

# **2021 IEEE Wireless Power Transfer Conference (WPTC 2021)**

**Virtual Conference  
1 – 4 June 2021**



**IEEE Catalog Number: CFP21WPT-POD  
ISBN: 978-1-7281-9634-3**

**Copyright © 2021 by the Institute of Electrical and Electronics Engineers, Inc.  
All Rights Reserved**

*Copyright and Reprint Permissions:* Abstracting is permitted with credit to the source. Libraries are permitted to photocopy beyond the limit of U.S. copyright law for private use of patrons those articles in this volume that carry a code at the bottom of the first page, provided the per-copy fee indicated in the code is paid through Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923.

For other copying, reprint or republication permission, write to IEEE Copyrights Manager, IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854. All rights reserved.

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

IEEE Catalog Number:	CFP21WPT-POD
ISBN (Print-On-Demand):	978-1-7281-9634-3
ISBN (Online):	978-1-7281-9633-6
ISSN:	2474-0225

**Additional Copies of This Publication Are Available From:**

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

CURRAN ASSOCIATES INC.  
**proceedings**  
.com

Keynote 1, Chairs: Chris Mi, Jenshan Lin

**Shaping the Future of RF Wireless Power Transmission**

Cesar Johnston, Chief Operating Officer and Executive Vice President of Engineering, Energous

The proliferation of handheld devices across our daily lives means we are often tethered via wires to power outlets. New, inductive-based technologies are enabling us to remove wires from the equation and eliminate the frustration of having to periodically plug in our gadgets. But, as wireless charging evolves and customers’ requirements increase, a second-generation technology is needed to support multiple device charging, freedom of placement, and most important wireless power delivery at-a- distance from the wireless charger – not just at contact. Cesar Johnston, COO and EVP of Engineering at Energous and a leading authority on wireless power, will share his vision for the future of Wireless Power Transmission and the five big breakthroughs that are enabling this emerging technology to transform the way consumers and industries wirelessly charge and power electronic devices at home, in the office, in the car and beyond.

**Technical Session TS1: Coil and Inductive Coupler**

Chairs: Jenshan Lin, Zhizhang David Chen

- TS1.1 Design of Reactive Shield Coil for Wireless Charger With Multiple Coils.....1
- WPTC Sungryul Huh (Korea Advanced Institute of Science and Technology (KAIST), Korea (South)); Jaehyoung Park (Samsung Electronics, Korea (South)); Seonghun Lee and Kyunghwan Kim (LG Electronics, Korea (South)); Seongho Woo, Changmin Lee, Jaewon Rhee, Seokhyeon Son and Seungyoung Ahn (Korea Advanced Institute of Science and Technology, Korea (South))

TS1-2	A Low-Cost, Open-Sourced Platform for High-Fidelity Characterization of Large WPT Coils.....5
WPTC	Gregory E Moore, Usman Khan, Timmy Yang and Kedi Yan (University of Washington, USA); Tri Nguyen (San Diego State University, USA); Shi Ming Kuang, Chase Whyte, Vaishnavi Ranganathan and Joshua R. Smith (University of Washington, USA)
TS1-3	Multi-Band Parity-Time-Symmetric Wireless Power Transfer Systems.....9
WPTC	Zhilu Ye, Minye Yang and Pai-Yen Chen (University of Illinois at Chicago, USA)
TS1-4	Optimized Rectangular Planar Coil Design for Wireless Power Transfer With Free-Positioning.....13
WPTC	Guilherme Germano Buchmeier (LAAS-CNRS, Université de Toulouse UPS & Continental Automotive France SAS, France); Alexandru Takacs and Daniela Dragomirescu (LAAS-CNRS, France); Juvenal Alarcon Ramos and Amaia Fortes Montilla (Continental Automotive, France)
TS1-5	An Adjustable Coupling Method for Planar Wireless Power Transfer System.....17
WPTC	Jun Zhu, Zhimeng Xu, Yisheng Zhao and Zhizhang Chen (Fuzhou University, China)
TS1-6	Embroidered Textile Coils for Wireless Charging of Smart Garments.....21
WPTC	Chin-Wei Chang (University of Florida & Analog Devices, USA); Patrick Riehl (Analog Devices, USA); Jenshan Lin (University of Florida, USA)
TS1-7	Miniature Coil Design for Through Metal Wireless Power Transfer.....25
WPTC	Juan Romero-Arguello (University of California Davis, USA); Anh-Vu Pham (University of California at Davis, USA); Christopher Gardner and Brad Funsten (Lawrence Livermore National Laboratory, USA)
TS1-8	Contactless Energy Transfer - Analytical Calculation of the Coil Systems' Efficiencies for Different Topologies.....N/A
WoW	David Maier, Weizhou Ye and Nejila Parspour (University of Stuttgart,

