipment in an islanded power system like ships. The voltage and current behavior of the equipment under test were measured and recorded at four different points simultaneously using a multi-point measurement technique. From the analysis, it was found that when the frequency of the mains supply is deviated by 5 % the current at the UPS input is modulated and the maximum current is increased.

14:20 Comparison of Selected Support Vector Machine Approaches for Stochastic Power Electronic Circuit Simulation with Parasitics
Karol Niewiadomski, Sharmila Sumsurooah, David W.P. Thomas, *University of Nottingham, United Kingdom*
Abstract: This paper provides a comparison between optimization methods used for tuning the hyperparameters of Support Vector Machine model in a stochastic circuit simulation for conducted interference. The methodology is used to create a surrogate model of the frequency and amplitude of the dominant mode of the interference, which is a result of presence of parasitics in the considered switching circuit. Optimization algorithms are compared by obtaining the computational time and by computing a posteriori error of their predictions. The best optimization algorithm in the example provided here is found to be the quasi-Newton Broyden–Fletcher–Goldfarb–Shanno algorithm.
BEST EMC PAPER FINALIST

14:45 Using Time-Efficient Wavelet Packet Transform Decompositions to Analyze EMC Issues in Transportation Systems
Ileana-Diana Nicolae, Kostic Dusan, Petre-Marian Nicolae, Radu-Florin Marinescu, *University of Craiova, Romania*
Abstract: The paper deals with the design, test and usability of an optimized time-efficient decomposition relying on the wavelet packet transform (WPT) when used to analyze EMC interferences. Firstly, one describes the mathematical support and implementation aspects relative to deducing cutoff frequencies from the harmonic range 40...100 that can be used to separate and analyze components of high frequencies (depending on different accepted accuracies), when using an original WPT tree, denoted by T7. An original technique was conceived in order to generate flags (0/1) associated with the terminal nodes of T7 such as to reduce the number of decompositions required for their computation. Based on them, labels with 4 values were deduced for the nodes in the upper levels of T7, in the same idea of runtime saving. Simulations on synthetic data proved runtime savings of around 67.5% for both decomposition and re-composition of T7. The technique accuracy was tested by comparing the results of „low-pass" filtering with those yielded by the Matlab toolkit used for denoising and respectively with those obtained without the labeling technique. The set of cut-off frequencies available for filtering with T7 proved to be significantly larger than that provided by the Matlab toolkit. After the successful validation stage, the method was applied on 2 real datasets acquired from the terminals of an auxiliary converter from a locomotive.

TECHNICAL PAPERS
TP-THU-1A

POWER SYSTEMS

(SPONSORED BY TC-2)

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

11:00 Anticipating Common-Mode Conducted Emission of DC-DC Converter from Electric Near-Field Scan
A. Boyer, N. Nolhier, F. Caignet, S. Ben Dhia, *LAAS-CNRS, France*
Abstract: This paper aims at proposing a method based on electric near-field measurement to estimate common-mode conducted emission produced by DC-DC converter along a cable harness. The method is evaluated on two case studies: an academic board with simple rectangular copper island and buck converter board.

11:25 Practical Measurement of Aircraft Electrostatic Charging
Per Thaastrup Jensen, Anders Struwe Mynster
Force Technology, Denmark
Abstract: As part of risk assessment for helicopter hoisting operations a measurement campaign for practical evaluation of charge voltage and energy of an aircraft was performed. An electrostatic field meter setup was developed and tested using a drone setup and a helicopter setup. The measurement capability of the setups was demonstrated as being useable. The conversion factor between static field meter reading and the helicopter to ground potential as function of distance (height above ground) for the test setup has been derived and showed an inverse square root proportionality. This allowed for a helicopter potential measurement system without conductive wires between the helicopter and ground. The generation of electrostatic charging for a helicopter was confirmed using the developed test setup although weather conditions only allowed retrieval of one data series.

11:50 Voltage Distribution in Group-Grounded 8 x 2 Solar PV Panel Assembly during Lightning Strike
Faisal Peer Mohamed[1], Wah Hoon Siew[2]
[1]Military Technological College, Oman; [2]University of Strathclyde, United Kingdom
Abstract: This paper is focused on the effect of group grounding of solar PV assemblies using both end-point and mid-point grounding on the potential rise across the solar PV panels during a lightning strike. This system consists of 16 assemblies forming an 8x2 array. Simulation has been carried out for various lightning attachment points in PSPICE using the lossy transmission line model. Voltage drop at various points in the assembly is determined for various soil resistivities. Based on the simulation results, group grounding of solar PV panels with middle grounding shows a lower voltage transient potential rise compared to end grounding.

TECHNICAL PAPERS
TP-THU-2A

AUTOMOTIVE

(SPONSORED BY TC-2)

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

11:00 Forensic Analysis of Automotive Controller Area Network Emissions for Problem Resolution
Yu Xian Teo, Jiaqi Chen, Neil Ash, Alastair R. Ruddle, Anthony J.M. Martin
HORIBA MIRA Ltd., United Kingdom
Abstract: Electromagnetic emissions associated with the transmission of automotive controller area network (CAN) messages within a passenger car have been analysed and used to reconstruct the original CAN messages. Concurrent monitoring of the CAN traffic via a wired connection to the vehicle OBD-II port was used to validate the effectiveness of the reconstruction process. These results confirm the feasibility of reconstructing in-vehicle network data for forensic purposes, without the need for wired access, at distances of up to 1 m from the vehicle by using magnetic field measurements, and up to 3 m using electric field measurements. This capability has applications in the identification and resolution of EMI issues in vehicle data network, as well as possible implications for automotive cybersecurity.

11:25 Research on Non-Standard Transient Conduction Waveform Measurement of Automotive Low Voltage Electronic Components
Dengyu Zhang, Shuai Hou, Yue Zhang, Li Jiang
China Automotive Technology and Research Center Co., Ltd., China
Abstract: ISO 7637-2:2011 is the main standard for electrical transient conducted immunity test of automotive lowvoltage electronic components. It provides signals of different strength and different parameters for manufacturers to verify product performance of their products. However, with the development of the automotive industry, more and more signals not included in ISO 7637-2:2011 have been found to affect automotive electrical and electronic components and threaten vehicle safety. Detailed analysis and elaboration of these nonstandard signals has been provided in this paper, which can explain many vehicle failure problems during start-up, driving and parking.

11:50 Forensic Analysis of Automotive Data Network Traffic during Vehicle Radiated Immunity Tests
Yu Xian Teo, Jiaqi Chen, Neil Ash, Alastair R. Ruddle, Anthony J.M. Martin
HORIBA MIRA Ltd., United Kingdom
Abstract: Radiated immunity testing of vehicles has the potential to cause changes in, or corruption of, in-vehicle network messages, which may not necessarily result in a directly observable effect on the vehicle. Nonetheless, such effects may have undesirable impacts that are not currently considered or are only identified if message logs are analysed post-test. Analysis of in-vehicle automotive controller area network (CAN) traffic recorded before and during radiated immunity tests has been used to identify changes in CAN messages to highlight the susceptibility of particular electronic modules or the direct corruption of CAN messages. This capability has applications in the identification and resolution of possible vehicle radiated immunity issues, as well as possible implications for automotive cybersecurity.

TECHNICAL PAPERS
TP-THU-3A

ADVANCED METHODS TO MODEL, EVALUATE, AND MEASURE ELECTROMAGNETIC INTERFERENCE AT LOW FREQUENCY IN TRANSPORTATION AND RENEWABLE ENERGY SYSTEMS
(SPONSORED BY TC-7)

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

11:00 The Influence of Commercial PC Switched Mode Power Supply Interference on the PRIME PLC Performance
Waseem El Sayed[1,2], Paolo Crovetti[3], Piotr Lezynski[1], Robert Smolenski[1], Amr Madi[1,2], Flavia Grassi[4]
[1]University of Zielona Góra, Poland; [2]University of Twente, The Netherlands; [3]Politecnico di Torino, Italy; [4]Politecnico di Milano, Italy
Abstract: In the last few decades, the use of power converters has become essential in the smart grid environment. Consequently, this leads to the presence of a high-level of conducted electromagnetic interference between the smart grid elements. This paper studies the effect of two power converter modulation techniques: conventional fixed-frequency modulation and spread-spectrum modulation, on the performance of the Power Line Communication (PLC) signal. The paper presents a practical implementation of the system and discusses the results for different operating scenarios.

11:25 Concept of Impedance Diversity for Conducted Interference Mitigation
Muhammad Ammar Wibisono[1,2], Niek Moonen[1], Deny Hamdani[2], Frank Leferink[1,3]
[1]University of Twente, The Netherlands; [2]Institut Teknologi Bandung, Indonesia; [3]Thales Nederland B.V., The Netherlands
Abstract: This paper presents the concept of impedance diversity to mitigate the disturbance caused by varying impedances of non-linear loads in the time domain. Simulations were performed in LTSpice to show the concept of the impedance diversity, and measurements were performed using a speed-controlled water pump as the source of interference and PLC modems as the victim. The impact of the interference from the water pump on the PLC modem is quantifiedwith the Frame Error Rate (FER), which is calculated as the ratio between the erroneous frames and total frames sent by the PLC. The measurement result shows that the impedance mode of the PLC modem affects the frame errors caused by the interference from the water pump.

11:50 Mode Decomposition in Multichannel Time-Domain Conducted Emission Measurements
Daria Nemashkalo1, Niek Moonen1, Frank Leferink1,2
[1]University of Twente, The Netherlands; [2]Thales Nederland B.V., The Netherlands
Abstract: A conventional conducted emission test provides insufficient information in terms of differential and common mode interferences. Only the normal mode interference can be measured, which complicates the design or optimization process for a power line filter if needed. Moreover, measurements performed with conventional test receivers are time-consuming and only one measurement channel is available. In this paper, a measurement approach for digital mode decomposition is presented using multiple channels simultaneously. Results obtained with the proposed approach are compared with regular active and passive separation networks.

TECHNICAL PAPERS
TP-THU-4A

TRANSPORTATION EMC
(SPONSORED BY TC-7)

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

11:00 Efficient Multichannel Time-Domain Multiaxis Loop Antenna Measurement for Frequencies below 30 MHz
Denys Pokotilov[1], Robert Vogt-Ardatjew[1], Frank Leferink[1,2]
[1]University of Twente, The Netherlands; [2]Thales Nederland B.V., The Netherlands
Abstract: Conventional frequency-domain measurements are slow and are not able to grab time-varying effects, compared to time-domain measurements. Standard measurement procedures, for example CISPR 36 for electric vehicles, requires measurements at multiple positions around the equipment under test. Small resolution bandwidth in combination with long dwell time for every frequency step, results in a long measurement time. This is especially true in the lower frequency range as the bandwidths are small and thus need more measurement time. CISPR 36 requires also using only one antenna in parallel or perpendicular position to the equipment under test at once. Using time-domain measurements, the measurement speed can be already significantly improved. The effectiveness of measurements can be increased drastically if multiple antennas are positioned at several locations around the equipment under test, and multiple digitiser channels are used in parallel. A new antenna construction for multidirectional measurements in combination with a cost-efficient multichannel digitizer for time-domain measurements in the frequency range below 30 MHz is proposed in this paper. Simulation results, theoretical background and initial measurements are shown, proving that such a method is indeed viable.

11:25 Overvoltages Induced in the Supplying Line by an Electric Railway Vehicle
Petre-Marian Nicolae[1], Marian-Stefan Nicolae[1], Ileana-Diana Nicolae[1], Alexandru Netoiu[2]
[1]University of Craiova, Romania; [2]SC SOFTRONIC SA, Romania
Abstract: The paper focuses on a railway traction system. A railway vehicle, driven by a.c. three-phase asynchrnnous motors supplied thrnugh inverters from a single phase transformer, is connected to it. A brief description of the single phase a.c. (50 Hz, 25 kV) driving system is prnvided. The traction substation consists in down step voltage transformers supplied from the power system. The single phase traction system, when connected to the three-phase supplying system, intrnduces non-symmetries and cunent harmonics. A 50 km line segment from a simple supplying line was considered for simulation of overvoltages at cunent harmonics. A conect design of the rnilway vehicle driving system must meet the requirements imposed by the standard EN 50388 relative to its connection to the supplying line. Prnctical validation concerning overvoltages is discussed.

11:50 Mathematic Modelling of Distribution of Traction Current Harmonics
Tetiana Serdiuk, Kseniia Serdiuk
Dnipro National University of Railway Transport named after Academician V. Lazaryan, Ukraine
Abstract: The questions of propagation of traction current harmonics along the length on an homogeneous feeder zone at the one- and two-end power supply and the definition of their influence on code current flowing in rail lines were elaborated. The mathematic modelling of a traction supply net was carried out. The spectrum of traction current and the most dangerous harmonics influencing the track circuits were assessed for the application of electric locomotive with the PWM-invertors. To this end, the values of current and voltage on the primary winding of the traction transformer of the double-section electric locomotive were determined.

12:15 Highly Compact Dual-Band Lumped Element Band-Pass Filters in LTCC for Avionic Systems
S. Hassan Mousavi, Aref Pourzadi, Ammar Kouki
École de Technologie Supérieure, Canada
Abstract: The Dual Band Pass Filters (DBPF) with high stop band rejection at center frequencies of 122 and 330 MHz are designed. The DBPF filters are fabricated in low temperature co-fired ceramic (LTCC) technology using a lumped element approach. Measured results show close agreement with simulations with very small form factor. The overall size of the dual band-pass filter is 32 mm × 18 mm × 2.2 mm.

TECHNICAL PAPERS
TP-THU-5A

EM INFORMATION LEAKAGE AND LIGHTNING

(SPONSORED BY TC-5)

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

11:00 Multiple and Reproducible Fault Models on Micro-Controller using Electromagnetic Fault Injection
Vanthanh Khuat[1,2], Oualid Trabelsi1, Laurent Sauvage[1], Jean-Luc Danger[1]
[1]Télécom Paris, France; [2]Le Quy Don Technical University, Vietnam
Abstract: In this paper, we present a method to obtain multiple and reproducible fault models on a 32-bit Micro-controller (MCU) using Electromagnetic Fault Injection (EMFI). By using different Pulse Width (PW), this method allows to obtain either a replay or skip of instructions fault model with a fault rate up to 100%. Specifically, a replay of an instruction block is obtained with the PW of 1.5 nano second (ns), whereas a skip of an instruction block is observed with the PW of 7.0 ns. With these types of fault model, an adversary may be able to retrieve secret information, as cryptographic key, by using efficient attacks. The study is carried out by enabling or disabling the cache. The only difference is that the resulting faulty block is either 32 bits when the cache is disabled or 64 bits when the cache is enabled. The impact of the Pulse Amplitude (PA) has been analyzed, and the fault model has been characterized at bit level. These results demonstrate the efficiency and the flexibility of the EMFI which should be considered for designing robust MCU.

11:25 Machine Learning Voice Synthesis for Intention Electromagnetic Interference Injection in Smart Speaker Devices
Tanner Fokkens, Zhifei Xu, Omid Hoseini Izadi, Chulsoon Hwang
Missouri University of Science and Technology, USA
Abstract: This work presents the effectiveness of using machine learning (ML) synthesized voice samples to control smart speaker devices through radiated intentional electromagnetic interference (I-EMI). In previous works, the feasibility of using IEMI to control smart speaker devices was shown. However, devices that are trained to only recognize a single person's voice or only execute certain commands from that person will not be as susceptible to this attack. By training a generative adversarial network (GAN) using samples of the target's voice, this security feature can be bypassed directly, increasing the feasibility of the attack.

11:50 The Application of the Duffing Oscillator to Detect Electromagnetic Leakage Emitted by HDMI Cables
Ye Li[1,2], Wei Fan1, Weiqing Huang[1,2]
[1]Chinese Academy of Sciences, China; [2]University of Chinese Academy of Sciences, China
Abstract: HDMI (High Definition Multimedia Interface) cables could emit EM (Electromagnetic) leakage when transmitting video signals, such that it could cause sensitive information leakage, leading to a severe security threat. However, the radio signals are too weak to be detected due to the complex electromagnetic environment. Therefore, we propose a novel non-linear detection method based on the Duffing oscillator, which is immune to noises and sensitive to periodic signals, and can even detect signals with very low SNR (Signal-to-Noise Ratio). In this paper, we first verify this method through simulation. Then this method would be applied to real signal detection in a shielded room. Overall, we achieve detecting real signals and successfully verify this method.

12:15 On the Calculation of Electrical Surges in Underground Cables due to a Direct Lightning Strike
Susana Naranjo-Villamil[1], Christophe Guiffaut[2], Julien Gazave[1], Alain Reineix[2]
[1]EDF Group, France; [2]Institut de recherche XLIM, France
Abstract: When a building is struck by lightning, the lightning current travels through its reinforcement and along the lightning channel, generating a transient electromagnetic field. A part of the current reaches the ground termination system and the other part is distributed among the cable ducts and soil-containing conductors leading away from the building. Electrical surges can be induced by the transient fields, the coupling between the structures, and a partial lightning current entering the cables via its grounding. Since the Lightning Protection System (LPS) is generally designed based on the worst-case scenario, a parametric study is conducted using the FDTD method to identify the configurations in which the surges in the cables interconnecting two buildings are maximized. The results are compared to the case in which the cables are grounded at the entrance to the buildings. The direct connection to the reinforcement increases the currents and shifts the resonances towards higher frequencies.

TECHNICAL PAPERS
TP-THU-6A

COMPUTATIONAL ELECTROMAGNETICS II

(SPONSORED BY TC-9)

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

11:00 Nearfield to Farfield Transformation of a Small Patch Antenna by using Plane Wave Spectrum Method
Tao Wang[1], Xinxin Tian[2], Wei Zhang[1], Xin Yan[1]
[1]Missouri University of Science and Technology, USA; [2]Guangdong University of Technology, China
Abstract: Modern planar scanning techniques in the near-field measurement of antennas and scatters are based on the planewave spectrum (PWS) representation of the field. The theoretical development of planar near-field antenna measurements is usually based on this plane wave spectrum representation of electromagnetic fields. This work provides a detailed derivation of the coordinate-free form of the near-field to far-field transform that is central to the planar near-field measurement methodology. A patch antenna that works at 10GHz is designed and used as the validation example. Results from 3D electromagnetic simulation and PWS method correlate well demonstrating that PWS can be used to predict the antenna's far-field once the nearfield measurement is completed. This PWS method is suitable for quickly characterizing antennas used in nowadays's mobile system without conducting antenna measurement in an anechoic chamber. In this paper, the PWS method is revisited and demonstrated that it can be used to analyze the miniaturized antenna used in mobile systems.

11:25 Efficient Computation of Partial Elements for Non-Orthogonal PEEC Meshes
Luca Di Angelo[1], Daniele Romano[1], Giulio Antonini[1], Ivana Kovačević-Badstübner[2], Ulrike Grossner[2]
[1]University of L'Aquila, Italy; [2]ETH Zurich, Switzerland
Abstract: The partial element equivalent circuit (PEEC) method has proven to be able to provide a valid solution method of the Maxwell's equations in the time as well as the frequency domain. The extension of the basic PEEC approach to non-orthogonal geometries has significantly expanded the applicability of the method. The computation of interaction integrals is typically performed numerically and it results to be time-consuming. This work presents a new flexible and accurate computational method for determining the partial inductances in the quasi-static limit. More specifically, an automatic decomposition of the non-orthogonal geometries into parallelepipeds is proposed so that analytical formulas which are available in this case can be used. The accuracy, and speed of the proposed method is compared with standard integration routines exhibiting a satisfactory accuracy and reduced computation time.