Germany)

- TS1-9 Difference in Geometrically Optimized Wireless Power Transmission Systems With SS and SP Compensations.....N/A
- WoW Rafael Aubakirov and Arseny A. Danilov (National Research University of Electronic Technology (MIET), Russia)

Keynote 2, Chairs: Alessandra Costanzo, Simon Hemour

**To Get A Grip on The Earth and Shake It: Nikola Tesla's Scheme for Wireless Power Transmission**

W. Bernard Carlson, Vaughan Professor of Humanities, University of Virginia

Along with developing a practical AC motor, Nikola Tesla [1856-1943] contributed to electrical engineering by working for fifteen years on a scheme to transmit power wirelessly around the world. Inspired by the experiments of Heinrich Hertz and spurred on by a rivalry with Guglielmo Marconi, Tesla built two broadcasting stations, first in Colorado Springs [1899-1900] and then at Wardencllyffe on Long Island [1901-1905]. At these locations, Tesla pumped energy into the earth's crust in order to set up a stationary electromagnetic wave at the earth's resonant frequency. Tesla believed that people would tap into this wave for power and messages by simply grounding a receiver that "would be no bigger than a pocket watch." In this talk, I will outline the evolution of Tesla's thinking about wireless power in the 1890s and 1900s as well as his unsuccessful efforts to launch a business around this technology with funding from J.P. Morgan and others. Overall, I will suggest that Tesla was motivated to provide messages and power to millions of people and hence was among the first to recognize that the Information Revolution of the twentieth century would be about empowering individual users.

## Technical Session TS2: Rectifiers and Rectennas

Chairs: Simon Hemour, Alessandra Costanzo

- TS2-1 Joint Impact of Input Power, PAPR, and Load Resistance on the Receiver Efficiency of Multisine Waveforms in RF Energy Harvesting.....29  
WPTC Nachiket Ayir and Taneli Riihonen (Tampere University, Finland)
- TS2-2 On the Analytical Optimal Load Resistance of RF Energy Rectifier.....33  
WPTC Lichen Yao (Eindhoven University of Technology & Holst Centre / IMEC-NL, The Netherlands); Guido Dolmans (Holst Centre / IMEC-NL, The Netherlands); Jac Romme (IMEC / Holst Centre, The Netherlands)
- TS2-3 Dispenser Printed Flexible Rectenna for Dual-ISM Band High-Efficiency Supercapacitor Charging.....37  
WPTC Mahmoud Wagih, Alex S Weddell and Stephen Beeby (University of Southampton, United Kingdom (Great Britain))
- TS2-4 The 2.4 GHz Band SOI-CMOS High Power Bridge Rectifier IC With the Cross Coupled CMOS Pair.....41  
WPTC Atsuya Hirono, Yuki Muramoto, Shunya Tsuchimoto, Naoki Sakai and Kenji Itoh (Kanazawa Institute of Technology, Japan)
- TS2-5 A 2.45 GHz Shielded, Miniature Power and Data Receiver.....45  
WPTC Hubregt J. Visser (imec The Netherlands, The Netherlands); Khodr Hammoud (Eindhoven University of Technology, The Netherlands)
- TS2-6 Analysis of mmWave Rectifiers With an Accurate Rectification Model.....49  
WPTC Si-Ping Gao (National University of Singapore, Singapore); Hao Zhang (Northwestern Polytechnical University, China); Yong-Xin Guo (National University of Singapore, Singapore)
- TS2-7 Development of Class-R Rectifier for Microwave Wireless Power Transmission to EV Trucks.....53

- WPTC Koki Miwatashi and Naoki Shinohara (Kyoto University, Japan)
- TS2-8 A Nano-Power Self-Clocked D-LDO for RF Energy Harvesting.....57
- WPTC Christos Konstantopoulos (University Of Innsbruck, Austria); Thomas Ussmueller (Universität Innsbruck, Austria)
- TS2-9 Transparent and Flexible Self-Dual Antennas for Hybrid Inductive/Capacitive and Radiative Power Transfer.....61
- WPTC Liang Zhu, Xuecong Nie and Pai-Yen Chen (University of Illinois at Chicago, USA); L. Jay Guo (University of Michigan, USA)

Keynote 3, Chairs: Khurram Afridi, Zhichao Luo

### **Wireless Charging for Electrified Roadways**

Burak Ozpineci, Distinguished R&D Staff Head | Vehicle and Mobility Systems Research Section, Oakridge National Laboratory (ORNL), USA

With the demonstrations of high power static wireless charging systems, high power dynamic wireless charging is a possibility for future electrified roadways. Dynamic wireless charging feasibility has been studied at Oak Ridge National Laboratory (ORNL) where it was shown that with higher than 200kW wireless power transfer, less than 10% of each mile could be electrified for charge sustaining operation. The idea is not necessarily charging the electric vehicle batteries to full state of charge but to provide enough energy to the vehicles so that the charge they use during a mile of roadway can be recovered. This potentially opens up opportunities for unlimited range for electric vehicles. A recent update on ORNL's work in this area will be covered in this presentation as well as challenges observed. Possible comparisons to extreme fast charging systems will also be discussed.

### **Technical Session TS3: Stationary and Dynamic EV Charging**

Chairs: Zhichao Luo, Seungyoung Ahn

- TS3-1 Study on Soft Start-Up and Shut-Down Methods for Wireless Power Transfer Systems for the Charging of Electric Vehicles.....N/A
- WoW Calvin Riekerk and Francesca Grazian (Delft University of Technology, The Netherlands); Thiago Batista Soeiro (Delft University of Technology & TU delft, The Netherlands); Jianning Dong (Delft University of Technology, The Netherlands); Pavol Bauer (TU Delft, USA)
- TS3-2 A 110 W E-Scooter Wireless Charger Operating at 6.78 MHz With Ferrite Shielding.....N/A
- WoW Christopher H Kwan (Imperial College London & Bumblebee Power Ltd., United Kingdom (Great Britain)); Juan Arteaga (Imperial College London, United Kingdom (Great Britain)); Nunzio Pucci (Imperial College, United Kingdom (Great Britain)); David Christopher Yates and Paul Mitcheson (Imperial College London, United Kingdom (Great Britain))
- TS3-3 A Z-Class LCC-P Compensated IPT System With a Reverse Coupled Compensation Inductor.....N/A
- WoW Amr Mostafa, Yao Wang, Hua Zhang and Fei Lu (Drexel University, USA)
- TS3-4 Output Power Control of an S-S IPT System Based on Voltage and Frequency Tuning for EV Charging.....N/A
- WoW Amr Mostafa, Yao Wang, Hua Zhang and Fei Lu (Drexel University, USA)
- TS3-5 A Highly Efficient and High Degree of Freedom of Position kW-Class Wireless Power Transfer System in Seawater for Small AUVs.....65
- WPTC Ryosuke Hasaba (Panasonic Corporation, Japan); Tatsuo Yagi (Panasonic, Japan); Katsuya Okamoto, Souichi Kawata, Shuichiro Yamaguchi, Satoru Kotani and Kazuhiro Eguchi (Panasonic Corporation, Japan); Yoshio Koyanagi (Panasonic, Japan)
- TS3-6 400-W UAV/Drone Inductive Charging System Prototyped for Overhead Power Transmission Line Patrol.....69
- WPTC Shuichi Obayashi, Yasuhiro Kanekiyo, Hiroshi Uno and Tetsu Shijo (Toshiba



Corporation, Japan); Kiyokazu Sugaki (Prodrone, Japan); Hiroaki Kusada, Hajime Nakakoji, Yasuhiko Hanamaki and Kiichirou Yokotsu (Tokyo Electric Power Company Holdings, Japan)

TS3-7 Analysis of a Three-Phase IPT Secondary Side in Interoperable Single-Phase Operation.....N/A

WoW Thorsten Kurpat and Lutz Eckstein (RWTH Aachen University, Germany)  
[Paper has been withdrawn]