11:50 Efficient and Flexible Huygens' Source Replacement of mm-Scale Human Brain Implants
Cheng Yang, Morten Schierholz, Eileen Trunczik, Leon Maximilian Helmich, Heinz-D. Brüns, Christian Schuster
Technische Universität Hamburg, Germany
Abstract: Implants for monitoring or stimulation of nervous activity in the human brain offer multiple challenges for electromagnetic compatibility. Both the electromagnetic emission into the surrounding brain tissue and the electromagnetic interference with other implants have to be tightly controlled. From a computational perspective the hierarchical structure and the frequency dependence of the brain tissue as well as the high aspect ratio between implant features and the size of the brain offer multiple challenges. Here, we propose an approach based on the Huygens' principle in combination with a method of moments to overcome part of these challenges with respect to the computation of possible interference between implants. The approach makes use of the fact that due to high losses in the brain tissue at frequencies below 1 GHz the interaction between implants can be characterized as weak coupling. Apart from being computationally more efficient the proposed approach is also flexible in the sense that different victim implants can easily be computed. Results for a realistic head model show good agreement between this approach and a traditional full-wave simulation.
BEST EMC PAPER FINALIST

12:15 The Impact of Shimming Strategies and Scan Regions on RF-Induced Heating near a Bone Screw under 3T MRI
Xiaolin Yang, Jianfeng Zheng, Ji Chen, *University of Houston, USA*
Abstract: This paper investigates the impact of shimming strategies and scan regions on the radiofrequency (RF) induced heating near a bone screw in the ASTM phantom under 3T magnetic resonance imaging (MRI). Three shimming strategies, i.e. B1 homogeneity, focusing performance, and power efficiency, and two scan regions, head and chest, were studied. The peak RF-induced heating in terms of local specific absorption rate (SAR) is compared among quadrature source excitation and the three shimmed source excitations obtained by using a particle swarm optimization method. For the scan region of the head, all three shimming strategies can reduce the RF-induced heating. For the scan region of the chest, the shimming strategies of B1 homogeneity and focusing performance can reduce the peak SAR while the shimming strategy of power efficiency increases the peak SAR.

TECHNICAL PAPERS
TP-THU-7A

MACHINE LEARNING/CLOUD COMPUTING 2

(SPONSORED BY TC-9 AND TC-10)

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

11:00 Accelerating the Simulation of Finite Difference Time Domain (FDTD) with GPU
Yongjun Liu, Jing Wang, Jian Liu
Cadence Design Systems Inc., USA
Abstract: In this paper, we discuss the implementation of three dimensional FDTD method to Nvidia's CUDA architecture. Finite-difference time-domain is a numerical analysis technique used for modeling computational electrodynamics. Since it is a time-domain method, FDTD solutions can cover a wide frequency range with a single simulation run, and treat nonlinear material properties in a natural way. Because FDTD requires the grid must be sufficiently fine to resolve both the smallest electromagnetic wavelength and the smallest geometrical feature in the model, it may result in very long simulation time. OpenMP, MPI, SIMD technique can be used to speed up the simulation. Another technology, Nvidia's CUDA, allows the time to be reduced a lot.

11:25 A Modified Genetic Algorithm for the Selection of Decoupling Capacitors in PDN Design
Jack Juang[1], Ling Zhang[1], Zurab Kiguradze[1], Bo Pu[1], Shuai Jin[2], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]Google Inc., USA
Abstract: Decoupling capacitors are used to provide adequate and stable power for integrated circuits in printed circuit boards (PCB). For complicated and large designs, it is difficult to select capacitors to meet voltage ripple limits while also minimizing cost because the search space is too large. In this work, a new genetic algorithm (GA) is proposed for the selection and placement of capacitors to meet a target impedance using as few capacitors as possible. The GA is centered around controlling the number of unused port locations in the GA population solutions, with the result of smoothing out the GA convergence and speeding up the convergence rate. A result comparison is made of the proposed GA against other algorithms and found the GA competitive if not better for the select test cases.
BEST SIPI STUDENT PAPER FINALIST

11:50 Reinforcement Learning-Based Decap Optimization Method for High-Performance Solid-State Drive
Jaeyoung Shin, Soomin Kim, Kihyun Sung, Hyunwoo Jung, Jinwook Song, Wooshin Choi, Hyungjong Ko, Junghwan Choi, Sanghyun Lee
Samsung Electronics Co., Ltd., Korea
Abstract: In this paper, we propose an improved optimal decoupling capacitor (decap) design method based on Qlearning algorithm for high-performance solid-state drive (SSD). The proposed method selects optimal decap combinations that satisfies target impedance with minimum decap number. Based on Q-learning algorithm combined with transmission line theory, optimal decap combinations of power distribution network (PDN) can be provided. The proposed method was verified with voltage ripple measurement and PDN impedance simulation using SSD for high-performance server application. Conventional decap optimization method are using complex and time-consuming analytical tool with power integrity (PI) domain expertise. However, the proposed method requires only the PDN and decap information along with a simple Q-learning model without PI knowledge, providing faster and accurate results than full search optimization method. For example, in 21 decaps combination problem, the proposed method's computing time consumes only few minutes, 89.09 sec, which is significantly reduced result compared with the conventional full search simulation. Therefore, we expected the proposed method can be widely used to solve for decap optimization problem with complex PDN.

TECHNICAL PAPERS
TP-THU-8A

EVALUATION AND SIMULATION OF EMI IN WIRELESS SYSTEMS

(SPONSORED BY TC-12)

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

11:00 Estimating Regions of Wireless Coexistence with Gaussian Process Surrogate Models
Jacob D. Rezac[1], Noel C. Hess[2], Jason B. Coder[1]
[1]National Institute of Standards and Technology, USA; [2]Univeristy of Colorado-Denver, USA
Abstract: Simultaneous coexistence of multiple wireless communications systems sharing the same spectrum is critical for the success of modern and future communications. We develop a technique for estimating regions of wireless coexistence (RWC) – the transmission configurations of each of the wireless systems which permit coexistence – based on measurements of key performance indicators (KPIs) of those systems. In this article we focus on two-way coexistence tests, which aim to determine the impact each of the communications systems have on each other. The new technique is based on a Gaussian process surrogate model of the unknown transmission-configuration-to- KPI functions. We introduce a sequential design of experiments based on this surrogate model which is designed to reduce the number of measurements necessary to reach a highly-accurate estimate of a RWC. On an illustrative example, this technique reduces the average number of required measurements by over 40% compared to a baseline experimental design. Similar results are achieved for a measurement-informed simulation based on a coexistence test between an Bluetooth Low Energy device and an IEEE 802.11n Wi-Fi devices.

11:25 Simulation based EMI Prediction for High Speed Differential Signals
Qiaolei Huang, Jaswanth Vutukury, Deepak Pai, Gary Rara, Akshay Mohan, Jagan Rajagopalan
Amazon Lab126, USA
Abstract: Electromagnetic Interference (EMI) failure is a common occurrence in electronic devices. Failing to comply with FCC/CE requirements set by government agencies delays the product time to market. Besides following proper design guidelines of layout, grounding, shielding, filtering, etc., using simulation to predict EMI failures during early design stage will greatly save time and cost. In this paper, EMI from a practical product with multiple pairs of high speed differential signals are studied. The power spectrum density of both common mode and differential mode on those differential pairs are measured. By combining with noise source information and simulated far field transfer functions, the simulated EMI can be obtained. The simulation results are later compared with measured results to show the accuracy of simulations.

11:50 DoE-Based Evaluation of the Impact of the Twisted-Pair-Cable Parameters on the Wireless Communication Performance
Oussama Sassi[1], Pascal Hervé[2], Moncef Kadi[3]
[1]Volkswagen AG, Germany; [2]CSA Group Bayern GmbH, Germany; [3]ESIGELEC, France
Abstract: In the automobile industry world, connectivity and autonomous driving have become a new trend. The next generation of vehicles should support the new communication technologies for infotainment systems and streaming services. In addition, for the autonomous deriving, the vehicles should be equipped with advanced driving assistance device and highspeed network. That is why the requirements for ensuring high performance and robustness especially of the wireless communications systems in modern connected vehicles are significantly greater compared to systems from even a couple of years ago. The electronic devices and the data network in the vehicle emit electromagnetic interference and can disturb the communication systems. This paper presents a calculation approach to evaluate the electromagnetic field radiated from a twisted pair cable. Based on an equivalent wire model, we calculate wire currents to perform the radiated electromagnetic field. Application of the Design of Experiment DoE approach can be used to analyze the influence of wire parameters and the results help to characterize the cable impedance. This enables the estimation of the Over-the-Air packet error rate obtained in a typical radiated test setup. The results can be used to evaluate the performance of the communication system in the early phase of vehicle project.
BEST EMC PAPER FINALIST

12:15 Intelligent Energy Saving Solution of 5G Base Station based on Artificial Intelligence Technologies
Rumeng Tan[1], Tong Wu[2], Ying Shi[1], Yanpu Hu[3]
[1]China Telecom Corp Ltd., China; [2]National Institute of Metrology, China; [3]China Academy of Information and Communications Technology, China
Abstract: This paper introduces the basic energy-saving technology of 5G base station, and puts forward the intelligent energy-saving solutions based on artificial intelligence (AI) and big data technologies to forecast and optimize the management of 5G wireless network energy consumption. With the continuous innovation and evolution of 5G energy-saving technology based on AI and other emerging technologies, the operating expense (OPEX) of mobile network operators will be effectively reduced.

TECHNICAL PAPERS
SS-THU-A

RISK-BASED EMC

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

11:00 A Methodology for Estimating the Criticality of Energy Infrastructures in the Context of IEMI
Fernando R. Arduini[1,2], Marian Lanzrath[1], Thorsten Pusch[1], Michael Suhrke[1], Heyno Garbe[2]
[1]Fraunhofer Institute for Technological Trend Analysis INT, Germany; [2]Leibniz Universität Hannover, Germany
Abstract: The power system has been undergoing a modernization process due to the insertion of Smart Electronic Devices (SEDs) and advanced communication systems. However, along with the advances allowed by such modernization, new security threats to the electricity sector have emerged. One of these threats is known as Intentional Electromagnetic Interference (IEMI), where criminals misuse high power electromagnetic sources aiming to interfere with and disrupt critical devices belonging to energy infrastructures. In this perspective, the development and enhancement of IEMI threat analysis strategies oriented to the electricity sector are relevant to guarantee the security and reliability of the power system. Therefore, this paper proposes a user-friendly methodology to classify energy infrastructures' criticality with respect to IEMI targeting grid operators willing to address security issues in their energy facilities. The application of the methodology is exemplified with a typical transmission substation part of the power system.

11:25 Risk-Based EMC System Analysis Platform of Automotive Environments
Vasiliki Gkatsi[1], Robert Vogt-Ardatjew[1], Frank Leferink[1,2]
[1]University of Twente, The Netherlands; [2]Thales Nederland B.V., The Netherlands
Abstract: Constantly on-going changes in new technologies applied in modern vehicles introduce many challenges in the automotive electromagnetic compatibility engineering. So far, the currently implemented EMC requirements and methods present sufficient performance. However, they do not illustrate thoroughly an actual automotive environment. They tend to focus on the EMC validation of each system individually without always considering other possible influential factors and coexisting systems. Aim of this paper is to introduce an EMC system investigation platform using a simplified model that demonstrates an automotive environment in order to point out the importance and scale of significance of various parameters. In this paper, the structure of the introduced three-point model is first described and explained. Then, experiments are presented in order to point out the influence of selected macroparameters. Finally, suggestions for further extension of the model through Monte Carlo simulations are proposed with a brief presentation of a modelling procedure.

11:50 Vulnerability of Wireless Smart Meter to Electromagnetic Interference Sweep Frequency Jamming Signals
Arash Nateghi, Martin Schaarschmidt, Sven Fisahn, Heyno Garbe
Leibniz Universität Hannover, Germany
Abstract: The installation and use of smart home technology that uses wireless communication channels, according to the 802.11 standard series, is rapidly increasing. This article discusses the effect of Electromagnetic Interference Sweep Frequency Jamming Signal applied to a wireless smart meter installed in a three-phase domestic and light commercial electricity distribution board. More specifically, a method of frequency jamming signal generation technique, jamming signal radiation and its interference measurements method are explained in this paper. Then, the impact of disturbances are discussed and mitigation mechanisms such as construction material shielding, digital filtering and a systematic approach of electromagnetic risk assessment are given.

12:15 Risk Assessment Approach for EM Resilience in Complex Systems using Bayesian Networks
Lokesh Devaraj[1], Alastair R. Ruddle[1], Alistair P. Duffy[2], Anthony J.M. Martin[1]
[1]HORIBA MIRA Ltd., United Kingdom; [2]De Montfort University, United Kingdom
Abstract: Current trends in the automotive industry are reshaping the architectures and electromagnetic characteristics of road vehicles. Increasing electrification and connectivity are enabling considerable packaging flexibility and leading to radically different electromagnetic environments. At the same time, increasing automation of driving functions will require unprecedented levels of system dependability. However, existing EMC engineering processes were developed in a very different world of low system complexity and incremental technological development. In order to adapt to rising system complexity and the increasingly rapid pace of technological change, it is considered that a more agile risk-based approach is better suited to ensure the electromagnetic resilience of future vehicles and other complex systems. This paper outlines a Bayesian network approach that allows the combination of both technical and nontechnical aspects in assessing the likelihood of issues that could lead to system-level risks. This approach could be used to help achieve EM resilience from the earliest stages of product development, where the detailed information required to undertake detailed risk assessment is generally unavailable.

TECHNICAL PAPERS
TP-THU-1B

IMMUNITY

(SPONSORED BY TC-2)

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

13:30 Examination of the RF Output Power on Electromagnetic Susceptibility Tests of the Radio Equipment
Umut Doğan, Ugur Sukru Ceran, Kadir Arslan
Vestel, Turkey
Abstract: In recent years, wireless smart devices which use radio frequencies are emerging increasingly in all areas of our life. This article presents the influences of radio frequency (RF) output power level on RF electromagnetic field and RF common mode immunity tests of wireless radio equipment. According to the ETSI EN 301 489-17, the RF output power level should be adjusted to the maximum level during the tests. However, the use of RF output power level in daily life may not work at the maximum or fixed level in a wireless device. In order to observe the effects on test results, RF common mode and RF electromagnetic field immunity tests are performed at the maximum RF output power level as stated in the standard and at different RF output power levels as independent from the standard. The results of the measurements are compared with each other at the certain frequencies.

13:55 Design of a Reference Device for Burst Immunity Interlaboratory Comparison
Emrah Tas, Frédéric Pythoud
Swiss Federal Institute of Metrology, Switzerland
Abstract: In order to improve and to standardize the quality in EMC testing services, increasing efforts have been given in the organisation of interlaboratory comparisons and proficiency testing. Several devices have been designed and realized for this purpose for various emission and immunity tests. In this publication, we pursue this development and propose a new reference device for interlaboratory comparisons and proficiency testing services in electrical fast transients/burst immunity testing according to IEC 61000-4-4. The device is equipped with adapted detecting circuitry to measure and record the burst pulses and relevant parameters for offline evaluation. The concept and the architecture of the device and its operation principles are explained in detail. The preliminary evaluation of its stability and linearity is performed and its capabilities to detect errors in a typical testing scenario is explained.

14:20 Study on Noise Distribution Generated from Multiple LED Lights Installed on Duct Rail
Ifong Wu, Kaoru Gotoh
National Institute of Information and Communications Technology, Japan
Abstract: The radiation noise from LED lights in the simultaneous use of multiple LED lights is not a simple linear increase with respect to the number of LED lights. The amount of increase in radiation noise becomes more complex with frequency as the number of LED lights increases. To clarify the radiation noise characteristics from multiple LED lights, a radiation model was simulated when multiple LED lights were connected to the same power line. In this study, the change in noise distribution on the power line depending on the installation position of multiple LED lights was investigated to clarify the relationship between the radiation noise and LED lights on the power line.

TECHNICAL PAPERS TP-THU-3B

LOW-FREQUENCY EMC ISSUES

(SPONSORED BY TC-7)

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

13:30 Performance of Representative Transformer-Less Topologies for Photovoltaic Applications
Duc-Thanh Do, Holger Hirsch, *University of Duisburg-Essen, Germany*
Abstract: This paper faces the effectiveness of transformerless topologies for small-scale photovoltaic (PV) applications. The main issues of leakage current and common-mode (CM) voltage are adapted by some representative proposed topologies as full-bridge, H5, H6, HERIC. Due to the lack of knowledge, the CM noise source should be internally reduced. Meanwhile, the performance of advanced transformer-less topologies have been reproduced analytically and analyzed for common-mode and differential-mode components. Similarly, the reduction of the harmonic emission can be clarified by considering different control strategies of pulse width modulation (PWM) as random PWM schemes. Based on simulation results, the deduced conclusions are produced to recommend the disturbance properties of single-phase PV applications.

13:55 Square Wave Shaper with Filter Characteristics to Reduce EMI and Passive Component Count
Rahul Nadgouda[1], Herbert Hackl[1,2], Bernd Deutschmann[1,2]
[1]Technische Universität Graz, Austria; [2]Silicon Austria Labs GmbH, Austria
Abstract: Filters and pulse shapers are widely used to reduce Electromagnetic Interference (EMI) by shaping the signal waveform. As the order of filter increases so does the silicon area requirement, which becomes an issue specially for low frequency applications. This paper outlines a methodology to implement a square wave shaper which approximates low-pass filter (LPF) characteristics using squaring circuits, with the aim of reducing component count for significant gain in silicon area. The shaper is analyzed in comparison to an ideal Bessel LPF and resulting differences are presented. Lastly, area savings are estimated and an outline of possible implementation of the shaper on schematic is presented.

14:20 Magnetic Field Produced by Current in Typical Planar and Three-Dimensional Elements of Metal Structures
Melania Pavlova, Petr Vorshevskii, Alexander Worshevsky
Saint-Petersburg Marine Technical University, Russian Federation
Abstract: Results of low frequency modeling for some shapes of metal structures with current make it possible to predict the magnetic strength around the structure. The obtained graphs and calculation model are useful for EMC evaluation and education.

14:45 How to Earn Money with an EMI Problem: Static Energy Meters Running Backwards
Tom Hartman[1], Bas ten Have[1], Niek Moonen[1], Frank Leferink[1,2]
[1]*University of Twente, The Netherlands;* [2]*Thales Nederland B.V., The Netherlands*
Abstract: The increased use of non-linear appliances in households has resulted in several conducted electromagnetic interference issues, such as misreadings of static energy meters used for billing purposes of the households' energy consumption. In this paper a case is presented where a static energy meter indicates a power generation, while power is actually being consumed. A perceived power generation of more than 430W is measured by a static energy meter installed in a household when a television with a commercial off the shelf remote controlled switch with dimming functionalities consumed 21W. The same situation is reproduced in a controlled lab environment, to eliminate possible influences of other appliances in the grid, which confirmed the on-site results. The current waveforms causing this supposed generation of power are investigated and it is observed that the phase firing angle of the current pulse drawn by the load in combination with the commercial off the shelf remote controlled switch affects the metering errors and determines whether the errors indicate a false generation, a too high consumption of power, or no error at all. A combination of the household equipment and a basic unloaded switched mode power supply in conjunction with two remote controlled switches resulted in a perceived power generation of more than 600W. Having these loads connected for the entire day would counteract the total consumption of an average household and could even "generate" energy, and thus generate money for the consumer.

TECHNICAL PAPERS TP-THU-5B

ESD AND SMART GRID IEMI

(SPONSORED BY TC-5)

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

13:30 Two Algorithms Analyzing Discharge Parameters based on Neural Network and Wavelet Transformer
Fangming Ruan[1], Sheng Guan[1], Yang Meng[2], Lan Yin[1], Yanli Chen[1], Kui Zhou[1]
[1]Guizhou Normal University, China; [2]Qilu University of Technology, China
Abstract: Special relationship exists between environmental conditions and discharge characteristic parameters in electrostatic discharge (ESD) events. The neural network can explore the potential law between input and output if taken discharge condition parameters as a neural network input. Characteristics of discharge results are affected by environmental conditions, and hence discharge parameters can be described with the output of a neural network. Two algorithms of artificial intelligence were used to analyzing discharge results in electrostatic discharge. The nonlinear relationship between discharge conditions and discharge effect may be a new potential discharge feature. Noise in discharge current can be suppressed with wavelet and Kalman filter method. The characteristics measured in the real experiment were compared with the prediction parameters from the neuronetwork calculation result. According to the prediction data, the discussion was conducted on correctness accuracy and the discharge process trend analysis.