TS3-8 Comparison of Lumped Primary Coil Systems With SAE J2954 Secondary Coils for Dynamic Wireless Charging.....N/A

WoW Anna Lusiewicz, Nejila Parspour and Minyao Chen (University of Stuttgart, Germany)

TS3-9 Power Electronics Packaging for In-Road Wireless Charging Installations.....N/A

WoW Alex N Ridge, Silvia Konaklieva, Stuart Bradley and Richard McMahon (University of Warwick, United Kingdom (Great Britain)); Krishna Kumar (University of Texas in Austin, USA)

TS3-10 Basic Evaluation of Electrical Characteristics of Ferrite-less and Capacitor-less Coils by Road Embedment Experiment for Dynamic Wireless Power Transfer.....N/A

WoW Koki Hanawa and Takehiro Imura (Tokyo University of Science, Japan); Nagato Abe (Toa Road Corporation, Japan)

TS3-11 Influence of Contamination Between Receiver Coil and Embedded Transmitter Coil for Dynamic Wireless Power Transfer System.....N/A

WoW Zhe Feng, Osamu Shimizu, Sakahisa Nagai and Hiroshi Fujimoto (The University of Tokyo, Japan); Hayato Sumiya (DENSO Corp., Japan); Masanori Sato (Obayashi Corporation, Japan)

TS3-12 Semi-Dynamic Wireless Power Charging System for Autonomous Electric Vehicle.....72

WPTC GuHo Jung (KAIST, Korea (South))

Keynote 4, Chairs: Don Tan, Al-Thaddeus Avestruz

**Wireless Charging For Electric Vehicles: Moving To Mainstream**

Morris Kesler, Chief Technical Officer, WiTricity

The desire for wireless charging of electric vehicles has been around for at least a decade and is now poised to move onto mainstream electric vehicles (EVs). Interest in EVs and in electric mobility, in general, has never been greater, and automakers and other E-mobility companies are investing heavily in new platform development. Wireless charging technology is ready to make charging these platforms a simple, hassle-free experience and even enable new opportunities for mobility and autonomy. The first standard development activity for EV wireless charging recently (October 2020) culminated with the publication of the SAE J2954 standard for wireless charging of light-duty vehicles. This opens the door for broad deployment, providing a means for creating systems that are interoperable across different manufacturers and vehicle types and makes public wireless charging infrastructure possible. However, a wireless power product involves much more than just power transfer. In this presentation, we will review requirements for a practical EV wireless charging system, explore key system considerations and solutions, and look at where the technology is headed as we move into the age of E-mobility.

**Technical Session TS4: IoT, Industrial, Safety, and Sensors**

Chairs: Al-Thaddeus Avestruz, Don Tan

- TS4-1 Sensorless Metal Object Detection Using Transmission-Side Voltage Pulses in Standby Phase for Dynamic Wireless Power Transfer.....N/A
- WoW Yuya Deguchi, Sakahisa Nagai, Toshiyuki Fujita and Hiroshi Fujimoto (The University of Tokyo, Japan); Yoichi Hori (Tokyo University, Japan)
- TS4-2 Study of the Induced Electric Field Effect on Inductive Power Transfer System.....N/A

- WoW Zeeshan Shafiq (Kunming University of Science and Technology, China); Jinglin Xia (Jilin University, China); Qingyun Min, Siqi Li and Sizhao Lu (Kunming University of Science and Technology, China)
- TS4-3 Wireless Series-Parallel Capacitor Charger for DC Circuit Breaker Applications.....N/A  
 WoW Reza Kheirollahi, Shuyan Zhao and Hua Zhang (Drexel University, USA); Jun Wang (University of Nebraska-Lincoln, USA); Fei Lu (Drexel University, USA)
- TS4-4 Foreign Object Detection of Wireless Power Transfer System Using Sensor Coil.....76  
 WPTC Seokhyeon Son (Korea Advanced Institute of Science and Technology, Korea (South)); Seonghi Lee (KAIST, Korea (South)); Jaewon Rhee, Yujun Shin and Seongho Woo (Korea Advanced Institute of Science and Technology, Korea (South)); Sungryul Huh (Korea Advanced Institute of Science and Technology (KAIST), Korea (South)); Changmin Lee and Seungyoung Ahn (Korea Advanced Institute of Science and Technology, Korea (South))
- TS4-5 EMI Reduction Method in Wireless Power Transfer System With Increasing Efficiency Using Frequency Split Phenomena.....80  
 WPTC Changmin Lee, Seongho Woo, Yujun Shin and Jaewon Rhee (Korea Advanced Institute of Science and Technology, Korea (South)); Sungryul Huh (Korea Advanced Institute of Science and Technology(KAIST), Korea (South)); Seokhyeon Son (Korea Advanced Institute of Science and Technology, Korea (South)); Jung Ick Moon (Electronics and Telecommunications Research Institute, Korea (South)); Seungyoung Ahn (Korea Advanced Institute of Science and Technology, Korea (South))
- TS4-6 EMI Reduction Method for Over-Coupled WPT System Using Series-None Topology.....84  
 WPTC Seongho Woo, Yujun Shin and Changmin Lee (Korea Advanced Institute of Science and Technology, Korea (South)); Sungryul Huh (Korea Advanced Institute of Science and Technology(KAIST), Korea (South)); Jaewon Rhee (Korea Advanced Institute of Science and Technology, Korea (South)); Bumjin Park (Korea Advanced Institute of Science and Technology (KAIST),