TECHNICAL PAPERS
TP-THU-6B

AEROSPACE/AUTOMOTIVE COMPUTATIONAL ELECTROMAGNETICS

(SPONSORED BY TC-9)

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

13:30 Estimating Fields in Spacecraft Cavities: Experimental Validation of Finite-Difference Time-Domain and Power Balance Computational Tools
Javier J. Pazos[1], Jeff Phillips[2], Eric Miller[1], Timothy McDonald[1], Jennifer Kitaygorsky[1]
[1]Electro Magnetic Applications, Inc., USA [2]Jeff Phillips Consulting, USA
Abstract: Electromagnetic fields in representative spacecraft cavities were successfully predicted using finite-difference time-domain and power balance computational tools. Results were validated with measurements of two test articles, showing excellent correlation in shielding effectiveness from 300 MHz to 18 GHz. The tools and methods presented here can serve as part of a toolkit to rapidly estimate shielding effectiveness, the impact of payloads, and overall fields in spacecraft cavities.

13:55 The Impacts of Solar Cell Size, the Spacing between Current-Collecting Fingers, and Switched Strings, on the Electromagnetic Radiation from Solar Panels for Satellite Applications
David Norte, *Ball Aerospace, USA*
Abstract: Conventional solar panels are comprised of a given number of rows and columns of solar cells such that the overall array of solar cells forms a rectangular pattern. In applications of solar panels, it is sometimes necessary to regulate the current extracted from a solar panel by switching the strings of solar cells within the panel. This switching action can also extend the life of the solar cells by preventing a given cell from being actuated 100% of the time.

14:20 Black-Box DC-DC Integrated Circuit Modeling towards Design for EMC in Automotive Electronics
N. Ishibashi[1], L.K. Manepalli[2], D. Nath[2], B.P. Nayak[2], S. Kadam[2], D. Gope[2,3]
[1]Indian Institute of Science, India; [2]Panasonic Corporation, Japan; [3]Simyog Technology Pvt. Ltd., India
Abstract: Recently, IoT and sensor networks have developed rapidly and design for EMC has become challenging. In automotive electronics, V2X technology that enables Advanced Driver Assistance Systems (ADAS) has led to stringent EMC requirements for in-vehicle equipment. Therefore, in addition to noise countermeasure technology, it is becoming important to predict EMC risk. Simulation is an effective method to analyze and monitor EMI/EMC performance right from the early design stage, such that possible upstream problems can be addressed in a cost-effective manner. A primary challenge towards such a simulation methodology is the non-availability of models for Integrated Circuits which are the sources of noise. In this work, by measuring the EMC characteristics of the DC-DC converter IC from outside, a macro-model is created without including any proprietary information of the IC interior. This is combined with an electromagnetic simulation framework to generate system-level EMC results. The proposed model-based simulation methodology is validated with measurements for a DC-DC converter system.

14:45 Extraction of Single Cell Impedance from within a Battery Pack by Virtual De-Embedding: A Proof of Concept
Herbert Hackl[1,2], Martin Ibel[1,2], Juliano Mologni[3], David J. Pommerenke[1,3], Bernhard Auinger[1,2]
[1]Silicon Austria Labs GmbH, Austria; [2]Technische Universität Graz, Austria; [3]ANSYS Inc., USA
Abstract: Models for the simulation of battery pack impedance are usually composed of models for the individual cells which the pack is made of, linked with a description of cell-to-cell and cellto- housing coupling. Thus, conventional battery pack modeling requires knowledge of the cell first, which is usually obtained by measurement on single cells. In this work, a solution to the inverse problem is described, i.e. measurement of the pack is available and impedance of the cells within shall be derived. Therefore, the pack's impedance needs to be partitioned into the cells' 'internal' impedances and exterior coupling effects, like mutual inductance. Proposed method employs 3D simulation of the battery pack with surrogate cell models. Measurement data and simulation model are then combined to find individual cell impedances by fitting the simulated pack impedance to the measured. For validation of the approach, single cell impedances obtained by virtual deembedding from different measurement setups are compared and related to reference results from literature. Considered frequencies range from 9 kHz to 1 GHz. This paper proves usability of the concept by using two 18650 Lithium-ion cells connected in series.

TECHNICAL PAPERS
TP-THU-7B

HIGH-SPEED LINK/BUS DESIGN 1

(SPONSORED BY TC-10)

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

13:30 Far-End Crosstalk Control Strategy for High-Volume High-Speed PCB Manufacturing: The Concept of Critical Resin Content Percent
Yuandong Guo[1], Shaohui Yong[1], Yuanzhuo Liu[1], Jiayi He[1], Bo Pu[1], Xiaoning Ye[2], Albert Sutono[2], Vijay Kunda[2], Amy Luoh[2], DongHyun Kim[1], Jun Fan[1]
[1]Missouri University of Science and Technology, USA; [2]Intel Corporation, USA
Abstract: Far-end crosstalk (FEXT) can reduce the eye opening and eventually decrease the maximum data rate that can be transmitted through the high-speed interconnections. Therefore, FEXT is an important concern in high-speed digital design. The contributors of stripline FEXT include the dielectric inhomogeneity and the proximity effect. In addition, a characterization technique for the effective relative dielectric constant (Dk) of both core and prepreg has been proposed recently for the analysis of the inhomogeneous medium and induced FEXT. In our study, the FEXT levels of the striplines on various printed circuit boards (PCBs) are measured and compared. It is brought to our attention that for some PCB striplines sharing the same stack-up, same PCB material, and manufactured by the same vendor, the corresponding measured FEXT magnitudes of these coupled single-ended traces could vary drastically, which may bring great challenges to the hardware engineers about FEXT level control during the highvolume PCB production phase. In this paper, the root cause of this issue is investigated and analyzed. The "critical resin content percent" concept is proposed to explain the variations in the Dk values of prepreg that result in the FEXT level variance. The full wave simulations are conducted to identify the "critical glass weave". A measurement-based statistical analysis is performed to verify the "critical resin content percent" concept. A design guideline for FEXT control strategy in the high-volume PCB manufacturing is presented based upon this investigation.

13:55 Far-End Crosstalk Analysis for Stripline with Inhomogeneous Dielectric Layers (IDL)
Yuanzhuo Liu[1], Shaohui Yong[1], Yuandong Guo[1], Jiayi He[1], Liang Liu[1], Nick Kutheis[1], Albert Sutono[2], Vijay Kunda[2], Amy Luoh[2], Yunhui Chu[2], Xiaoning Ye[2], DongHyun Kim[1], Jun Fan[1]
[1]Missouri University of Science and Technology, USA; 2Intel Corporation, USA
Abstract: Far-end crosstalk (FEXT) noise is a critical factor that affects signal integrity performance in high-speed systems. The FEXT level is sensitive to the dielectric inhomogeneity of the stripline in fabricated printed circuit boards (PCB). Stripline is typically modeled as a 2-layer model with core and prepreg layers. However, in reality, the stripline is laminated by multiple inhomogeneous dielectric layers (IDL). The dielectric layers of the stripline are laminated with epoxy resin and glass bundles. The dielectric permittivity (□□) of the epoxy resin and glass bundles are different, which causes the inhomogeneity of the dielectric layers while also increasing the FEXT magnitude. Therefore, a typical 2- layer structure is inaccurate to model the FEXT. In this paper, the stripline model is constructed with the core, prepreg, and resin pocket layers. To analyze the stripline with three IDL, a practical superposition method is proposed. A design guideline to mitigate the FEXT level in the stripline design is proposed based on the method.
BEST SIPI STUDENT PAPER FINALIST

14:20 The Simulated TDR Impedance in PCB Material Characterization
Yuandong Guo[1], DongHyun Kim[1], Jiayi He[1], Shaohui Yong1, Yuanzhuo Liu[1], Bo Pu[1], Xiaoning Ye[2], Jun Fan[1]
[1]Missouri University of Science and Technology, USA; [2]Intel Corporation, USA
Abstract: High-speed PCB design for signal integrity (SI) is about feasible material selection, trace geometry determination and optimization of discontinuities, where the accurate PCB material characterization is essential since incorrect material properties may lead to misleading results and wrong design descisions. The previous studies have revealed that the simulated time-domain reflectometry (TDR) impedance in material characterization, which is based upon the transmission-line-based methods, is erroneous when compared to the measured value, although a good agreement between simulation and measurement in the frequency domain can always be reached. In addition, it is also shown that achieving a satisfactory correlation in both transmission phase and trace impedance is a challenge for SI engineers. This implies that the transmission-line-based approaches, which are widely used in industries, are not perfect and that the extracted PCB material properties are not accurate enough. In this paper, a step-by-step investigation is performed and demonstrated to disclose the root causes of the TDR impedance discrepancy. It is found that the disagreement in TDR impedance is contributed by multiple factors which need to be taken into consideration during material characterization. The improved simulation result exhibits excellent consistency with the measured trace impedance. The suggestions to hardware designers on how more accurate PCB dielectric properties can be obtained are given by addressing the TDR impedance discrepancy issue.

14:45 Application of IEEE-370 for PCIe Interconnect Test with 2X-Thru De-Embedding
Se-Jung Moon, Xiaoning Ye, Kai A. Wang, Umair I. Khan, Timothy Wig, *Intel Corporation, USA*
Abstract: When PCIe 5.0 CEM connector testing result came out differently depending on the 2X-Thru de-embedding tools, we performed the tool accuracy test adopting the IEEE 370 specification and the framework. The key to success in this test was to ensure that the actual values of DUT (Device Under Test) were known and the qualities of data in use were good. Hence, we utilized PCIe 5.0 CEM connector and fixture model data for the direct comprehension in the compliance test and 370 plugand- play module data which provided the DUT direct measurement data. Best utilizing the metrics and criteria defined in 370 specification, four different states of art 2X-Thru de-embedding tools were tested, and the test results are summarized.

TECHNICAL PAPERS
TP-THU-8B

AERONAUTICS AND SPACE EMC

(SPONSORED BY TC-8)

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

13:30 RF Field and ESD Immunity Test on Cable Assembly Type AL SpaceWire Link
Christos D. Nikolopoulos[1], Anargyros T. Baklezos[2], Panagiotis K. Papastamatis[2], Theodoros N. Kapetanakis[1], Ioannis O. Vardiambasis[1], Ioannis F. Gonos[2]
[1]Hellenic Mediterranean University, Greece; [2]National Technical University of Athens, Greece
Abstract: Many past, current, and future ESA's, NASA's and JAXA's science missions are using extensively SpaceWire (SpW) links, implementing LVDS for the physical layer, in order to transmit science data. Electrostatic discharge (ESD) events in wires and cables used on spacecraft, can damage electronics or affect data integrity and ultimately compromise the mission objectives. Consequently, it is imperative to determine the levels of susceptibility to electromagnetic effects of electrostatic discharges. In this work, indicative RF field and ESD immunity tests are performed on a cable assembly type AL SpaceWire link based on common EMC standards in order to evaluate SpW link performance under harsh conditions.

13:55 The Changing Electromagnetic Environment Onboard All-Electric Aircraft, an EMC Perspective
Leonardo C. Malburg[1], Niek Moonen[1], Frank Leferink[1,2]
[1]University of Twente, The Netherlands; [2]Thales Nederland B.V., The Netherlands
Abstract: All-electric aircraft (AEA) is an emerging subject, due to its environmental contributions and economical appeal, thus, such technology is progressing at a fast pace towards commercial applications. The changing electromagnetic environment (EME) which such aircraft will endure, encompass not only current technologies, but will experience new EMI effects, originating from future mobile communication, power conversion, and increase in air-traffic. As a consequence of an operation relying solely on electric and electrical systems (avionics), together with the implementation of a high-power electric powertrain, AEA will experience increased levels of EMI. Therefore, to regulate the EMI changes onboard AEA, current aerospace standards must be assessed in order to identify possible limitations and bottlenecks. This paper presents an insight into the future EME, its EMC issues, and the intricacies towards the implementation of AEA for regional commercial flights.

TECHNICAL PAPERS
SS-THU-B

RISK-BASED EMC

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

13:30 EMI Risk Estimation for System-Level Functions using Probabilistic Graphical Models
Lokesh Devaraj[1], Alastair R. Ruddle[1], Alistair P. Duffy[2]
[1]Horiba Mira Ltd., United Kingdom; [2]De Montfort University, United Kingdom
Abstract: In general, the functions provided by complex systems often involve multiple sub-systems and components that are functionally dependent on each other. The dependency could be to receive power, control signals, input data, memory storage, feedback etc. With the increasing use of electronic systems to perform critical functions, the potential for malfunctions due to electromagnetic interference need to be identified and mitigated. Hence, a risk analysis, estimating the likelihood and severity of electromagnetic interference effects, is desirable from the very early stages of system development. In this paper, the use of probabilistic graphical models for estimating the likelihood of electromagnetic disturbances causing system malfunctions with various degrees of severity is demonstrated using a very simple case study. Statistical data are synthesised to illustrate the construction of conditional probability distribution tables for a Bayesian Network system model. Factorization and inference techniques are then applied to demonstrate the formulation and answer of queries that could be of value during system risk assessment.

13:55 Time-Efficient EMI Risk Evaluation Method in a Hospital Environment
Mumpy Das[1], Robert Vogt-Ardatjew[1], Bärbel van den Berg[2], Frank Leferink[1,3]
[1]University of Twente, The Netherlands; [2]Medisch Spectrum Twente Hospital, The Netherlands; [3]Thales Nederland B.V., The Netherlands
Abstract: Hospitals are one of the most critical and sensitive environments where possible EMI issue may have life-threatening effects. Although the electronic equipment placed within satisfies various EMC standards, a risk of EMI still exists. Due to the high complexity and dynamics of this system, the electromagnetic environment substantially differs from the one of an EMC laboratory. A full risk-based EMC analysis can significantly help mitigate this problem but requires plenty of effort, time, and careful management. In this paper, we present a simplified but robust, time efficient method of evaluating the electromagnetic risks, as an intermediate step before implementing a full riskanalysis campaign. Such an analysis allows to get the first impression about the environment and its influence on the medical device within.

14:20 Analysis and Estimation of Electromagnetic Energy Coupled into IC packages
Hui Tang[1], Arunkumar H. Venkateshaiah[2], John F. Dawson[2], Andrew C. Marvin[2], Martin P. Robinson[2], Jie Ge[3]
[1]Nantong University, China; [2]University of York, United Kingdom; [3]Nantong Vocational University, China
Abstract: Interference analysis and prediction in integrated circuits (ICs) is of significant interest to the Electromagnetic Compatibility (EMC) community. In this paper, an easy method is introduced to estimate the level of RF interference coupled into ICs through the package. Although IC packages are in different forms with large number of pins, the presented analysis method provides a general solution and greatly shortens the computation time by creating a simplified model with consideration of the cross coupling between pins. The expected voltage range at the outer ends and inner ends of the pins are also investigated for resistive loads. The levels of energy coupled into PCB traces and packages are also compared for immunity analysis.

14:45 Resilience of Reed-Solomon Codes against Harsh Electromagnetic Disturbances: Influence of Over-Voltage Detection
Pejman Memar, Jens Vankeirsblick, Dries Vanoost, Tom Holvoet, Jeroen Boydens
Katholieke Universiteit Leuven, Belgium
Abstract: Communication networks are the backbone of the modern safety-critical systems. Thus, it is crucial to protect these error-prone networks against electromagnetic disturbances in ever more polluted electromagnetic environments. One major vulnerability in communication networks, even the networks which are armed with Error Detection and Correction Codes, is undetected incorrect data, also known as false negatives. From the safety viewpoint, false negatives must be mitigated to an as low as reasonably practicable level. This paper presents the influence of over-voltage detection on the behavior of primitive Reed- Solomon Codes under harsh single-frequency electromagnetic disturbances. In this regards, three different threshold pairs are employed. Our simulations show that by choosing an appropriate range, over-voltage detection could substantially decrease the number of false negatives. Furthermore, it is found that this improvement in the electromagnetic resiliency of Reed-Solomon Codes has been obtained at a cost: decreasing the availability. Nevertheless, this study takes advantage of this trade-off to provide a more resilient system in a safety-critical environment, as is the aim of this paper.

TECHNICAL PAPERS TP-FRI-1A

NOISE, JITTER AND COMMUNICATIONS

(SPONSORED BY TC-2)

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

11:00 **Jitter-Based Reconstruction of Transmission Line Pulse using On-Chip Sensor**
Bhuvnesh Narayanan[1], Bernhard Weiss[1], Tvrtko Mandić[2], Adrijan Barić[3]
[1]ams AG, Austria; [2]Innovation Centre Nikola Tesla, Zagreb, Croatia; [3]University of Zagreb, Croatia
Abstract: A technique for reconstruction of on-chip high frequency signals is demonstrated. The majority of the on-chip reconstruction methods based on subsampling technique are applicable to synchronized systems. This paper demonstrates a jitter-based subsampling technique for non-intrusive reconstruction of on-chip high frequency signals in nonsynchronized systems. The proposed technique is demonstrated on a custom designed IC in 180 nm technology. The on-chip sensors are used for acquisition of high frequency signals as a response to the transmission line pulses (TLP) applied to the IC. The presented technique is also used to investigate the influence of the TLP on the internal nodes of the IC.

11:25 **Design of Common Mode and Differential Mode Separator for Electromagnetic Noise based on Autotransformer**
Guo Jiandong, Zhang Yue, Li Xiaoguang, Sun Kaiyi, Zhang Haoseng, Ma Mingyu
China Automotive Technology and Research Center Co., Ltd., China
Abstract: The application of common mode and differential mode separators for electromagnetic noise is of great significance for improving the efficiency of electromagnetic compatibility trouble-shooting. By analyzing the characteristics of different electromagnetic noise separators, a common mode and differential mode separator network model for electromagnetic noise based on autotransformers is proposed. Through parameter extraction and simulation analysis, a common mode and differential mode separator for electromagnetic noise is designed. After comparing the actual measurement and simulation results of the separator parameters, the effectiveness of the separator design is verified.

11:50 **Deferred Time-Frequency Cross-Correlation for EM Source Determination with One-Port Measurements**
Umberto Paoletti, *Hitachi, Ltd., Japan*
Abstract: Time cross-correlation between near and far field is useful for electromagnetic noise source determination, but it requires synchronous two-port measurements. This is a problem when near field measurements may affect far-field. In this work it is shown that the deferred cross-correlation between frequency modulation and time domain signal can be used for source determination using only one-port measurements.

TECHNICAL PAPERS TP-FRI-2A

SHIELDING

(SPONSORED BY TC-2)

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

11:00 **Experimental Verification of Board Level Shielding Variability at Microwave Frequencies**
Andrew Marvin, John Dawson, Martin Robinson
University of York, United Kingdom
Abstract: This paper shows that the Shielding Effectiveness of a printed circuit board shield (PCBS) varies depending on the shield's external environment when the circuit board level shield is installed within a larger external enclosure. A reverberation chamber based technique is demonstrated that allows the underlying Shielding Effectiveness of the circuit board level shield to be evaluated along with an estimate of its expected variability due to the external enclosure.
BEST EMC PAPER FINALIST

11:25 **Limitations of Shielding Effectiveness Measurements of Planar Materials using a DTEM Cell**
Vasiliki Gkatsi[1], Evangelia Tourounoglou[2], Robert Vogt-Ardatjew[1], Hans Schipper[2], Frank Leferink[1,2]
[1]University of Twente, The Netherlands; [2]Thales Nederland B.V., The Netherlands
Abstract: This paper addresses issues encountered in a method for measuring the shielding effectiveness of planar materials using a dual transverse electromagnetic cell. The aim of this work is to evaluate the performance of the setup and to point out its strengths and weaknesses. The effect of placement of several materials varying in size and texture is examined. Additionally, techniques for improving the setup and therefore the measurement accuracy and sensitivity are presented. The size of the aperture is investigated by applying two different methods in order to observe its effect on the shielding effectiveness results. Restrictions and limitations of the measurement method are discussed and supported by experimental results.