Korea (South)); Seokhyeon Son and Seungyoung Ahn (Korea Advanced Institute of Science and Technology, Korea (South))

- TS4-7 Wireless Power Transfer System of On-Line Monitoring Equipment for High Voltage Transmission Line Based on Double-Sided LCC Resonant Network.....N/A
- WoW Xinyu Hou, Yugang Su, Zhe Liu, Zhipeng Deng and Renwei Deng (Chongqing University, China)
- TS4-8 Wireless Sensor Node Powered by Unipolar Resonant Capacitive Power Transfer.....N/A
- WoW Jonathan M Dean (Tennessee Technological University, USA); Michael R Coultis (Tennessee Technological University & Center for Energy Systems Research, USA); Charles W Van Neste (Tennessee Technological University, USA)
- TS4-9 Modular Wireless Power Transfer System for the Supply of Mobile Industrial Production Equipment.....N/A
- WoW Javier Stillig (University of Stuttgart & Bosch Rexroth AG, Germany); Alexander Enssle and Nejila Parspour (University of Stuttgart, Germany)
- TS4-10 2-MHz Compact Wireless Power Transfer System With Voltage Conversion From 400 V to 48 V.....88
- WPTC Tim Krigar and Martin Pfof (TU Dortmund, Germany)

Keynote 5, Chairs: Grant Covic, Rod Kim

### **Wireless Power 2.0: What Will It Take to Get There and When Will It Happen?**

Alex Lidow, CEO and Co-Founder, Efficient Power Conversion

There are hundreds of millions of people who have experienced the first generation of wireless power transfer technology based on inductive coupling and the Qi format. The promise of convenience has only partially

been realized as the limitations of precise positioning and slow charging speeds have become more acute as fast charging of cell phones has become more important to the consumer. Magnetic resonance has long promised to overcome the limitations of Qi with its ability to (a) safely transfer much higher power, (b) enable spatial freedom stemming from large surfaces that can produce uniform magnetic fields, and (c) the ability to have one transmitter couple to a multitude of receivers. In this talk we will discuss the technological, financial, and emotional barriers that need to be broached before widespread consumer adoption of this next generation wireless power technology will gain traction.

### Technical Session TS5: Inductive WPT Circuits and Systems

Chairs: Rod Kim, Grant Covic

- |       |   |
|-------|---|
| TS5-1 | Analysis and Design of a T-Compensation Network With Switch-Controlled Capacitor for Wireless Power Transfer System.....N/A             |
| WoW   | Siyuan Lu and Timo Lämmle (MAHLE International GmbH, Germany);<br>Nejila Parspour (Universität Stuttgart, Germany)                      |
| TS5-2 | Novel Synchronous Rectification Method for WPT Only by DC Current Sensor.....N/A  |
| WoW   | Daisuke Shirasaki (University of Tokyo, Japan); Hiroshi Fujimoto (The University of Tokyo, Japan)                                       |
| TS5-3 | Wide-Range Stability of Concurrent Load Regulation and Frequency Synchronization for a 7-Level Switched Capacitor WPT Rectifier.....N/A |
| WoW   | Spencer P Cochran (University of Tennessee, USA); Daniel Costinett (University of Tennessee Knoxville, USA)                             |
| TS5-4 | Stable and Efficient Class E 2 Wireless Power Transfer System Based on Parity-Time Symmetry.....N/A                                     |
| WoW   | Xiayi Huang and LiangZong He (Xiamen University, China)   |
| TS5-5 | 1.7 kW 6.78 MHz Wireless Power Transfer With Air-Core Coils at 95.7% DC-DC Efficiency.....92  |