11:50 **Shielding Effectiveness Controlling of Coated Glass Assembly in Mobile and Positioning GPS Frequency Bands**
Xavier Radu[1], Michael Bruscaglia[1], Davide Micheli[2], Luca Bastianelli[3], Franco Moglie[3], Valter Mariani Primiani[3]
[1]AGC Glass Europe SA, Belgium; [2]CT.NEO.A.M–TIM S.p.A., Italy; [3]Università Politecnica delle Marche, Italy
Abstract: The increasing of frequencies for the bands assigned to mobile services has threatened the indoor coverage performances. The present paper is giving a solution to this issue introducing a technology able to mitigate glass metallic coating attenuation effects.

12:15 **Material Investigation on Radio Frequency Transparency and Thermal Stress Relaxation**
Nika Amralah, *Raymond EMC Enclosures Ltd., Canada*
Abstract: An investigation on thermally resistant and radio frequency (RF) transparent materials was performed. Thermal stress relaxation tests from 20°C to 150°C showed that polystyrene foam board and polycarbonate demonstrate signs of creep deformation over time. Polyurethane foam demonstrated no thermal stress relaxation. For RF penetrability testing, the 100 MHz to 40 GHz range was studied using an outdoor test setup. Open air measurements of two collinearly faced antennas were compared to measurements taken when material samples were placed between the two antennas. This demonstrated that rigid polyurethane foam, Teflon polytetrafluoroethylene (PTFE) and borosilicate glass are RF penetrable.

TECHNICAL PAPERS TP-FRI-3A

RISK-BASED EMC

(SPONSORED BY TC-1)

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

11:00 A System's Perspective on the use of EMI Detection and Correction Methods in Safety Critical Systems
Tim Claeys, Hassan Tirmizi, Hasan Habib, Dries Vanoost, Guy A.E. Vandenbosch, Davy Pissoort
Katholieke Universiteit Leuven, Belgium
Abstract: In this paper we discuss the condition assessment definitions previously used to analyse the effectiveness of ElectroMagnetic Interference (EMI) detectors/correctors. It is shown that those definitions do not resemble the correct condition and an expansion is needed. New expanded condition assessment definitions are presented and evaluated in comparison with the old ones for a two out of three majority voter system used in an Electro Magnetic (EM) diverse system. The new definitions provide a better insight into the effectiveness of EMI detectors on its own or in correctors. We also discuss the use of the new definitions in a multi-layer error detection and correction system.

11:25 A Comparative Study of On-Chip CMOS S&H Voltage Sensors for Power Integrity: SOI vs. Bulk
Qazi Mashaal Khan[1,2], Richard Perdriau[1,3], Mohammed Ramdani[1,3], Mohsen Koohestani[1,3]
[1]ESEO, France; [2]INSA Rennes, France; [3]IETR, France
Abstract: This paper evaluates the performance of two onchip sample & hold (S&H) voltage sensors, usable for power integrity measurements, with the aim to compare silicon-oninsulator (SOI) & bulk CMOS technologies. Both sensors were designed and simulated in 180 nm 5 V AMS-bulk and XFAB-SOI processes, using optimized parameters and compatible devices. The fundamental variables analyzed were power consumption, leakage current, slew rate (SR), and transient output voltage, under process, voltage and temperature variations. Compared to bulk technology, SOI was found to have lower power consumption (by 2.2 mW in average) and leakage supply current (by 9.5 pA at 27°C), higher sensitivity to process variations (up to 88% additional slew rate versus 39% at 80°C), higher resilience to temperature changes (6% in output voltage), and a larger occupied area. The SOI sensor is intended to be fabricated and used to evaluate injected continuous wave and transient disturbances as well as voltage fluctuations due to internal activity on power distribution networks.

11:50 Sensitivity of Shielded Cable Transfer Impedance Measurement to Triaxial Cell Diameter
Oskari Leppäaho[1], Frédéric Lafon[1], Priscila Fernandez-Lopez[1], Marine Stojanovic[1], Richard Perdriau[2], Mohammed Ramdani[2]
[1]Valeo, France; 2ESEO, France
Abstract: Triaxial measurement is an effective means to determine the transfer impedance of a shielded cable. It is based on coupled transmission line principle. In an ideal case, both transmission lines in the setup would be matched to guarantee the high frequency performance. In practice, matching is hard to achieve without compromising on usability and generality of the measurement setup. This paper discusses how triaxial cell diameter and the resulting impedance mismatch affects transfer impedance measurement results. In addition, the paper shows how impedance mismatches can be modeled, presents a simplified model to quickly understand the effects of impedance mismatch, and compares the model to results measured with different triaxial cell sizes. The simple model presented achieved similar accuracy to a more complex model defined in IEC 62153.

12:15 Mutual Influence of Cavity Resonances of a Shielding Enclosure on the Resonance of a Dipole inside that Enclosure
Zhao Chen[1], Tim Claeys[2], Ronny Deseine[1], Davy Pissoort[2]
[1]Barco NV, Belgium; [2]Katholieke Universiteit Leuven, Belgium
Abstract: In recent years, a risk-based approach has been proposed to better manage EM-related risks of electronic systems. Within this approach it is critical to detect potential risks as much and as early as possible. Unfortunately, many hazards (potential contributors to risks) are "hiding" deep in the system and/or can only appear when "excited" under certain conditions. One such example is electromagnetic (EM) resonance of components and structures (e.g., traces, heatsinks, PCBs, enclosures) within electronic systems. These resonances can further lead to unintended and increased coupling effects which may result in seriously hazardous situations. In this paper, we consider the relatively simple but basic case of a trace (modelled as a dipole) within a closed metallic enclosure. Both quantitative calculations and full-wave EM-simulation results reveal the complexity of the possible resonance mechanisms and interactions.
BEST EMC PAPER FINALIST

TECHNICAL PAPERS TP-FRI-5A

PIM EVALUATION AND CHARACTERIZATION

(SPONSORED BY TC-12)

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

11:00 A Recommended Practice for PIM Test of Antennas in Wireless Communication Systems
Z.H. Cai, L. Liu, Y. Qi
General Test Systems Inc., China
Abstract: A test method is proposed to IEEE Standard Association recently for testing of passive intermodulation of base station or satellite antennas. PIM product may deteriorate the performance of sensitive communication systems. An innovative test system and calibration method have been proposed to remedy the defects in the current standards. The proposed anechoic chamber and method are suitable for testing antennas with PIM residual below -150dBc which cannot be measured accurately according to the method defined by the current standards.

11:25 Self-Contact Introduced Passive Intermodulation Characterizations for Captured Springs
Jiangshuai Li[1], Shengxuan Xia[1], Zhifei Xu[1], Yang Xu[1], Yansheng Wang[2], Yuchu He[2], Ken Wu[2], Nicholas McDonnell[2], Warren Lee[2], Haicheng Zhou[2], Jun Fan[1], Hwang Chulsoon[1]
[1]Missouri University of Science and Technology, USA; [2]Google LLC, USA
Abstract: Passive intermodulation (PIM) is one of the most common nonlinear behavior that exists in a variety of applications. Nowadays, consumer electronics designs use a variety of mechanical features for radio-frequency (RF) antenna feeds and grounding, such as springs, gaskets, screws, etc. When these components are placed in the path or nearby the RF antennas, the unsatisfying connection such as loose contact will generate PIM and create noise in the receiving frequency range. This can potentially cause RF desense issues. In product design, the most intrinsic method to improve the electrical connection is applying more compression between the spring tip and the landing substrate, but seldom will the engineers notice the spring structure itself can also introduce a lot of PIM. This paper concentrates on characterizing and validating the captured RF springs that can introduce noticeable PIM due to its structural self-contact phenomenon. An integrated camera recorded the spring side-view under compression. The measured information indicates that high PIM tends to occur when the spring contacts itself unintentionally

11:50 Gaussian Process Regression Analysis of Passive Intermodulation Level and DCR for Spring Contacts
Shengxuan Xia, Jiangshuai Li, Yang Xu, Ze Sun, Zhifei Xu, Yansheng Wang, Yuchu He, Nick McDonnell, Haicheng Zhou, Ken Wu, Jun Fan, Chulsoon Hwang
Missouri University of Science and Technology, USA
Abstract: In modern consumer electronic devices, for the purpose of having easier access for assembly and repair in a compact designed product, metallic connection components such as springs are universally used for metallic connections between modules or chassis. However, the non-ideal metallic connections tend to have a certain level of non-linearity. Therefore, significant attention has been aroused recently because the passive-intermodulation (PIM) can degrade the radio-frequency (RF) antennas' receiving quality especially when the unsatisfying spring connections are placed near the RF antenna. Typically, advanced and expensive instruments and components are required to estimate the non-linearity levels of the springs. However, those instruments are usually not available for the manufacturing factories for massive tests. This paper is focused on investigating the feasibility of estimating the nonlinearity level of spring contacts using DC resistance (DCR), which has easier access to be tested with much lower cost. Study showed that the DCR, when under certain conditions, can serve as the alternative figure of merit for PIM prediction. Then, the Gaussian process regression (GPR) analysis based on measured data can provide a statistical estimation to the generated PIM from the DCR values.
BEST EMC STUDENT PAPER FINALIST

TECHNICAL PAPERS
TP-FRI-6A

COMPUTATIONAL ELECTROMAGNETICS III

(SPONSORED BY TC-9)

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

11:00 **Time Domain Computation of Full-Wave Partial Inductances based on the Numerical Inversion of Laplace Transform Method**
Fabrizio Loreto[1], Daniele Romano[1], Giulio Antonini[1], Martin Stumpf[2], Albert E. Ruehli[3]
[1]University of L'Aquila, Italy; [2]Brno University of Technology, Czechia; [3]Missouri University of Science and Technology, USA
Abstract: This paper presents the computation of time-domain partial inductances. The numerical inversion of the Laplace transform (NILT) is adopted to compute the time samples of the partial inductance. Furthermore, the causality can be strictly guaranteed by using a delayed implementation of the NILT method making use of the minimum distance between the spatial supports of the basis functions. The proposed method is tested by comparing the results with analytical ones existing for coplanar zero-thickness regions and with inverse Fourier transform techniques for non-orthogonal volumes.

11:25 **EMC Results Analysis using Statistical Comparison Criteria**
Samuel Leman[3], Sébastien Serpaud[3], Philippe Besnier[2]
[1]IRT Saint Exupéry, France; [2]INSA Rennes, France
Abstract: This paper presents an evaluation of statistical comparison criteria applied to analyze and to interpret EMC data results with their uncertainties characterizing an electronic system. Based on EMC simulated and/or measured results of shielded harness test case, five comparison criteria are used firstly to validate a data with a referent EMC results, secondly to identify sensitive parameters, and thirdly to estimate input parameters uncertainties.

11:50 **System Identification of Electromagnetic Devices based on Full-Wave Computations**
Carl Holmberg[1,2], Thomas Rylander[1], Jan Carlsson[1,3], Tomas McKelvey[1]
[1]Chalmers University of Technology, Sweden; [2]Volvo Car Corporation, Sweden; [3]Provinn AB, Sweden
Abstract: We present a framework that allows for the estimation of port-to-port characteristics of electromagnetic devices, which are linear and passive. Our approach is based on system identification (SI) techniques applied to the numerically computed admittance or impedance matrices of the electromagnetic device. The SI procedure yields a low-order model expressed in terms of a Pad´e approximant, which is represented as the ratio of two polynomials with respect to frequency. In this article, we demonstrate that the admittance and impedance matrices computed at a rather small number of frequency points can yield a highly accurate low-order model that describes the system response as a continuous function throughout the frequency band used for estimation of the model. The computational cost to store and evaluate the low-order model is basically negligible in comparison to the computational cost required by the numerical full-wave solver. The derived port-to-port model allows for the individual and independent analysis of subsystems that do not couple electromagnetically, where such subsystems can be combined later to form a complete system and this allows for great flexibility in a virtual design-process. We test our approach on two different crosstalk problems.

12:15 **A Simulation approach to Predict the Radiated EMI from a TV Panel**
Taeshin Kang[1], Matt Commens[1], Jihyun Lee[2], Jinho Kim[2], Seonha Lee[3], Sungwook Moon[3]
[1]Ansys Inc., USA; [2]Samsung Electronics Co. Ltd., Korea
Abstract: EMI (Electrical Magnetic Interference) regulation is strictly applied to display panel products, and it needs to be considered from IC design stage. In this work, we propose a virtual EMI simulation technique for TV products to simulate the EMI test of the CISPR 16 standard. The virtual EMI simulation implements both display panel and EMI measurement environment by Ansys HFSS simulation software, which enable to predict the EMI problem of the display panel products in IC design stage. The proposed simulation technique showed a good correlation with the EMI measurement results of the 55-inch 4K display model.

TECHNICAL PAPERS
TP-FRI-7A

POWER INTEGRITY ANALYSIS AND DESIGN 1

(SPONSORED BY TC-10)

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

11:00 **Design of Power Delivery Network Droops**
Long Yang
Cisco Systems Inc., USA
Abstract: Based on a simple and typical power delivery network structure, the impedance profile is expressed in a novel form through a complicated derivation and then the Fourier transform is used to calculate the time-domain impedance response. After that, an exactly analytical formula of the load voltage droop induced by an ideal current step is derived. The analytical results are exactly matched with the commercial simulation tool. The resonant frequency is derived, and its damped property is discussed. Through the properties derived from the simple structure, a more complicated power delivery network is designed in control. The step current response in timedomain is also simulated to show the voltage droops, as the design expected.

11:25 **Achieving a Sub Miliohm Load Line on a Discrete Graphics Product**
Umesh HM[1], Kinger Xingjian Cai[2], Ashwini Anil Kumar[1], Pete Tirkas[2]
[1]Intel Corporation, India; [2]Intel Corporation, USA
Abstract: The Direct Current Load Line (DCLL) and the Alternating Current Load Line 3 (ACLL3) target of 0.5mOhm has been defined for a graphics core power delivery network in order to achieve the preferred peak performance on the next generation discrete graphics product. The pathfinding effort led to explore various innovative solutions to have a line of sight for achieving this challenging impedance target, which includes A. Study of various stack up and routing strategies to achieve the lower Resistance path (Rpath) B. Novel idea of bulk capacitors provision beneath System on Chip (SoC) cavity to lower Load Line (LL) around the Voltage Regulator Module (VRM) bandwidth C. Improved Power Integrity (PI) design methodology for an accurate ACLL and reasonable DCLL estimation D. Enhancement in Package Design for Manufacturing (DFM) rules to gain extra margins

11:50 **Decoupling Capacitor Optimization to Achieve Target Impedance in PCB PDN Design**
Shuang Liang[1], Biyao Zhao[1], Siqi Bai[1], Samuel Connor[2], Matteo Cocchini[2], Stephen Scearce[3], Dale Becker[2], Michael Cracraft[2], Matthew S. Doyle[2], Albert Ruehli[1], James Drewniak[1]
[1]Missouri University of Science and Technology, USA; [2]IBM Corporation, USA; [3]Cisco Systems Inc., USA
Abstract: With increasingly stringent requirements for lower voltage supply, and higher density in PCB (Printed Circuit) PDN (Power Distribution Network) design, power integrity has an increasingly important role in PCB design. The PI performance of the PCB design must meet requirements, or modification and trial-and-error are necessary to ensure the target impedance is satisfied. Lots of design practices and commercial tools are utilized to aid PI designers, e.g., developing a suitable stack-up, saving cost while placing enough decoupling capacitors, best layout for IC pins and so on. It is essential in the PCB PDN design to place as fewer decoupling capacitors as possible to achieve target impedance and voltage ripple goals while saving cost. In this paper, the influence from the types of decoupling capacitor and stack-up is considered. The variety of decoupling capacitors contributes to the objective of reaching the target with minimum number of decoupling capacitors.
BEST SIPI STUDENT PAPER FINALIST

12:15 **Cloud based FastPI Streamlining Platform Power Integrity Design**
Angela Chen[1], Kinger Xingjian Cai[1], Chi-te Chen[1], Chaitra Kotehal[2], Morgan Tseng[3], Joseph Chen[1]
[1]Intel Corporation, USA; [2]Intel Corporation, India; [3]Intel Corporation, Taiwan
Abstract: Cloud based FastPI, using Intel's first developed platform design automation methodology, facilitates Intel customers' board level PI design. For every power rail of the SoC, it provides quick design review, PDN optimization and sign-off to expedite Time-to- Market (TTM). Flexibility feature of the trade-offs among performance, cost, and form factors including stack-up and Zheight greatly helps customers' platform differentiation and product innovation.

TECHNICAL PAPERS
TP-FRI-8A

PRINTED CIRCUIT BOARD TECHNOLOGY AND SI DESIGN 1

(SPONSORED BY TC-10)

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

11:00 Automated 3D Discontinuity Optimization with Speed Sensitivity for High Speed Serdes Channels
Qian Dong[1], Kevin Cai[2], Anna Gao[2], Bidyut Sen[2]
[1]Stanford University, USA; [2]Cisco Systems, Inc., USA
Abstract: With the data rate increasing to 112 Gb/s, optimization of differential vias becomes critical for high-speed designs, as discontinuity of differential vias can severely impact signal qualities. Achieving a good differential via design for higher frequencies is becoming more and more challenging. In this paper, we present an unconventional way to optimize the differential vias, which is using different antipad sizes for input/output antipads and middle anipads. We then perform sweeping with different parameters and analyze the S-parameters by examining their impact on TDR, TDT, Group Delay, and eye diagrams. Our Python coding helps identify the optimization trend and make the complete sweeping fully automated with designated signal speed as a sensitive target.

11:25 Dielectric Constant Extraction for Microstrip Transmission Lines based on S-Parameter Measurements and Cross-Section
Yuanzhuo Liu, Shaohui Yong, Jiangshuai Li, Victor Khilkevich
Missouri University of Science and Technology, USA
Abstract: In this paper, a new dielectric constant extraction method for the microstrip substrate material is proposed, which is based on measured S-parameter and cross-section analysis of the transmission lines. The calculation process is detailed and application examples are given. The phase constant is calculated from the measured S-parameters. By analyzing the cross-section geometry using a 2D solver, the per-unit-length inductance and capacitance of the air-filled line are obtained. Then using analytical expressions, the dielectric constant of the substrate is extracted from the effective dielectric constant. Comparing to the published method that requires knowing the characteristic impedance of the line, the new method will introduce less error to the extraction procedure and will provide more accurate results.

11:50 Signal Integrity and Crosstalk Analysis of PCBs within a PEC-PMC Bandgap Metallic Cavity
Francesco de Paulis[1], Muhammet Hilmi Nisanci[2]
[1]University of L'Aquila, Italy; [2]Sakarya University, Turkey
Abstract: The PEC-PMC type of metallic cavities has been shown to be effective to inhibit cavity resonances within welldefined bandgap limits. Such cavities are realized by appropriately placing metallic pins on the cavity lid. However, the presence of such pins, may affect the signal transmission over interconnects routed in close proximity, or right underneath the pins. The systematic analysis carried out in this paper demonstrates the feasibility of such cavities from a signal integrity and crosstalk point of view. Different distances between the pin and the traces are analyzed, such that the pinned lid is demonstrated to have not detrimental impact on the traces insertion loss. Moreover, since cavity resonances cannot occur within the bandgap, the crosstalk among traces is not affected by the cavity, thus typical PCB design and layout rules can be simply applied for the design of digital and RF interconnects.

12:15 Analysis on Unintentional Resonances in High-Speed Signals from Non-Ideal Routing Stub
Yuanzhuo Liu, Siqi Bai, Bo Pu, JongJoo Lee, DongHyun Kim
Missouri University of Science and Technology, USA
Abstract: As more components are integrated into a denser area in electronic devices, the complexity of routing increases. A routing design resulting from routing tools may pass all design rule checks, but it can also result in signal integrity problems, which affect the performance of the entire link path, often not realized until the layout stage. In this paper, such designs are analyzed for their unintentional resonances in the insertion loss and the crosstalk of the signals. As an example, an unintentional power plane stub created by trace routing revisions adjacent to the signal trace behaves as a quarter-wavelength resonant structure. To avoid such unintentional resonances in high-speed signals, trace routing should be carefully designed and design rule checks must be improved to detect and warn the users of such potential signal integrity hazards.

TECHNICAL PAPERS
SS-FRI-A

ROBUST DESIGN FOR SYSTEM LEVEL ESD: DEVICE, PCB AND SYSTEM LEVEL

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

11:00 Generic ESD Generator Model using Artificial Neural Network
Jawad Yousaf[1], Kamran Javed[2], Mohammed Ghazal[1]
[1]Abu Dhabi University, United Arab Emirates; [2]Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Pakistan
Abstract: Different commercial ESD gun models, although complying with the standard ESD waveform requirements in terms of rise time and current values for standard Pellegrini target, produce different ESD waveforms. The variations of the ESD source and target impedance in real-time with the change in the gun model affects the ESD susceptibility compliance testing results and immunity analysis for the estimation of possible ESD failure in a product. This study presents, for the first time, a novel generic ESD generator model using artificial neural network (ANN) based deep learning techniques. The developed deep learning model incorporates the characteristics of the real-time generated ESD waveforms by various commonly used commercial ESD gun models with different target load impedances. The presented model could be used as a generic ESD source for fast ESD susceptibility and immunity testing's at the design stage of a product using numerical or circuit-analysis-based tools.

11:25 Improvement of SPICE based ESD Protection Models for IO Protection Modeling
Amin Pak[1,2], Seyed Mostafa Mousavi[1], David Pommerenke[1,2], Giorgi Maghlakelidze[3], Yang Xu[3]
[1]Technische Universität Graz, Austria; [2]Silicon Austria Labs GmbH, Austria; [3]Missouri University of Science and Technology, USA
Abstract: Modeling ESD protection using the System Efficient ESD Design (SEED) methodology enables optimal protection of an IO using TVS and external components. The success of modeling depends on the accuracy of the models. This work shows improvements to SPICE models used to characterize TVS diodes and IC I/O. The improvement is twofold. The transition phases between snapback and main current flow have been adjusted to achieve realistic waveforms for the rise times from 500 ps to 5 ns in a voltage range from Vt1 to the high current region, and complex curvatures of the IV curve are included. The model is capable of operating in generic SPICE and being tested in ADS and LT-SPICE. The paper explains this in detail to enable the reader to apply this modeling principle.

11:50 IC-based Antenna Switch Modeling and Robustness Evaluation for SEED Applications
Seyed Mostafa Mousavi[1], Gabriel Fellner[1], David Pommerenke[1,2], Sandeep Chandra[3], Ketan Shringapure[3], Warwick Ka Kui Wong[3]
[1]Technische Universität Graz, Austria; [2]Silicon Austria Labs GmbH, Austria; [3]Google, Inc., USA
Abstract: ESD discharges to antennas can damage the RF front end. In particular, antennas with highly inductive ground connections allow large ESD-induced voltages at their RF terminals. This work investigates the ESD properties of an RF switch used as an antenna tuner by measuring the voltages and currents at its terminals and building a SPICE model. The goal is to predict the damage threshold when the switch is used in an RF front end.

12:15 ESD Susceptibility Analysis: Coupling to Traces and Interconnect
Mehdi Gholizadeh[1,2], Seyed Mostafa Mousavi[1], David Pommerenke[1,2], Amin Pak[1,2], Gabriel Fellner[1], Jin Min[3]
[1]Technische Universität Graz, Austria; [2]Silicon Austria Labs GmbH, Austria; [3]Amber Precision Instruments, USA
Abstract: ESD susceptibility scanning is an effective method to find the causes of ESD soft failures in electronic systems. A local probe is used to scan the system for sensitive areas. However, the voltages induced by the probe are often unknown. This paper quantifies the induced voltages from different probes when injected into traces and flex cables, and compares the values to the induced voltages caused by an IEC 61000-4-2 ESD gun in contact mode. The goal is to guide the reader to select voltage levels and probes during susceptibility scans in a way that avoids levels that may be associated with ESD gun injection and cause failure.

TECHNICAL PAPERS TP-FRI-1B

NEAR FIELD MEASUREMENTS

(SPONSORED BY TC-2)

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

13:55 **Using the ANOVA F-Statistic to Isolate Information-Revealing Near-Field Measurement Configurations for Embedded Systems**
Vishnuvardhan V. Iyer, Ali E. Yilmaz
The University of Texas System, USA
Abstract: The analysis of variance (ANOVA) F-statistic is proposed as a tool to isolate near-field measurement configurations that are sensitive to targeted chip processes in embedded systems. It is hypothesized that the desired measurement configurations have high F-values, i.e., the variation in a target process is a major contributor whereas obfuscating background processes and measurement uncertainty are minor contributors to the variance of measured signals. The concept is demonstrated by isolating data-dependent measurement configurations for a commercially available variant of the 8051 microcontroller: First, a multi-stage measurement protocol using Fvalues is developed to rapidly isolate optimal measurement configurations within the 4-D search space of 2-D probe location over chip area, probe orientation, and time. Then, signals captured using configurations with high F-values are analyzed to identify the Hamming weights of the output data computed by a randomized test code running on the 8051. It is shown that configurations with higher F-values generally result in more accurate classification of the output data; the configuration with the highest F-value results in 100% accuracy.

TECHNICAL PAPERS TP-FRI-3B

RISK-BASED EMC

(SPONSORED BY TC-1)

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

13:30 **The 4+1 Principles for EM Risk Management**
D. Pissoort[1], M. Nicholson[2]
[1]Katholieke Universiteit Leuven, Belgium; [2]University of York, United Kingdom
Abstract: In this contribution, we translate the existing 4+1 principles for the safety assurance of software, as enshrined in standards such as Def-Stan 00-055, to 4+1 principles for electromagnetic risk management. These principles can be used as a guidance for a proper risk-based approach to manage (functional) safety risks or other risks due to electromagnetic disturbances.

13:55 **Characterizing the Robustness of Wi-Fi and Bluetooth against Continuous Wave EM Disturbances inside a Reverberation Chamber**
Aleksandr Ovechkin[1], Tim Claeys[1], Dries Vanoost[1], John F. Dawson[2], Guy A.E. Vandenbosch[1], Davy Pissoort[1]
[1]Katholieke Universiteit Leuven, Belgium; [2]University of York, United Kingdom
Abstract: This paper describes a detailed test setup and procedure to characterize the robustness of Wi-Fi3 and Bluetooth 4.2 against continuous wave electromagnetic disturbances inside a reverberation chamber. Bluetooth 4.2 robustness was also characterized by continuous broadband noise. These experiments aim to reveal the susceptibility of commonly used wireless communication protocols against continuous wave noise. Results show that Wi-Fi3 has an abrupt rise in the packet error rate (up to 100%) when the continuous wave noise overlaps with the Wi- Fi3 working frequency. Bluetooth 4.2 is robust against continuous wave noise, thanks to the frequency hopping technique, but fails against broadband noise.

14:20 **Effects of the 3rd Harmonic Component on False Negatives in a Time Diverse Triple Modular Redundant System Under Reverberation Conditions**
Hassan Tirmizi, Jonas Lannoo, Dries Vanoost, Guy A.E. Vandenbosch, Davy Pissoort
Katholieke Universiteit Leuven, Belgium
Abstract: In this paper, time diversity is used as an EM resilience technique in a Triple Modular Redundant (TMR) communication channel that is subjected to a multi-harmonic electromagnetic disturbance under reverberation conditions. The study shows that time diversity proves to be quite an effective measure in order to incorporate fault tolerance in the system. However, when compared to the single frequency case for which time diversity eliminates all potential false negatives, the multi-harmonic disturbance tends to have a slight percentage of false negatives, especially at high field strengths. Together with reverberation simulation results, a theoretical explanation is also presented that explains this phenomenon of multi-harmonic Electromagnetic Interference (EMI) induced false negatives.

TECHNICAL PAPERS
TP-FRI-4B

CIRCUIT EMC ANALYSIS, TESTING AND CONSIDERATIONS

(SPONSORED BY TC-4)

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

13:30 **Analytical Method to estimate Magnetic Fields from a 2D Scalar Potential for a Normative Setup**
Guido A. Rasek, Madhavi Dhara
Valeo Siemens eAutomotive Germany GmbH, Germany
Abstract: Components in the electric drive train of vehicles must meet strict requirements from standards with regard to magnetic field emissions. High voltage cables play an important role in the distribution of intended functional and unintended parasitic currents. These currents result in radiated magnetic field emissions that are influenced by geometric configurations. A 2D approach with simplifications to calculate current to field transfer functions is presented to estimate the effect of the geometric configurations of the current loops on the resulting magnetic fields. Furthermore for analytical calculations, they are decomposed into geometric subareas based on the distribution of functional and parasitic currents. As a result transfer functions are presented for practical application in typical automotive laboratory setups from an analytical method without exaggerated complexity.

13:55 **Radio Frequency Interference Due to Power Plane Radiation and Mitigation using RFI and PI Co-Optimized Design in Mobile Platforms**
Farnaz Foroughian, Jaejin Lee, Christian Chaves Bejarano, Pujitha Davuluri, Steven G. Gaskill
Intel Corporation, USA
Abstract: This paper's main focus is to study the noise radiation risk from motherboard power planes, including the mechanism of power plane radiation. A design for a power plane that is optimized for radio frequency interference (RFI) and power integrity (PI) is studied and simulation and measurement results are presented. This design has been proposed to reduce the level of RFI radiated from the power plane to the nearby antennas.

14:20 **Permittivity Measurement System using Stripline Method for the Europa Clipper Mission**
Rohit Gawande, Alina Moussessian, Emmanuel Decrossas
NASA Jet Propulsion Laboratory, USA
Abstract: High radiation Jovian environment can deposit electrons in highly resistive dielectric materials, which could result in internal electrostatic discharge (IESD) causing damage to sensitive electronics such as the radar for Europa Assessment and Sounding: Ocean to Near-Surface (REASON) instrument on NASA's Europa Clipper mission. Special dielectric materials like static dissipative Polyetheretherketone (PEEK) ESD are under consideration for the Europa Clipper mission. PEEK loaded with carbon nanofibers improves the ESD performance for this material but the RF characteristics are unknown. We have developed a method to characterize the dielectric constant of a material as a function of frequency and temperature down to 30K. We present the measurement results of four samples of ESD. The measured data shows the permittivity of TECAPEEK ESD 11 is in the range of 7.16 to 9.87 at HF and in the range of 6.8 to 8.55 for VHF frequencies. The change in permittivity of ESD 11 down to 30 K is less than 7% at HF and less than 3% at VHF frequency. The sample to sample variability can be attributed to the inhomogeneity of the material.

14:45 **Estimating Electromagnetic Emissions from a Site Installation with Multiple Racks of Server Equipment**
Ze Sun[1], Xu Wang[1], Chunyu Wu[1], Ben Kim[2], DongHyun Kim[1], Jun Fan[1]
[1]Missouri University of Science and Technology, USA; [2]Facebook Inc., USA
Abstract: More than hundreds, sometimes even thousands, of servers operate simultaneously inside a data center. Their radiation can be a problem and cause electromagnetic interference (EMI) issues. However, it is not feasible to perform full-wave 3D simulation of these racks because of the large electrical size of the model. In this paper, an algorithm is proposed to predict the emission from rack arrays. The equivalent dipole source is extracted from EMI measurement data of a single rack and reconstructed as a radiation source in a multiple rack model. The racks in an array can be divided into a few categories and the racks in each category have similar radiation patterns. Thus only one modeling of a representative rack is needed for each category. In order to take rack to rack scattering into consideration, a simplified model for each category is developed and method of moments is used to describe the radiation of representative racks. After the radiation calculations from a representative rack in all the categories are completed, the total radiation from the data center is predicted based on these representative-rack calculations. This method is much faster than the brute-force simulation of the entire data center, and is highly scalable to handle arbitrary number of racks in the data center.

TECHNICAL PAPERS
TP-FRI-5B

RADIATED EMI MODELING AND REDUCTION FOR POWER CONVERSION SYSTEMS

(SPONSORED BY SC-5)

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

13:30 **Radiated EMI Reduction with Double Shielding Techniques in Active-Clamp Flyback Converters**
Zhedong Ma[1], Juntao Yao[1], Shuo Wang[1], Honggang Sheng[2], Srikanth Lakshmikanthan[2], Doug Osterhout[2]
[1]University of Florida, USA; [2]Google Inc., USA
Abstract: Electromagnetic interference (EMI) issue becomes a headache problem when the switching frequency has been pushed higher and higher for the smaller size and higher power density. Up to now, the conducted EMI can be controlled very well with decades of exploration and research. However, the radiated EMI is still hard to be understood and controlled, the techniques to reduce the radiated EMI are limited. In this paper, active-clamp flyback converters are taken as the example, the radiation model is developed, the double shielding technique is proposed to mitigate the radiated EMI effectively no matter the EMI filters are placed on the AC line or DC bus. The concept of this technique is explained in detail, the experiments are conducted to verify the analysis. The guideline to choose the appropriate connection method of the double shielding technique is given for both the AC line and DC bus EMI filters.

13:55 **Radiated Electromagnetic Interference Source Modeling for a Three Phase Motor Drive System with a SiC Power Module**
Boyi Zhang, Shuo Wang
University of Florida, USA
Abstract: SiC power modules have become the most promising candidates to replace the Si power modules in threephase motor drive systems. However, the fast switching speed and switching frequency of SiC power modules raise the concern of radiated electromagnetic interference (EMI). In this paper, an analytical time-domain model is firstly proposed for the EMI noise sources of SiC power modules. The influence of the non-linear junction capacitance, power loop parasitic inductance, and the operation conditions on the radiated EMI are then investigated in depth. Simulation and experimental results show a good agreement between the proposed analytical model and the measured radiated EMI.

14:20 **Impact for Radiated Noise by Current Smoothness with Bare SiC MOSFET and Si RC-IGBT Chips**
Toshiya Tadakuma[1], Michael Rogers[2], Koichi Nishi[1], Motonobu Joko[1], Masahito Shoyama[3]
[1]Mitsubishi Electric Corporation, Japan; [2]Mitsubishi Electric US Inc., USA; [3]Kyushu University, Japan
Abstract: Power device structures have been improved to shrink area of chip and to reduce power loss. The switching speed has continued increasing to reduce switching loss, and electromagnetic noise also has been increasing and shifting to higher frequency. It is important to reduce generation of noise for establishing proper operation of power converters or inverters for motor control, thus simple switching behavior should be reconsidered anew. This report describes the relationship between switching behavior and intensity of the electric field at an antenna using electromagnetic potential and wavelet transform with switching data measured by extended double pulse test for bare SiC MOSFETs and Si RC-IGBTs.

14:45 **A Survey of Modeling and Reduction Techniques of Radiated EMI in Power Electronics**
Juntao Yao, Zhedong Ma, Yanwen Lai, Shuo Wang
University of Florida, USA
Abstract: Radiated electromagnetic interference (EMI) is an important and challenging topic in modern power electronics. To analyze radiated EMI, modeling research is the foundation. Modeling research can reveal fundamental mechanisms including switching noise generation, noise conversion into the radiation excitation, antenna characteristics, and near field couplings' impact. Radiated EMI models are developed. Based on radiated EMI modeling research, noise reduction techniques are developed, including component improvement, printed circuit board (PCB) layout improvement, high-frequency EMI filters, and shielding. This paper summarizes recent research advances and discusses future radiated EMI challenges and research topics.

TECHNICAL PAPERS
TP-FRI-6B

TRANSMISSION LINE COMPUTATIONAL ELECTROMAGNETICS

(SPONSORED BY TC-9)

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

13:30 Calculation of Radiated Emission from STP Cable by Chain-Parameter-Matrix
Nobuo Kuwabara, Tohlu Matsushima, Yuki Fukumoto
Kyushu Institute of Technology, Japan
Abstract: Radiated emission from shielded twisted pair (STP) cable was calculated using a chain-parameter-matrix. The series connection of the matrix represented the transmission line inside the shield, and the common-mode (CM) cunent was obtained by solving the matrix equation. The induction voltage on the outside of the shield was determined from the CM cunent using the shield's transfer impedance. The cunent on the outside of the shield was calculated from this induction voltage. And then, the radiated electric field was calculated from this cunent. The matrix elements representing the transmission line between conductors and shield were determined from the measurement, and the transfer impedance was also determined from the measurement. The line constants between shield and grnund were determined from the theory by assuming the shield as a copper rnd. The maximum cunent on the outside of the shield and the maximum radiated electric field were measured in the frequency range from 30 MHz to 300 MHz, and these were compared to the calculated value. The calculation results of the maximum cunent intensity were well agreed with the measured value, and the calculation results of the maximum radiated electric-field strength were almost agreed with the measured value.
BEST EMC PAPER FINALIST

13:55 Multi-Output Variable-Fidelity Bayesian Optimization of a Common Mode Choke
Rodrigo Silva Rezende[1], Mirsad Hadžiefendić[1], Jan Hansen[2], Rolf Schuhmann[1]
[1]Technische Universitat Berlin, Germany; [2]Robert Bosch GmbH, Germany
Abstract: In this paper, we propose a modification of the wellknown kriging modeling technique and its multi-fidelity variant in order to generate a surrogate model of a vector-valued output of a common mode choke. Combined with Bayesian optimization, we solve a multi-objective optimization problem to find the tradeoff between inductance, total volume, and resonance frequency. With the proposed method, we calculate a Pareto front of the objective functions more than 200 times faster compared to the solution without the surrogate.
BEST EMC STUDENT PAPER FINALIST

14:20 Network Model of a Transmission Line with a Cable Ferrite for Simulation in LTspice
Steffen Schulze[1], Moawia Al-Hamid[2], Marco Leone[2]
[1]Würth Elektronik eiSos GmbH, Germany; [2]Otto-von-Guericke University, Germany
Abstract: Cable ferrite sleeves are common suppression components for reducing common-mode noise on wires and cables. This paper continues previous work on the characterization of those components regarding their electrical parameters. In this paper the parameters of a low-permeability nickel-zinc ferrite sleeve are extracted using the core geometry and measured permittivity and permeability data up to 5 GHz. Then a lumped element transmission line model, including the ferrite, is set up as a netlist for numerical circuit simulation in LTspice®. From the results the current distribution along the transmission line is extracted at different frequencies and compared with the analytical solution. In the second part a 3D full-wave model of the transmission line, created and simulated in CONCEPT-II, is presented. The results of this approach are compared with the analytical solution for the current distribution, showing a perfect match.

14:45 Data-Driven Discovery of the Governing Equation for the Transmission Lines System
Yanming Zhang, Lijun Jiang
The University of Hong Kong, Hong Kong
Abstract: Sophisticated structures in the transmission line system introduce the nonuniformity and nonlinearity, which brings the challenge for its characterization and modeling. In this work, a novel data-driven method is proposed to derive the governing partial differential equations of the transmission line. Based on the polynomial interpolation of the spatialtemporal samples of current and voltage, the time and spatial derivatives can be obtained. Then, the ridge regression algorithm is adopted to determine the active spatial differential terms from the candidate functions. Three benchmarks, the uniform and nonuniform transmission line, and a soliton generation system, are provided to demonstrate the validity of the newly proposed approach.