- WPTC Lei Gu and Juan Rivas-Davila (Stanford University, USA)
- TS5-6 A Research on Characteristics of Wireless Power Transfer System Based on LCC/N Magnetic Integration Compensation Circuit.....N/A
- WoW Zhimeng Liu (University of Chinese Academy of Sciences, China); Chengxuan Tao (Institute of Electrical Engineering, Chinese Academy of Sciences, China); Lifang Wang (IEE of CAS, China); Yuwang Zhang (University of Chinese Academy of Sciences, China); Fang Li (Institute of Electrical Engineering, Chinese Academy of Sciences, China)
- TS5-7 Time Domain Modelling of a Wireless Power Transfer System Using a Buck-Boost Converter for Voltage Regulation.....96
- WPTC Arpan Laha and Praveen Jain (Queen's University, Canada)
- TS5-8 Relation Between Operation Frequency Range and Coupling Coefficient Variations in WPT Under Subresonant Frequency Control.....N/A
- WoW Andrey Vulfovich (Ben Gurion University, Israel); Alon Kuperman (Ben-Gurion University of the Negev, Israel)
- TS5-9 Efficiency Evaluation of Receiving Current Control Using Pulse Density Modulation for Dynamic Wireless Power Transfer.....N/A
- WoW Sakahisa Nagai, Toshiyuki Fujita and Hiroshi Fujimoto (The University of Tokyo, Japan); Shogo Tsuge and Toshiya Hashimoto (TOYOTA MOTOR Corporation, Japan)

Keynote 6, Chairs: Christopher Rodenbeck, Mohamed Abouzied

### **Wireless Power and Power Beaming**

Paul Jaffe, U.S. Naval Research Laboratory (NRL)

Language and nomenclature affect the way we think. In recent years, the taxonomy of wireless power has grown to include technologies and modalities across a wide range. Whether it refers to short- range energy

transmission between systems without connectors or long-range delivery of energy over distances far exceeding a meter, there is value in defining the different classifications of wireless power transmission. In this keynote, Dr. Jaffe will give a summary overview of different approaches to one such classification scheme, in which power beaming will be distinguished as a clear subset of wireless power transmission. He will review recent progress for microwave, millimeter-wave, and optical power beaming, and discuss near-term plans and next steps. The discussion will be framed by the contexts of emerging applications and of longer-term visions of future possibilities.

### Technical Session TS6: Far Field WPT

Chairs: Mohamed Abouzieed, Christopher Rodenbeck

- TS6-1 Range Selective Power Focusing With Time-Controlled Bi-Dimensional Frequency Diverse Arrays.....100  
WPTC Enrico Fazzini (Università di Bologna, Italy); Alessandra Costanzo (DEI, University of Bologna, Italy); Diego Masotti (University of Bologna, Italy)
- TS6-2 28 GHz Microwave Power Beaming to a Free-Flight Drone.....104  
WPTC Ryoma Moro, Naoki Keicho, Kota Motozuka, Maho Matsukura and Kohei Shimamura (University of Tsukuba, Japan); Masafumi Fukunari (University of Fukui, Japan); Koichi Mori (Nagoya University, Japan)
- TS6-3 Electric Field Resonant Antenna for Wireless Power Transfer Based on Infinitesimal Dipole.....108  
WPTC Takanori Washiro (Nippon Telegraph and Telephone Corporation, Japan)
- TS6-4 Theoretical Analysis of Retro-Reflective Beamforming Schemes for Wireless Power Transmission to Multiple Mobile Targets.....112  
WPTC Min Liu, Xin Wang and Songpeng Zhang (Nanjing University of Aeronautics and Astronautics, China); Mingyu Lu (West Virginia University Institute of Technology, USA)