TECHNICAL PAPERS
TP-FRI-7B

HIGH-SPEED LINK/BUS DESIGN 3

(SPONSORED BY TC-10)

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

13:30 A Review of Kramers-Kronig Integral Relations for Signal Integrity Applications
Ravi Shaw[1], Gerardo Romo Luevano[2], Timothy Michalka[2]
[1]Qualcomm India Private Limited, India; [2]Qualcomm Technologies, Inc., USA
Abstract: This paper presents an overview and applications of the Kramers-Kronig (K-K) integral equations which are used to characterize a causal system. The conventional form of the KK integral is discussed which involves a singularity in the integrand. A modified form of the K-K integral is presented which removes the singularity in theory. The causal dielectric permittivity model proposed by Djordjevic-Sarkar is used to demonstrate the evaluation of K-K integral using standard numerical integration techniques. Also, examples of passive impedance network and causal transmission line models are considered. Three different implementation methods of the K-K integral are shown, and their errors are compared. The results show a good match between the original data and K-K integral retrieved data.

13:55 The Sensitivity of ENRZ to Crosstalk – In Comparison to NRZ, PAM3, and PAM4
Sherman S. Chen, Zhifei Xu, Brian Holden, Armin Tajalli
Kandou Bus, United Kingdom
Abstract: In this article the performances of ENRZ (Ensemble NRZ) under the interferences of crosstalk, in conjunction with NRZ (Non-Return-to-Zero), PAM4 (Pulse Amplitude Modulation of 4-level), and PAM3 are investigated. Two typical crosstalk patterns with varying levels of crosstalk are studied. The simulation results and the underlying causes are analyzed. Overall, ENRZ shows more robustness than NRZ, PAM3, and PAM4 in terms of crosstalk.

14:20 LPDDR5 (6.4 Gbps) 1-tap DFE Optimal Weight Determination
Sunil Gupta
Qualcomm Technologies, Inc., USA
Abstract: SI (Signal Integrity) analysis of a LPDDR5 SoCDRAM PoP (Package-on-Package) system using 1-tap DFE (Decision Feedback Equalization) is presented. The system was running at 6.4 Gbps with 0.47V VDDQ at SS corner. The DFE mitigates the reflection based ISI and results in improved eyeaperture. DFE has been extensively used in serial differential interfaces such as USBSS and PCIe but their use in LPDDR5 parallel single-ended interface is new and presents unique challenges as the JEDEC standard hexagonal eye-mask defines two timing specifications, namely @Vref+/-0mV and @Vref+/- 50mV. Vref being the reference voltage in the eye center used for measuring the eye-opening. Based on the channel analyzed, during Writes, the optimal 1-tap DFE feedback-weight was ~5mV which improved eye-aperture @Vref+/-50mV without degrading the eyeaperture @Vref+/-0mV. Further increasing the feedback-weight resulted in over-equalization causing the eye-aperture @Vref+/- 0mV to decrease even though the eye-aperture @Vref+/-50mV kept increasing.

TECHNICAL PAPERS
TP-FRI-8B

IBIS BASED POWER INTEGRITY MODELING

(SPONSORED BY TC-10 AND SC-5)

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

13:30 Improving Power Supply Induced Jitter Simulation Accuracy for IBIS Model
Yin Sun[1], Chulsoon Hwang[2]
[1]Zhejiang Lab, China; [2]Missouri University of Science and Technology, USA
Abstract: This work presents a new algorithm for improving the simulation accuracy of power supply induced jitter (PSIJ) in input/output buffer specification (IBIS) model. The improvement is realized by modifying the switching coefficient Ku and Kd as a function of both time and power rail voltage. The incorporation of time averaged effect of the power rail noise on buffer output switching edge during the time range of buffer propagation delay is the key element for the enhanced accuracy. In addition, implementation of the proposed algorithm in an open source spice simulator Ngspice is demonstrated. The accuracy of the proposed new algorithm is validated through transistor level circuit simulations.

13:55 Continuous Time Model of Current Mode Buck Converter with Adaptive On-Time Controller for Power Delivery Network Design
Anfeng Huang[1], Jingdong Sun[1], Hongseok Kim[1], Jun Fan[1], Zhenxue Xu[2], Shuai Jin[2]
[1]Missouri University of Science and Technology, USA; [2]Google Inc., USA
Abstract: Proper power integrity (PI) analysis is essential for modern electronics devices to minimize voltage noise. The lowfrequency response of a power distribution network (PDN) is determined by the voltage regulator modules (VRMs) installed on the board. However, the conventional VRM model is either represented by an over-simplified passive circuit or an encrypted model provided by then vendor. These models can only work for limited operating conditions. In this paper, a generic average model for up-to-date DC converter is proposed. Both time and frequency domain responses of a current-mode buck converter with adaptive on-time control (AOT) method are captured by the proposed model. This cycle-by-cycle averaged model can be extended for converters with other control methods.
BEST SIPI STUDENT PAPER FINALIST

14:20 A Behavior Model of Voltage Regulator Module with Adaptive Voltage Positioning and PCB Parasitics for Power Distribution Network Design
Junho Joo[1], Anfeng Huang[1], Runbing Hua[1], Bin-Chyi Tseng[2], Hank Lin[2], Chulsoon Hwang[1]
[1]Missouri University of Science and Technology, USA; [2]ASUSTek Computer Inc., Taiwan
Abstract: In this paper, a behavior modeling method of a buck converter with adaptive voltage positioning (AVP) and PCB parasitics for power distribution network design (PDN) is introduced. The behavior model of voltage regulator module (VRM) is previously proposed for the power integrity modeling and analysis. The proposed behavior model is applied to the buck VRM in a practical high-speed digital board. For the completeness of the behavior model, an AVP design and PCB parasitics are applied to reproduce the power supply rail noise in the practical design. To validate the behavior model, the design parameters of voltage and current controllers of buck VRM in the board are extracted based on the measurement. The proposed model shows a good correlation with the measurement under various loading conditions.

TECHNICAL PAPERS
SS-FRI-B

ROBUST DESIGN FOR SYSTEM LEVEL ESD: DEVICE, PCB AND SYSTEM LEVEL

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

13:30 A Portable Test Platform for Capturing ESD Induced Fields
Nikola Becanovic, Seyed Mostafa Mousavi, Gabriel Fellner, David Pommerenke
Technische Universität Graz, Austria
Abstract: As a first step in a survey of the ESD risk to mobile devices, a small, battery powered portable system that emulates a mobile device for the purpose of capturing its electrostatic discharge environment is described. The system contains multiple electric, magnetic field sensors as well as a current sensor to capture ESD events and their associated transient fields. Bandwidths of > 2 GHz are achieved. The system is connected via an analog optical fiber. It is intended to provide reference data of fields captured in controlled conditions in order to determine the type and voltage of ESD discharges with these data in the second step. This will provide a data base of the occurrence rate and severity of ESD discharges at customer side. Goal is to better base the selection of ESD test levels on actual ESD levels.

13:55 New Implicit ESD Test Methodology and Simple Simulation Method for ESD Risk Evaluation
Scott Lee[1], Leo Wu[2], Kyle Chang[2], Ray Huang[2], Joseph Lin[2]
[1]Ring, Taiwan; [2]Quanta Computer Inc., Taiwan
Abstract: ESD test [1] is essential for IT product certification. While, usual test methodology requires complex system setup and have device damage risk. And, it is time consuming to evaluate ESD risk by current simulation method. Hence, this paper introduces new implicit ESD test methodology by using thermocouple to visualize discharging path and avoid complex process for system setup and device damage risk. Then, a simple simulation method to use s-parameter to check ESD risk by energy leakage examination are introduced as well to shorten simulation time required for ESD risk evaluation of board design.

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

14:45 SEED Modeling of an ESD Gun Discharge to a USB Cable Surrogate
Yang Xu[1], Jianchi Zhou[1], Javad Meiguni[1], Daryl G. Beetner[1], Sergej Bub[2], Steffen Holland[2], David Pommerenke[3]
[1]Missouri University of Science and Technology, USA; [2]Nexperia Germany GmbH, Germany; [3]Technische Universität Graz, Austria
Abstract: An IC protected by a transient voltage suppression (TVS) diode may fail if the TVS device does not turn on or does not turn on quickly enough, causing the IC to take the full brunt of the ESD event. System Efficient ESD Design (SEED) simulation can help predict when the TVS will turn on and the level of ESD stress seen by the IC. In the following paper, models are developed to predict the voltage and current through a TVS and on-chip protection diodes connected to a USB cable when an ESD gun discharges to a pin at the end of the cable. A hybrid simulation methodology is proposed, which uses a full-wave model of the ESD gun, cable, and enclosure combined with the ESD protection devices and test board's circuit-level models. The response of the ESD protection is studied in simulation and measurement for a variety of cable configurations. Simulations of the voltage and current waveforms match measurements 24-35%. The total charge delivered to the on-chip diode as a function of ESD gun voltage was predicted within 21%.
BEST EMC STUDENT PAPER FINALIST

HARDWARE EXPERIMENTS

COMMON MODE CONDUCTED SUSCEPTIBILITY TESTING – A SIMPLIFIED METHOD

Chair: John Cardinal McCloskey, *NASA/Goddard Space Flight Center, United States*

This demonstration shows an 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.ness of the behavior model, an AVP design and PCB parasitics are applied to reproduce the power supply rail noise in the practical design. To validate the behavior model, the design parameters of voltage and current controllers of buck VRM in the board are extracted based on the measurement. The proposed model shows a good correlation with the measurement under various loading conditions.

HARDWARE EXPERIMENTS

CONQUERING RADIATED EMISSIONS WHEN USING WIDE-BANDGAP DEVICES

Chair: Jared Quenzer, *Würth Elektronik, United States*

Wide bandgap devices, primarily silicon-carbide (SiC) and gallium-nitride (GaN) can lead to challenges passing radiated emissions tests due to faster rise times and higher switching frequencies. The speaker will look at a couple of techniques for reducing radiated emissions by first understanding how WBDs can cause more EMI issues. If you have always wondered when to use cable ferrites, how many turns, how many ferrites, and even what value of gate resistance to use for the switching transistor, then please join this session.

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6 August, 2021 - 10:00 AM - 10:45 AM

13 August, 2021 - 10:00 AM - 10:45 AM

HARDWARE EXPERIMENTS

DEBUGGING EMI/EMC PROBLEMS IN THE NEAR FIELD

Chair: Arturo Mediano, *University of Zaragoza, Spain*

EMI troubleshooting is considered black magic. You need some special eyes to "see" the sources and some special "thinking" to find fixes. We have three different strategies to solve an EMC problem: 1) to kill the source, 2) to reduce the coupling mechanism (increasing distance, reorientation, with filters, or shielding), and 3) to increase the immunity of the victim. Usually, the most effective way to solve the problem is to kill the source but many times to find the culprit is not easy. In this demo you will see some experiments demonstrating how useful is the work in the near field to debug EMI/EMC problems. We will use one scope and one spectrum analyser combined with near field probes and near field scanners to find culprits and test solutions. Funny and practical demos!

HARDWARE EXPERIMENTS

DEMONSTRATING THE COMBINED EFFECTS OF TESTING RADIATED IMMUNITY IN ACCORDANCE WITH EDITION 4.0 OF IEC 61000-4-3 USING MULTIPLE SIGNALS

STANDARDS

Chair: Dean F Landers, *AR RF/Microwave Instrumentation, United States*

With the release of the 4th Edition of IEC 61000-4-3, questions arise converning the multiple signal method of testing with regard to over-testing of EUTs, 3rd order harmonic issues when multiple signals are applied, and the overall time savings of applying multiple signals during a single sweep. This experiment will demonstrate and characterize the energy seen by the EUT in both the frequency and time domains, as well as demonstrate the time savings involved when testing multiple signals., display the time savings involved when testing multiple signals, and provide measurements of the power required during multiple signal testing.

HARDWARE EXPERIMENTS

FREQUENCY AND TIME-DOMAIN CALIBRATION OF VIBRATING INTRINSIC REVERBERATION CHAMBERS

Chair: Guillaume Andrieu, *Universite de Limoges Faculte des Sciences et Techniques, France*

Vibrating intrinsic reverberation chambers (VIRCs) [1] are a particular kind of reverberation chambers (RC) based on the time-varying modification of the cavity shape, generally through a flexible tent made of conducting material. Probably in reason of the continuous movement of the metallized tent, the standard procedure [2] (which probably would require some adjustments in this case) does not mention how to calibrate a VIRC. The aim of this demonstration is therefore to present an experimental approach published recently [3] able to characterize the performance of a VIRC in the frequency domain (as traditionally made for classical RC) using the "well-stirred condition method" [4] based on measurements of an antenna ;but also in the time domain from measurements of the same antenna in the constant-wave mode in order to define the "decorrelation time", defined as the interval of time to wait in order to collect two independent samples at the same position. The demonstration will be video-recorded. Targeted Audience: Primary: EMC engineers and EMC researchers working with reverberation chambers. Secondary: System design engineers, EMC test engineers and researchers. Duration: 45 minutes. Scenario: Introduction to VIRC Tutorial 1 : Q-factor measurement of a Tutorial 2 : Frequency-domain calibration of a VIRC using the "well-stirred condition method"Tutorial 3 : Time-domain calibration of VIRC measurement of the decorrelation time Conclusions and perspectives Discussion References: [1] F. Leferink, J. C. Boudenot, and W. van Etten, "Experimental results obtained in the vibrating intrinsic reverberation chamber," in Proc. IEEE Int. Symp. Electromagn. Compat. Symp. Rec., 2000, vol. 2, pp. 639–644. [2] Reverberation Chamber Test Methods, IEC 61000-4-21: January 2011. [3] G. Andrieu, M. Narjes, C. Jullien and N. Ticaud, "Complete Framework for Frequency and Time-Domain Performance Assessment of Vibrating Intrinsic Reverberation Chambers", IEEE Transactions on Electromagnetic Compatibility, vol. 62, no. 5, October 2020, pp. 1911-1920. [4] G. Andrieu, N. Ticaud, F. Lescoat, and L. Trougnou, "Fast and accurate assessment of the "well stirred condition" of a reverberation chamber from 11 measurements," IEEE Trans. Electromagn. Compat., vol. 61, no. 4, pp. 974–982, Aug. 2019.

HARDWARE EXPERIMENTS

FUNDAMENTAL EMC EFFECTS

Chair: Daria Nemashkalo, *University of Twente, Netherlands*

The demo focuses on presenting various fundamental EMC phenomena using a small and portable setup. This setup is typically used to educate university students learning EMC. It consists of a couple of PCBs that address the fundamental effects such as Lenz's law, crosstalk, discontinuities, parasitics, and transfer impedance. The measurements are performed in time and frequency domain.

HARDWARE EXPERIMENTS

MEASUREMENT OF MMWAVE RADIATED SPURIOUS EMISSIONS

STANDARDS

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

This virtual demonstration will present a multi-axis, effective isotropic radiated power (EIRP) and power spectral density (PSD) measurement solution for a 5G millimeter wave (mmWave) radiating device, as required by FCC Part 30, ETSI/EN 300 400, ETSI/EN 305 550 and other relevant specifications such as those from the 3GPP. Compatibility with traditional semi-anechoic chambers, which are common for EMC measurements, and fully anechoic rooms make this demonstration applicable to nearly any EMC or RF lab that handles wireless intentional transmitters. The demonstration will be of a radiated spurious emissions (RSE) measurement in the mmWave frequency range and will be accompanied by a presentation that explains the applicable standards, highlights the challenges associated with making the RSE measurement, and describes the measurement automation employed. Attendees will learn about some of the challenges of mmWave radiated emissions measurements, how to avoid common mistakes, as well as how improve their test efficiency and productivity.

HARDWARE EXPERIMENTS

PHASE-RESOLVED IN-HOUSE NEAR-FIELD SCANNER

Chair: Morten Sørensen, *Syddansk Universitet, Denmark*

Centre for Industrial Electronics, University of Southern Denmark, will provide a live demonstration of their in-house near-field scanner. With help of picture recognition, the setup of the near-field scan is very quick. With help of a VNA, the near-field scanner can make phase-resolved near-field scans up to 40 GHz in one scan. I.e., the system can sweep a broad frequency spectrum contrary to commercial scanners on the market which with the VNA only measure single frequencies in zero spans. The concept will be demonstrated on simple microstrips. In addition, near-field scans of power electronic vs. digital electronics will be demonstrated and discussed.

HARDWARE EXPERIMENTS

RADIATED EMISSION AND SIGNAL INTEGRITY ANALYSIS OF PCBS AND CABLE HARNESSES FOR CONSUMER ELECTRONICS APPLICATIONS

Chair: Jaehoon Kim | Smit Navin Baua, *Altair Engineering Inc | Altair Engineering Inc, United States | United States*

The intense competition in the consumer electronics product market continuously requires shortening the development period and cutting down on the development cost for the timely product launch to the market. To satisfy these requirements, the PCB (Printed Circuit Board) design technology has been steadily improved for quite some time. However, the PCB designs still demand engineering challenges due to the increased EMI (Electromagnetic Interference) of clock speeds as well as the increasing density of digital designs. At the same time, more and more electronic products are introduced with High-Definition Multimedia Interface (HDMI) cable connections. As such, not only the radiation emissions from PCBs but also the conducted and radiated emissions from the attached HDMI cables is of significant concern. Additionally, the quality of the PCB signal transmitted to the cable is degraded by the cable attached to the PCB. Therefore, it is highly recommended to perform the radiated emission (RE) and signal integrity (SI) analysis of the PCBs to mitigate any potential EMI issues. In this demonstration, the procedure of analyzing the signal quality and radiation effects of the PCB with a high data rate cable, specifically HDMI, will be presented. Additionally, techniques to mitigate the radiated and conducted emissions from HDMI cables will also be presented.

HARDWARE EXPERIMENTS

RADIATED EMISSIONS TESTING PER CISPR 22/32 USING REMOTE LOCATION

STANDARDS

Chair: Jack McFadden, *ETS-Lindgren, Cedar Park, TX, USA*

This virtual demonstration will discuss the test setup and test methodology for performing RF radiated emissions testing in accordance with CISPR22/32 using a 3m Semi-Anechoic Chamber and Emissions System. A fully functional and compliant test system is used to demonstrate testing of an actual EUT. This virtual demonstration will be conducted using test automation as well as vision-based software to illustrate techniques to increase quality and efficiency. The test control will be remote while the system is located within a laboratory. The program will start with a presentation that highlights the challenges and common mistakes when utilizing this test method. The following live demo will show the material presented in a real-world environment. Attendees will learn how to avoid common mistakes as well as improve their test efficiency and productivity.

HARDWARE EXPERIMENTS

TRANSFER IMPEDANCE MEASUREMENT, FROM SIMPLE TO COMPLEX SETUP

Chair: Charles Jullien, *Safran Electrical and Power, France*

The electrical wiring interconnection system (EWIS) can be protected either by shielding, i.e. by placing a conductive screen that protects and limits the electromagnetic radiation and coupling, either by separating the links from the others with a certain distance in order to create a segregation between the signals and powers transmitted. In the first case, we must be able to characterize the effectiveness of the shielding. For a large number of applications, the frequency band used rarely exceeds a few GHz. So we can divide the problem of a shielded cable into two sub-problems that we link with a transfer function: the transfer impedance. These internal (core VS shielding) and external (shielding VS environment) domains are linked by the transfer impedance which determines the interaction of one domain on the other and vice versa. The demonstration shows the evolution in complexity of the transfer impedance (Zt) characterization methods. Starting from a sample of a coaxial cable and a setup requiring only a few materials, we will carry out several assemblies allowing the Zt to be measured: triaxial bench [2], triaxial bench with shielding discontinuity, line injection and localized injection . This latter method will highlight the future of transfer impedance measurement by localized injection and its potential for extending the characterization of high frequency shields. The addressed topics: Transfer impedance; Shielding; Triaxial bench; Injection line; Localized injection; Cables; Harnesses; Connectors The demonstration will help the audience to test shielding cables, connectors and their assemblies for a wide range of frequency. Targeted Audience: Primary: EMC engineers in electric product industries Secondary: Cable, connector and their assembly designers; EMC researchers. Duration: 45min

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TECHNICAL PROGRAM
BEST SYMPOSIUM PAPER FINALISTS

FINALISTS FOR BEST EMC PAPER

TP-WED-2B CHAMBERS
Statistical Approach to Verification of Field Uniformity and Dominance of the Primary Field Component in the GTEM Cell
Yevhenii Hubariev, Jan Sroka, *Warsaw University of Technology, Poland*

TP-FRI-2A SHIELDING
Experimental Verification of Board Level Shielding Variability at Microwave Frequencies
Andrew Marvin, John Dawson, Martin Robinson, *University of York, United Kingdom*

TP-TUE-1A EMISSIONS
Auto Focus for Far Field Source Localization Using Emission Source Microscopy
Ling Zhang, Shaohui Yong, Yuanzhuo Liu, Victor Khilkevich, *Missouri University of Science and Technology, USA*

TP-TUE-4B TESTING AND EMC APPLICATION OF COMPOSITE MATERIALS
3D Printed Electromagnetic Absorber Built with Conductive Carbon-filled Filament
Rui Mi, Wei Zhang, Kaustav Ghosh, Sameer Walunj, Qian Liu, Jacques Rollin, Philippe Sochoux, David Pommerenke, Victor Khilkevich, *Missouri University of Science and Technology, USA; Juniper Networks Inc., USA; Technische Universität Graz, Austria*

TP-FRI-3A RISK-BASED EMC
Mutual Influence of Cavity Resonances of a Shielding Enclosure on the Resonance of a Dipole Inside that Enclosure
Zhao Chen, Tim Claeys, Ronny Deseine, Davy Pissoort, *Barco NV, Belgium; Katholieke Universiteit Leuven, Belgium*

TP-WED-5B INTENTIONAL EMI AND HEMP
Conducted Electromagnetic Pulse Testing of Digital Protective Relay Circuits
Tyler Bowman, Ross Guttromson, Tim Minteer, Travis Mooney, Matt Halligan, *Sandia National Laboratories, USA; Schweitzer Engineering Laboratories Inc., USA; The Boeing Company, USA*

SS-WED-B ADVANCED METHODS TO MODEL, EVALUATE, AND MEASURE ELECTROMAGNETIC INTERFERENCE AT LOW FREQUENCY IN TRANSPORTATION AND RENEWABLE ENERGY SYSTEMS
Comparison of Selected Support Vector Machine Approaches for Stochastic Power Electronic Circuit Simulation with Parasitics
Karol Niewiadomski, Sharmila Sumsurooah, David W.P. Thomas, *University of Nottingham, United Kingdom*

TP-TUE-3B CONDUCTED EMISSIONS
Electromagnetically Interfered Energy Metering Resulting from Droop of Current Transducers
Bas Ten Have, Niek Moonen, Frank Leferink, *University of Twente, The Netherlands*

TP-TUE-4A SPACE EMC
Statistical Field Model for Performance of Localized RF Absorption Blankets in a Payload Fairing
P.G. Bremner, M. Bahadorzadeh, J.C. West, C.F. Bunting, S. Kabiri, *Robust Physics, USA; Oklahoma State University, USA*

TP-THU-6A COMPUTATIONAL ELECTROMAGNETICS II
Efficient and Flexible Huygens' Source Replacement of mm-scale Human Brain Implants
Cheng Yang, Morten Schierholz, Eileen Trunczik, Leon Maximilian Helmich, Heinz-D. Brüns, Christian Schuster, *Technische Universität Hamburg, Germany*

TP-FRI-6B TRANSMISSION LINE COMPUTATIONAL ELECTROMAGNETICS
Calculation of Radiated Emission from STP Cable by Chain-Parameter-Matrix
Nobuo Kuwabara, Tohlu Matsushima, Yuki Fukumoto, *Kyushu Institute of Technology, Japan University of Science and Technology, China*

TP-WED-8B NUMERICAL MODELING AND SIMULATION TECHNIQUES 1
Simulation of Mode Division Multiplex Transmission Method in Shielded Four-wire Cable
Tohlu Matsushima, Takuya Sato, Yuki Fukumoto, Nobuo Kuwabara, Kyushu Institute of Technology, Japan

TP-WED-3B 2.5D/3D/EXOTIC ICS/PACKING AND EMERGING TECHNOLOGIES
Signal Integrity Design Methodology for Package in Co-packaged Optics Based on Figure of Merit as Channel Operating Margin
Bo Pu, Jiayi He, Aaron Harmon, Yuandong Guo, Yuanzhuo Liu, Qiangming Cai, *DeTooLIC Technology Co. , Ltd., China; Cisco Systems, Inc., USA; Missouri University of Science and Technology, USA; Southwest*

TP-WED-3B 2.5D/3D/EXOTIC ICS/PACKING AND EMERGING TECHNOLOGIES
Design and Analysis of On-package Inductor of an Integrated Voltage Regulator for High-Q Factor and EMI Shielding in Active Interposer Based 2.5D/3D ICs
Subin Kim, Seungtaek Jeong, Boogyo Sim, Seongsoo Lee, Hyunwook Park, Haeyeon Kim, Joungho Kim, *Korea Advanced Institute of Science and Technology, Korea*

TP-TUE-6A POWER INTEGRITY ANALYSIS AND DESIGN 2
Optimal Power Distribution Network Design for High-Performance Solid-State-Drive Based on Novel Target-Impedance Extraction Method
Jinwook Song, Chunghyun Ryu, Sangho Park, Donggon Jung, Jaeyoung Shin, Youngmin Ku, *Samsung Electronics Co., Ltd., Korea*

TP-THU-8A EVALUATION AND SIMULATION OF EMI IN WIRELESS SYSTEMS
DoE-based Evaluation of the Impact of the Twisted Pair Cable Parameters on the Wireless Communication Performance
Oussama Sassi[1], Pascal Hervé[2], Moncef Kadi[3]
[1]Volkswagen AG, Germany; [2]CSA Group Bayern GmbH, Germany; [3]ESIGELEC, France

TP-TUE-7A POWER ELECTRONICS EMI MODELING AND MEASUREMENT II
A Bias Tee for Broadband Measurement of Power Electronic Components
Michael Fuchs, Christoph Maier, David Pommerenke, *Technische Universität Graz, Austria*

TP-MON-8B POWER ELECTRONICS EMI CONTROL VIA OPTIMAL
Modulation and Driving Schemes Frequency-Selective Reduction of Power Electronic Switching Noise by Applying Synthesized Gate Signals
Caroline Krause, Andreas Bendicks, Stephan Frei, *Technische Universität Dortmund, Germany*

Photo by Richard Georgerian

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Subin Kim, Seungtaek Jeong, Boogyo Sim, Seongsoo Lee, Hyunwook Park, Haeyeon Kim, Joungho Kim, *Korea Advanced Institute of Science and Technology, Korea*

TP-FRI-8B IBIS BASED POWER INTEGRITY MODELING

Continuous Time Model of Current Mode Buck Converter with Adaptive On-time Controller for Power Delivery Network Design

Anfeng Huang[1], Jingdong Sun[1], Hongseok Kim[1], Jun Fan1, Zhenxue Xu[2], Shuai Jin[2], [1]*Missouri University of Science and Technology, USA;* [2]*Google Inc., USA*

TP-THU-7B HIGH-SPEED LINK/BUS DESIGN 1

Far-End Crosstalk Analysis for Stripline with Inhomogeneous Dielectric Layers (IDL)

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

TP-FRI-7A POWER INTEGRITY ANALYSIS AND DESIGN 1

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Shuang Liang[1], Biyao Zhao[1], Siqi Bai[1], Samuel Connor[2], Matteo Cocchini[2], Stephen Scearce[3], Dale Becker[2], Michael Cracraft[2], Matthew S. Doyle[2], Albert Ruehli1, James Drewniak1, [1]*Missouri University of Science and Technology, USA;* [2]*IBM Corporation, USA;* [3]*Cisco Systems Inc., USA*

TP-THU-7A MACHINE LEARNING/CLOUD COMPUTING 2

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Jack Juang[1], Ling Zhang[1], Zurab Kiguradze[1], Bo Pu[1], Shuai Jin[2], Chulsoon Hwang[1], [1]*Missouri University of Science and Technology, USA;* [2]*Google Inc., USA*

TP-FRI-5A PIM EVALUATION AND CHARACTERIZATION

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Photo by Richard Georgerian

TP-TUE-1A EMISSIONS

Radiated Emission Tests for High-frequency Router Systems in Class A: Discussion and Improvement

Wei Zhang, Zhekun Peng, Xu Wang, DongHyun Kim, James Drewniak, *Missouri University of Science and Technology, USA*

TP-WED-5B INTENTIONAL EMI AND HEMP

Non-invasive Optimal Coupling Upon Detection of a Local Change of Impedance in a Cable Network

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

SS-FRI-B ROBUST DESIGN FOR SYSTEM LEVEL ESD: DEVICE, PCB AND SYSTEM LEVEL

SEED Modeling of an ESD Gun Discharge to a USB Cable Surrogate

Yang Xu[1], Jianchi Zhou[1], Javad Meiguni[1], Daryl G. Beetner[1], Sergej Bub[2], Steffen Holland[2], David Pommerenke[3], [1]*Missouri University of Science and Technology, USA;* [2]*Nexperia Germany GmbH, Germany;* [3]*Technische Universität Graz, Austria*

TP-MON-6B COMPUTATIONAL ELECTROMAGNETICS I

Optimization of PDN decoupling capacitors for EMI Reduction based on Deep Reinforcement Learning

Chanjong Lee[1], Sangyeong Jeong[1], Jingook Kim[1], Jun-Bae Kim[2], Jeong Don Ihm[2], [1]*Ulsan National Institute of Science and Technology, Korea;* [2]*Samsung Electronics Co. Ltd., Korea*

TP-FRI-6B TRANSMISSION LINE COMPUTATIONAL ELECTROMAGNETICS

Multi-Output Variable-Fidelity Bayesian Optimization of a Common Mode Choke

Rodrigo Silva Rezende[1], Mirsad Hadžiefendić[1], Jan Hansen[2], Rolf Schuhmann1, [1]*Technische Universitat Berlin, Germany;* [2]*Robert Bosch GmbH, Germany*

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THURSDAY, 12 AUGUST
11:00 AM - 3:00 PM EDT

The IBIS Summit event will be held on Thursday, 12 August (11:00 am – 3:00 pm EDT). This virtual event is designed to promote interactions between model users, model makers, and EDA tool developers in the IBIS community as well as the IEEE EMC Society members. Presentations related to IBIS and IBIS-AMI basics and power integrity topics are highly encouraged, as well as other usual topics related to modeling and signal integrity. Advance registration is required to attend, and all presentation submissions will be reviewed by the IBIS Board and are subject to approval before presentation at the Summit. Contact information for presentation submittals can be found on the IBIS Events website **www.ibis.org/events**.

EMC SOCIETY TECHNICAL COMMITTEES – BUILD YOUR EXPERTISE AND YOUR CAREER

No matter where you are in the industry, at some point you will deal with an EMC issue. Maybe a device is causing interference or maybe it's vulnerable to radio-frequency fields. Maybe a device crashes or resets after an electrostatic discharge. Maybe you've been looking for help explaining an EMC problem to your customer or your boss. All of these things happen. **Become part of the solution.**

The **IEEE EMC Society's Technical Committees (TCs)** convene to set EMC standards and practices and develop tools for success. Covering topics ranging from professional development to nanotechnology, the TCs are volunteer consensus groups that build our industry's foundations.
Join remotely or in-person and help form important technical practices.

Find your place among these forward-looking committees. Join a TC today and set standards, explore emerging technology and help develop programs and create the tools that you and your industry need.

If you are interested in joining a committee, please complete the TC/SC Interest form.
www.emcs.org/tc-sc-interest.html

Photo by Richard Georgerian

TECHNICAL PROGRAM
TECHNICAL COMMITTEES

TC 1 EMC Management	This committee is concerned with the development and dissemination of Best Practices and Methodologies for the successful leadership, supervision and guidance of EMC related activities. These Best Practices and Methodologies shall be structured so as to provide assistance to all managers, and engineers. Appropriate and convenient tools shall serve as a foundation to these Best Practices and Methodologies.
TC 2 EMC Measurements	The committee reviews the adequacy of measurement procedures and measurement instrumentation specifications for radiated and conducted emission and immunity tests. Also discussed is the rationale for product emission limits and immunity test levels including performance requirements. The committee also supports EMC standards and procedures that deal with measurements and their uncertainty and how they are interpreted and applied.
TC 3 Electromagnetic Environment	The charter of TC3, the Technical Committee on Electromagnetic Environment is to encourage research on the: • electromagnetic environment (EME) • development of standards for EME measurement and characterization • natural and man-made sources of electromagnetic environment that comprise this environment • effects of noise (unwanted portions of EME) on systems performance • effects of international civil and military standards intended to control man-made intentional and unintentional emissions of electromagnetic energy.
TC 4 Electromagnetic Interference Control	This committee is concerned with design, analysis, and modeling techniques useful in suppressing interference or eliminating it at its source. Bonding, grounding, shielding, and filtering are within the jurisdiction of this committee. These activities span efforts at the system, subsystem, and unit levels
TC 5 High Power Electromagnetics	This committee is concerned with the effects and protection methods for electronic equipment and systems for all types of high power and other electromagnetic threat environments. These environments include electromagnetic pulse (EMP), intentional EMI environments (i.e., narrowband and wideband), lightning electromagnetic currents and fields, electrostatic discharge and geomagnetic storms. In addition this committee deals with the commercial data security issue through electromagnetic information leakage activities. Interactions with subsystems, systems and platforms are included.
TC 6 Spectrum Engineering	This committee is concerned with the analysis, design, and measurement techniques for intentional RF transmitting and receiving equipment to prevent interference and promote efficient spectrum use through technology and operational based approaches,such as software design, dynamic spectral allocation, waveform control, as well as frequency coordination and management procedures.
TC 7 Low Frequency EMC	This technical committee is concerned with low-frequency EMC including Power Quality in electric power systems. The committee is focusing on application of fundamental EMC concepts also to low frequency conducted disturbances. EMC in power systems is expected to be increasingly important. This is due to increased use of electronics in renewables, electric vehicles, energy efficient technologies and Smart Grid applications

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TC 8 Aeronautics and Space EMC

This committee is concerned with EMI/EMC issues in aircraft, spacecraft & space launch vehicles, robotic and crewed. The space environment provides unique challenges in the design, development, test and operation of space systems to avoid EMI and achieve EMC. Aeronautics & space EMC covers a wide range of topics on the part, board, box, system, multi-system, planetary and interplanetary levels. The harshness of the atmospheric, launch and space environments necessitates a broader view of EMC issues than traditional terrestrial projects, often leading to creative methods and solutions that can benefit our society's efforts elsewhere on Earth.

TC 9 Computational Electromagnetics

This committee is concerned with broad aspects of Applied Computational Electromagnetic techniques which can be used to model electromagnetic interaction phenomena in circuits, devices, and systems. The primary focus is with the identification of the modeling methods that can be applied to interference (EMC) phenomena, their validation and delineating the practical limits of their applicability. Included are low and high frequency spectral-domain techniques and time-domain methods.

TC 10 Signal and Power Integrity

This committee is concerned with the design, analysis, simulation, modeling and measurement techniques useful in maintaining the quality of electrical signals and power distribution network in printed circuit boards, ICs and within systems. These activities encompass all aspects of signal and power integrity from the integrated circuit level to the system level.

TC 11 Nanotechnology and Advanced Materials

Concerned with modelling, simulation and experimental characterization of nanomaterials and nanodevices for EMC applications. Nanotechnology is the understanding and controlling of matter at atomic and molecular scale. Nanotechnology has already found its way into various EMC applications. New materials such as single- and multi-phase composites filled with nanoparticles, nanotube and/or nanofibres have been designed and tested for gaskets and absorbing screens with outstanding performance and capabilities. Innovative nanostructured shields have shown multifunctional properties and higher efficiency than commonly used materials. Nanowires for high speed interconnects and high density integrated systems, could replace copper in the near future, but require adequate modelling and simulation approaches for signal integrity and also to avoid electromagnetic interference problems.

TC 12 EMC for Emerging Wireless Technologies

This committee is concerned with the EMC design, analysis, modeling, measurement, and testing aspects of emerging wireless products, such as Internet of Things and 5th Generation of Wireless Communication. The committee encourages research including but not limited to the following areas:

- Innovative Wireless Component Design for System Integration: wireless component design with integrated EMC functions and/or meeting certain EMC specifications
- Radio-Frequency Interference and De-sense: characterization and mitigation of interference from digital circuits to wireless antennas
- EMC and OTA Measurement & Testing of Wireless Systems: development of methods and standards for wireless performance and compliance testing
- Wireless Coexistence: interference control/mitigation among various wireless radios, as well as related testing methods and standard development
- Wireless Product or Subsystem EMC: wireless-specific EMC design for Autonomous cars, Phased Array, and others.

TECHNICAL PROGRAM

TECHNICAL COMMITTEES

SC 1 Smart Grid

This special committee is concerned with coordinating the EMC Society activity on providing EMC principles for those organizations and associated documentation and specifications that address the efficient use of the AC power grid including the control of power entering a house or building. Such control may be from a meter at the point of power entry into these facilities to control incorporated into appliances and other electronic devices in these facilities. Such controllers may be sources of undesirable RF emissions and at the same time vulnerable to the RF environment which speaks to the need for EMC. It is expected that the coordination aspect of this special committee will involve several EMCS Technical Committees.

SC 5 Power Electronics EMC

This committee is concerned with power electronics converters EMI/EMC issues. These are mainly, converters that use switching frequency schemes to control the output parameters, such as voltage and current. These converters, including inverters, can be found as interface between the raw power and the electrical grid to provide the end-user with the desired operating power. Applications can range from grid-connected PV systems, wind farms, automotive, aerospace, and communication systems.

Standards Advisory and Coordination Committee (SACCom)

The IEEE EMC Society Standards Advisory and Coordination Committee is responsible for providing technical liaison between the IEEE EMC Society Standards Development Committee and various non-IEEE entities involved with EMC standards activities.

In particular, the SACCom will include the following:

- Propose to the EMCS board of directors (BOD), the appointment of representatives to various non-IEEE standards developing entities.
- To monitor the activities of various non-IEEE standards developing organizations with a view toward making recommendations to the EMCS board of directors on any required coordination of those activities within the society.
- To communicate and coordinate with non-IEEE standards developing activities and the EMCS Standards Development Committee on matters relating to the development of EMC related standards.

Standards Development and Education Committee (SDECom)

The IEEE EMC Society Standards Development & Education Committee is responsible for guiding the development of IEEE EMC Standards, the training of those involved in the standards making process and the education of the EMC Society community on all aspects of EMC Standards. The IEEE EMC Society is the primary international developer of fundamental test, measurement and verification standards for EMC.

Education Committee (EdCom)

This committee's mission is to promote EMC education related activities of the IEEE EMC Society. Our vision is to provide opportunities for individuals and organizations involved with electrotechnology and products to become aware of EMC at levels consistent with their needs, and our goals are to establish an awareness of EMC fundamentals throughout industry and academia as well as to enhance EMC education through the development of improved education techniques, materials, opportunities, and communications.