TS6-5	Distributed Microwave Wireless Power Transfer With Backscatter Feedback.....116
WPTC	Yuki Tanaka (Panasonic Corporation & Connected Solutions Company, Japan); Kazuki Kanai, Ryosuke Hasaba and Hiroshi Sato (Panasonic Corporation, Japan); Yoshio Koyanagi (Panasonic, Japan); Takuma Ikeda, Hiroyuki Tani, Manabu Gokan and Shoichi Kajiwara (Panasonic Corporation, Japan); Naoki Shinohara (Kyoto University, Japan)
TS6-6	Ultra Wideband 4-PAM Backscatter Modulator Based on BiCMOS Technology for IoT/WPT Applications.....120
WPTC	Diogo Matos (Instituto de Telecomunicações & University of Aveiro, Portugal); Ricardo Torres (Instituto de Telecomunicações & DETI, Universidade de Aveiro, Portugal); Ricardo Correia (Instituto de Telecomunicações & University of Aveiro, Portugal); Nuno Borges Carvalho (University of Aveiro/IT Aveiro, Portugal)
TS6-7	Focus Location Measurement of a Quasioptical Double Reflector System.....124
WPTC	Ricardo A. M. Pereira (University of Aveiro, Institute of Telecommunications, Portugal); Nuno Borges Carvalho (University of Aveiro/IT Aveiro, Portugal); Apostolos Georgiadis (Heriot-Watt University, United Kingdom (Great Britain))
TS6-8	Efficiency Enhancement in Mid-Range RWPT Systems by GRIN Metasurface Lenses.....128
WPTC	Icaro V Soares (Institut d'Électronique et des Technologies du Numérique & Université de Rennes 1, France); Felipe Freitas and Ursula Resende (Federal Center for Technological Education of Minas Gerais, Brazil)
TS6-9	Wireless Power Transfer in the Radiative Near-Field Through Resonant Bessel-Beam Launchers at Millimeter Waves.....132
WPTC	Francesca Benassi (University of Bologna, Italy); Walter Fuscaldo (Consiglio Nazionale delle Ricerche, Italy); Diego Masotti (University of Bologna, Italy); Alessandro Galli (Sapienza University of Rome, Italy); Alessandra Costanzo (DEI, University of Bologna, Italy)



- TS6-10 Design of Three Layers-Stacked Metasurface and Its Application to Compact Dual-Band WPT System.....136
- WPTC Xin Jiang, Fairus Tahar, Takashi Miyamoto, Adel Barakat, Kuniaki Yoshitomi and Ramesh K. Pokharel (Kyushu University, Japan)
- TS6-11 Evaluation of Efficiency and Isolation in Wireless Power Transmission Using Orbital Angular Momentum Modes.....140
- WPTC Mizuki Mase (Kyoto University & Research Institute for Sustainable Humanosphere, Japan); Naoki Shinohara (Kyoto University, Japan); Tomohiko Mitani (Kyoto University, Japan); Shotaro Ishino (Furuno Electric, Japan)

Keynote 7, Chairs: Chris Mi, Amir Mortazawi

### **Addressing the Charging Problem for Every Vehicle Type: Universal Wireless Power**

Andrew Daga, CEO and Co-founder, Momentum Dynamics

As the world moves forward toward electrified transportation and logistics, it has become increasingly clear that charging infrastructure is critical to the rate of adoption, and even the rate of production of electric vehicles. We recognize that not all-electric vehicles are passenger cars – in fact, they necessarily include every type of vehicle – including all classes of trucks, buses, industrial equipment, logistics handling, and even rail and marine vehicles. Each of these use cases has a set of technical, operational, and economic requirements. The common challenges in the deployment and operation of EV charging infrastructure that can meet the needs of all of these types of vehicles are: maximizing utilization of the vehicles and charging equipment; minimizing the capital expense of the infrastructure and determining who will bear it; minimizing overall operating expense (including charging costs) and simplifying operations; operating within spatially constrained areas; minimizing changes to efficient operations; and determining how operators of charging equipment can build sustainable, profitable economic models. To date, these challenges have not been adequately addressed by manually operated conductive (or plug-in) charging. The presentation will provide a status update on the commercialization of automatically operated inductive charging, and how inductive charging has proven its capacity to solve each of these problems. The case for a common automatic charging system composed of inductive charging modules that can be scaled to any type of vehicle and any power level will be made.