ANCILLARY MEETINGS

COMMITTEES, STANDARDS, AND IEEE EMC SOCIETY MEMBER MEETINGS

All meetings will be held via WEBEX

Meeting Number is shown below - Password will be emailed with registration.

Meeting URL: https://ieeemeetings.webex.com/ieeemeetings

Meeting Name	Coordinator	Date	Time (EDT)	Meeting #
Technical Advisory Committee Meeting 1	Zhiping Yang	7/26/2021	11:00 AM - 1:00 PM	130 467 8824
Technical Advisory Committee Meeting 2	Zhiping Yang	8/18/2021	11:00 AM - 1:00 PM	130 720 2847
TC 1 - EMC Management	Tom Braxton	7/29/2021	10:00 AM - 11:00 AM	130 653 3366
TC 2 - EMC Measurements	Tom Fagan	7/27/2021	10:00 AM - 11:00 AM	130 056 0633
TC 3 - Electromagnetic Environment	Fred Heather	8/13/2021	10:00 AM - 11:00 AM	130 317 9051
TC 4 - Electromagnetic Interference Control	John Kraemer	7/28/2021	10:00 AM - 11:00 AM	130 881 5862
TC 5 High Power Electromagnetics	Bill Radasky	7/28/2021	11:00 AM - 1:00 PM	130 963 5588
TC 6 - Spectrum Engineering	Sarah Seguin	7/29/2021	10:00 AM - 11:00 AM	130 736 3386
TC 7 - Low Frequency EMC	Flavia Grassi	8/10/2021	10:00 AM - 11:00 AM	130 119 7282
TC 8 - Aeronautics and Space EMC	Jim Lukash	7/29/2021	10:00 AM - 11:00 AM	130 636 8119
TC 9 - Computational Electromagnetics	Scott Piper	8/11/2021	10:00 AM - 11:00 AM	130 830 2382
TC 10 - Signal and Power Integrity	Songping Wu	8/10/2021	10:00 AM - 11:00 AM	130 745 2611
TC 11 - Nanotechnology and Advanced Materials	Emmanuel Decrossas	8/11/2021	10:00 AM - 11:00 AM	130 475 1720
TC 12 - EMC for Emerging Wireless Technologies	Lie Liu	8/9/2021	10:00 AM - 11:00 AM	130 688 9193
SC 1 - Special Committee on Smart Grid	Michael K. McInerney	8/9/2021	10:00 AM - 11:00 AM	130 825 9089
SC 5 - Power Electronics EMC	Shuo Wang	8/9/2021	10:00 AM - 11:00 AM	130 875 3838
T-EMC AE Meeting	Tzong-Lin Wu	8/16/2021	8:00 AM - 9:00 AM	130 614 5816
L-EMCPA AE Meeting	Frank Sabath	8/17/2021	8:00 AM - 9:00 AM	130 381 7814
EMC-S PerCom	Heyno Garbe	8/18/2021	8:00 AM - 9:00 AM	130 613 1914
Standards Development and Education Committee	Ed Hare	8/16/2021	10:00 AM - 12:30 PM	130 510 9658
Standards Development and Education Committee	Ed Hare	8/16/2021	12:30 PM - 2:00 PM	130 914 2258
Standards Development Training	Ed Hare	8/16/2021	3:30 PM - 4:30 PM	130 458 4148
Available for Working Group Meetings	Ed Hare	8/17/2021	10:00 AM - 12:00 PM	130 235 5505
P2855: Cable and Connector Shielding Working Group	Ed Hare	8/17/2021	12:00 PM - 2:00 PM	130 417 7239
P1897: Power-Line EMC Working Group	Ed Hare	8/17/2021	2:30 PM - 6:30 PM	130 468 7222
P2715/2716 - Shielding Effectiveness Working Group	Ed Hare	8/18/2021	10:00 AM - 12:00 PM	130 468 0135
Available for Working Group Meetings	Ed Hare	8/18/2021	12:00 PM - 2:00 PM	130 098 2619
WebEx MeetingP2838 - Aircraft Lightning Working Group	Ed Hare	8/18/2021	2:30 PM - 4:30 PM	130 065 1593
IEEE EMC Standards Update	Ed Hare	8/20/2021	10:00 AM - 12:00 PM	130 359 6337
International EMC Standards Update	Ed Hare	8/20/2021	12:00 PM - 2:00 PM	130 383 0501
EMCS Chapter Chair Training	Caroline Chan	7/30/2021	11:00 AM - 12:30 PM	130 011 7372
IEEE Women in Engineering (WIE)	Susanne Kaule	8/12/2021	9:00 AM - 10:00 AM	130 277 1743
Whisky Appreciation Session	Alistair Duffy	8/12/2021	3:30 PM - 4:30 PM	Enter in Platform
IEEE Young Professionals Meeting - Trivia Event	Patrick DeRoy	8/13/2021	9:00 AM - 10:30 AM	130 164 6903
2021 EMC+SIPI Awards Ceremony	Farhad Rachidi	8/17/2021	11:00 AM - 12:30 PM	130 665 2907

TECHNICAL COMMITTEE Meetings
VP COMMUNICATION Meetings
STANDARDS Week
SOCIAL EVENTS

CHAPTER CHAIR TRAINING

FRIDAY, 30 JULY • 11:00 AM - 12:30 PM

Dear EMCS Chapter Chair and Chapter Representatives,

The IEEE EMC Society is pleased to invite you to attend the EMCS Chapter Chair Virtual Training Event taking place in conjunction with the 2021 IEEE International Symposium on Electromagnetic Compatibility, held from Monday, 26 July, to Friday, 20 August, 2021.

The meeting will be conducted on Friday 30 July from 11 am-12:30 pm EDT. All attendees are welcome to attend the event. You will NOT have to register for the Symposium in order to attend this meeting. You can just click in the follow website and enter the meeting number **130 011 7372**.

www.ieeemeetings.webex.com/ieeemeetings

OBJECTIVES:

The main objective of the meeting is to hold an exchange live forum with the different Chapter Chairs and Chapter Angels, in order to strengthen ties, to enhance cooperation and coordination, exchange information and discuss issues of common interest or concern. Additionally, the session gives the Chapter Chairs an opportunity to meet other Chapter Chairs from around the world and for the Chapter Coordinator to disseminate important information from IEEE headquarters and the EMC Society Board of Directors. More active Chapters are invited to share their best practices and exchange with all attendees their experiences, knowledge as well as methods about developing a chapter and organizing events. From the Society point of view the meeting is a forum to discuss ideas and improvements and hear out any concerns from the chapter chairs. The meeting will start with an introduction of the Society Angels, followed by a presentation on tools for the Chapter Chairs/volunteers and end with the best practices/ issues of each chapter. Thereafter, information shall be provided by the Regional Chapter Coordination Committee to the attendees, followed by discussion and feedback.

AGENDA: (EDT time)

11:00 AM	Welcome Address - Introduction
12:05 PM	Meet the Society Angels
12:15 PM	Presentation Caroline Chan, *Chapter Chair Coordinator*
	Overview of Chapter Meetings and Rebate
	OU Analytics – how to find your own members?
	Activity Reports, presented by the Chapter Chairs or Delegates
12:30 PM	Adjourn

Please prepare a short presentation (max 7 PowerPoint slides) of your top 5 Chapter best practices. You will be given time to share your practices with the attendees. Insert in your slide: What are the new hobbies you have discovered during the pandemic?

We look forward to welcoming you in our virtual platform

Best wishes,

Caroline Chan and Kris Hatashita

IEEE WOMEN IN ENGINEERING

THURSDAY, 12 AUGUST, 2021 • 9:00 AM EDT

@ EMC+SIPI 2021 Virtual – Joint IEEE International Symposium on Electromagnetic Compatibility, Signal & Power Integrity, and EMC Europe 27 July to 13 August.

IEEE Women in Engineering (WIE) is a global network of IEEE members and volunteers dedicated to promoting women engineers and scientists as well as to inspiring girls around the world to follow their academic interests in a career in engineering and science.

Our goal is to facilitate the recruitment and retention of women in technical disciplines globally. We envision a vibrant community of IEEE women and men collectively using their diverse talents to innovate for the benefit of humanity.

We will meet during the 2021 Virtual Symposium for a networking event to share experiences. This year´s Women in Engineering event during this year's virtual symposium will be an interesting panel discussion about "The Future of Leadership".

WHERE AND WHEN:

12 August, 9 AM EDT

www.ieeemeetings.webex.com/ieeemeetings

Webex Meeting Number: 130 277 1743

IEEE EMCS YOUNG PROFESSIONALS

FRIDAY, 13 AUGUST, 2021 • 9:00-10:30 AM EDT

EMC+SIPI TRIVIA EVENT

Please join us online, Friday August 13th at 9 AM EDT for our virtual Young Professionals event, EMC + SIPI Trivia! This event is free to attend with a symposium Guest Pass registration, and provides an opportunity to network with your peers and other EMC Society members, learn about the opportunities available to you in the EMC Society, as well as a chance to test your EMC + SIPI knowledge. The event is open to all but highly encouraged for undergraduate/graduate students, recent grads and all working professionals who have graduated within 15 years of their bachelor's degree. If you have recently graduated and are looking for a way to connect with fellow engineers, come join us! Relationships formed in the EMC Society can lead to future collaborations on projects and will provide valuable contacts when you need a friend to bounce ideas off of. Prizes will be awarded to the trivia winners!

IEEE young professionals 25th Anniversary

www.ieeemeetings.webex.com/ieeemeetings

Webex Meeting Number: 130 164 6903

2021 EMC+SIPI AWARDS CEREMONY

TUESDAY, 17 AUGUST, 2021
11:00 AM - 12:30 PM EDT

The Awards Ceremony is a wonderful opportunity to recognize achievements and network with EMC and Signal/Power Integrity professionals from academia, industry, government, military, and retired sectors. Please join us to honor members and non-members for their outstanding contributions to the EMC Society and for professional excellence. Highlights of the Awards Ceremony each year include the announcement of the Best Symposium Paper Award, the Best Symposium Student Paper Award, the Richard B. Schulz Transactions Prize Paper Award, and the Motohisa Kanda Award for Most Cited Transactions on EMC Paper Award. Winners of these awards and the topics addressed are those you'll want to track in the future as examples of leading researchers and technology trends. The popular Chapter-of-the-Year Award is also announced at the Awards Ceremony. Please join us!

The list of anticipated awards:

- EMC Society President's Memorial Award
- Richard R. Stoddart Award for Outstanding Performance
- Lawrence G. Cumming Award for Outstanding Service
- Hall of Fame Award
- IEEE Fellow Award
- Technical Achievement Award
- Honored Member Award
- Richard B. Schulz Transactions Prize Paper Award
- Motohisa Kanda Award for Most Cited Transactions on EMC Paper
- Best Symposium Paper Award
- Best Symposium Student Paper Award
- Best Student Design Award
- IEEE James C. Klouda Memorial Scholarship Award
- Chapter Founder Award
- Most Improved Chapter Award
- Chapter of the Year Award
- Symposium Chair Award
- Certificate of Acknowledgement
- Certificate of Recognition
- Certificate of Appreciation

www.ieeemeetings.webex.com/ieeemeetings
Webex Meeting Number: 130 665 2907

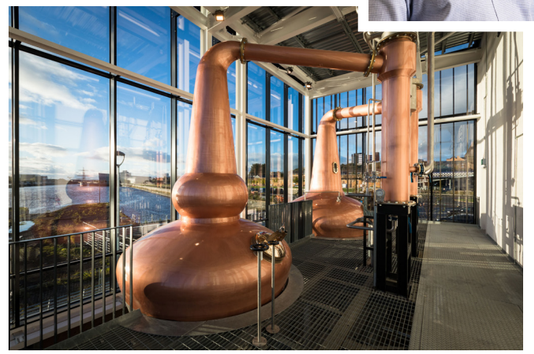
Photo by Richard Georgerian

WHISKY APPRECIATION SESSION

THURSDAY, 12 AUGUST, 2021 • 3:30 PM EDT

Join us for an exclusive evening hosted by Alistair McDonald, Distillery Manager at The Clydeside Distillery, as we uncover everything whisky and present the first Clydeside Single Malt Whisky!

Discover the history of our unique building on the banks of the river Clyde in the heart of Glasgow and learn how our excellent Lowland Single Malt is hand-crafted the time-honoured way. We'll also explore the characteristics and flavours of Scotch Whisky as Alistair introduces our very first whisky, due to be released later this year.



Bring along a dram of your choice and see what aromas you can discover from the spirit in your glass!

Full Conference Attendees Only

THE CLYDESIDE DISTILLERY
GLASGOW

ENTER THE VIRTUAL PLATFORM AT:
www.engagez.net/emc-sipi2021

TEAM EMC

Get on Your Bikes and Ride!

Whether you're in the Alpine Mountains, Chicago or Timbuktu, you can join in the TEAM EMC fun! TEAM EMC is the annual bike ride that usually takes place in person during **#IEEE_ESP**, when cycling enthusiasts share the joy of riding wherever the Symposium takes place.

This year, we're having a virtual challenge — just bike wherever you are! All you have to do is ride your bike and share pics in your TEAM EMC jersey!

The challenge runs through September, so send your request to: **marketing@emcs.org**

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SPONSORED TECHNICAL TALKS SCHEDULE

Company	Day	Topic	Start Time	End Time
EMC Partner	4-Aug	Methods for testing SPDs specified in IEEE/ANSI C62.41.2, Scenario I	10:00 AM	10:30 AM
Cadence	6-Aug	Re-Imagining 3D EM Extraction with Clarity 3D Solver	10:00 AM	10:30 AM
AR RF/Microwave Instrumentation	9-Aug	AR's Easily Serviceable "A" Series Amplifiers	10:00 AM	10:30 AM
AR RF/Microwave Instrumentation	10-Aug	Successfully Performing an IEC 61000-4-3 Field Calibration	10:00 AM	10:30 AM
EMC Partner	11-Aug	Avionic / MIL-STD – Impulse Testing Update	10:00 AM	10:30 AM
AR RF/Microwave Instrumentation	12-Aug	Getting to the Source: Integrated Circuits (ICs) and Component EMC Testing	10:00 AM	10:30 AM
AR RF/Microwave Instrumentation	13-Aug	emcware 6.0	10:00 AM	10:30 AM

SPONSORED BREAK SCHEDULE

Company	Day	Start Time	End Time
A2LA	2-Aug	10:30 AM	11:00 AM
Lightning EMC	2-Aug	1:00 PM	1:30 PM
AR RF/Microwave Instrumentation	3-Aug	10:30 AM	11:00 AM
Virginia Diodes	3-Aug	1:00 PM	1:30 PM
EMC Partner	4-Aug	10:30 AM	11:00 AM
ETS-Lindgren	4-Aug	1:00 PM	1:30 PM
Rohde & Schwarz	5-Aug	10:30 AM	11:00 AM
Elite Electronic Engineering	5-Aug	1:00 PM	1:30 PM
ANSYS UK	6-Aug	10:30 AM	11:00 AM
Advanced Test Equipment Rental	9-Aug	10:30 AM	11:00 AM
PMM-L3HARRIS-NARDA	10-Aug	10:30 AM	11:00 AM
AR RF/Microwave Instrumentation	10-Aug	1:00 PM	1:30 PM
EMC Partner	11-Aug	10:30 AM	11:00 AM
Wurth Elektronik eiSos GmbH & Co. KG	12-Aug	10:30 AM	11:00am
Schlegel Electronic Materials, Inc.	13-Aug	10:30 AM	11:00 AM

Thank you to all the Sponsors for their generous support of the 2021 IEEE Virtual Symposium on EMC+SIPI!

Keep up on Sponsor and Virtual Symposium news by **checking the website daily** and following us on social media - Facebook, Instagram, LinkedIn, Twitter, and YouTube.

Remember to tag us using the Symposium hashtag:

#IEEE_ESP21

THANK YOU

THANK YOU TO OUR REVIEWERS

With a programme as large and complex as we have for this year's Symposium, we rightly thank the authors for their time, hard work and effort in producing and communicating such an impressive array of world leading research. However, we should not overlook the Herculean task that is performed by our hundred or more technical reviewers who give up hours of their time, in the background, with no overt recognition for their work to ensure that the technical papers are outstanding new contributions to knowledge. We would like to extend this heartfelt "Thank You" to all of you who have taken the time to read the papers and provide the authors with valuable feedback to help improve the quality of the work. This is no easy task and, particularly with all the other challenges that we continue to face this year, your time and dedication is truly appreciated.

It is also with the greatest of pleasure that we say an equally big "Thank You" to our technical paper committee leadership who have dedicated hundreds of hours this year to bring everything together and make the Joint 2021 IEEE International Symposium on EMC + SIPI and EMC Europe "one for the books".

We know that these many hours are time that you could have been doing other things and our gratitude goes to you for dedicating them to the Symposium.

Thank you
Bruce and Alistair
Symposium Co-Chairs

Douglas Aguiar do Nascimento
Muhammad Septian Alamsyah
Judy Amanor-Boadu
Nika Amralah
Dave Arnett
Marco A. Azpúrua
Bumhee Bae
Alireza Baghai-Wadji
Sven Battermann
Philippe Besnier
Bart Boesman
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Tyler Bowman
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Alistair Duffy
Ihsan Erdin
Thomas J Fagan
Shirin Farrahi
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Sunil Gupta
Herbert Hackl
Carl Hager IV
Matthias Hampe
Seunghyup Han
Edward Hare
Yuichi Hayashi
Frederick William Heather
Ken Hillen
L. Gregory Hiltz
Naofumi Homma
Cheng-Lin Hsieh
Qiaolei Huang
Shaowu Huang
Chulsoon Hwang
David Inman
Junpeng Ji
Dong Jiang
Shuai Jin
Robert Johnk
Zbigniew Jóskiewicz
Charles Jullien
Sho Kanao
Taeshin Kang
Nikolaos V. Kantartzis
Cees Keyer
Qazi Mashaal Khan
Michael Khazhinsky
Zurab Kiguradze
Hongseok Kim
Jingook Kim
DongHyun Kim
Jim Knighten
Sebastian Koj
Marina Y. Koledintseva
Mohsen Koohestani
John G. Kraemer
Ireneusz Kubiak
Nobuo Kuwabara
Volodymyr Semenovych Lazebnyi
Scott Lee
Junesang Lee
Frank Leferink
Oskari Viljami Leppäaho
Huadong Li
Cong Li
shuang liang
Xiaokang Liu
Lie Liu
En-Xiao Liu
Hermes Jose Loschi
Tianjian Lu
Jim Lukash
Zhedong Ma
John Maas
Noboru Maeda
Mathias Magdowski
Irfan Majid
Francesca Maradei
Valter Mariani Primiani
Andrew Marvin
Mike McInerney
James McLean
Monrad Monsen
Mark Montrose
Se-Jung Moon
Niek Moonen
Rahul Nadgouda
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Christos D. Nikolopoulos
David Norte
Leszek Nowosielski
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Muqi Ouyang
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Morten Sørensen
Ahalya Srikanth
Adrian Suarez
Yin Sun
Xinglin Sun
Adrian Sun
Toshiya Tadakuma
Joe Tannehill
Yu Xian Teo
Jan Luiken ter Haseborg
Hassan Tirmizi
Ralf Vick
Francinei L Vieira
Mingchang Wang
Hanfeng Wang
Shuo Wang
Yansheng Wang
Tao Wang
William Wantz IV
Xing-Chang Wei
James West
Kia Wiklundh
Joost Willemen
Kimball Williams
Perry F Wilson
Michael Windler
Chunyu Wu
Songping Wu
Jiyu Wu
Xinglong Wu
Zhifei Xu
Liping Yan
Cheng Yang
Xiaolin Yang
long Yang
Juntao Zhihong Ye
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Jianmin Zhang
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