### **Technical Session TS7: Capacitive Power Transfer**

Chairs: Amir Mortazawi, Aiguo Patrick Hu

- TS7-1 Design of Efficient Double-Sided LC Matching Networks for Capacitive Wireless Power Transfer System.....N/A
- WoW Lifang Yi and Jinyeong Moon (Florida State University, USA)
- TS7-2 Preliminary Design by Modeling S-CPT System With Inductance Consideration.....N/A
- WoW Suziana Ahmad (Kyushu University & Universiti Teknikal Malaysia Melaka, Japan); Reiji Hattori (Kyushu University, Japan); Aam Muharam (Indonesian Institute of Sciences, Indonesia); An-yu Uezu (Kyushu University, Japan)
- TS7-3 Modular-Based PV System With Contactless Capacitive Power Transfer Interface.....N/A
- WoW Shaoge Zang, Kexin Yuan and Connor James (the University of Auckland, New Zealand); Aiguo Patrick Hu (The University of Auckland, New Zealand)
- TS7-4 Optimized Design of High-Efficiency Immittance Matching Networks for Capacitive Wireless Power Transfer Systems.....N/A
- WoW Sreyam Sinha (Cornell University, USA); Ashish Kumar (Texas Instruments, USA); Khurram K Afridi (Cornell University, USA)
- TS7-5 Theoretical Limits and Optimal Operating Frequencies of Capacitive Wireless Charging Systems.....N/A
- WoW Sounak Maji, Sreyam Sinha, Mausamjeet Khatua and Khurram K Afridi (Cornell University, USA)
- TS7-6 Tunable Multistage Matching Networks for Capacitive Wireless Power Transfer Systems.....144
- WPTC Yuetao Hou, Sreyam Sinha and Khurram K Afridi (Cornell University, USA)
- TS7-7 A New Coupling Insensitive Nonlinear Capacitive Resonant Wireless Power Transfer Circuit.....148
- WPTC Ruiying Chai and Amir Mortazawi (University of Michigan, Ann Arbor,

USA)

- TS7-8 Maximum Available Power of Undersea Capacitive Coupling in a Wireless Power Transfer System.....152
- WPTC Hussein Mahdi Yaseen Al-Sallami (UiT-The Arctic University of Norway, Norway); Bjarte Hoff and Trond Østrem (UiT - The Arctic University of Norway, Norway)
- TS7-9 A Multi-Receiver MHz WPT System With Hybrid Coupler.....N/A
- WoW Yaoxia Shao, Ming Liu and Chengbin Ma (Shanghai Jiao Tong University, China)

Keynote 8, Chairs: J.-C. Chiao, Souvik Dubey

### **Safety of RF Wireless Power Transfer Technology**

James Lin, Professor Emeritus, University of Illinois at Chicago

Wireless power transfer (WPT) systems are being deployed to provide needed electric power either directly or via battery-charging services using a very wide spectrum. The optimism on WPT technology is clearly driven by the ubiquity of cell phones, laptops, and other mobile communication devices. Aside from not having to plug in the mobile phone or laptop, an fascinating cause for the interest in battery charging through WPT comes from the potential for mobile communication devices to get their electrical power the same way they get their data through harvesting ambient electromagnetic radiation. The dream is a truly wireless mobility scenario with completely tether-free electric power supply for mobile phones, laptops, electric appliances, and various transportation systems. Beyond wireless communication uses, the level of transmitted electromagnetic power required for large-scale or commercial implementation of WPT would be substantial. A key facet of the system design and research effort should include consideration of biological effects and human safety, especially in the RF region of the electromagnetic spectrum. This talk will feature my perspectives

on RF safety of WPT technologies.

## Technical Session TS8: Biomedical Applications

Chairs: Souvik Dubey, Aasrith Ganti

- TS8-1 A Smart Health Tracking Ring Powered by Wireless Power Transfer.....156  
WPTC Son Nguyen (University of California Davis, USA); Connie Duong (University of California, Davis, USA); Rajeevan Amirtharajah (University of California Davis, USA)
- TS8-2 Wireless Power Supply System for Left Ventricular Assist Device and Implanted Cardiac Defibrillator.....160  
WPTC Tommaso Campi and Silvano Cruciani (University of L'Aquila, Italy); Francescaromana Maradei (University of Rome La Sapienza, Italy); Mauro Feliziani (University of L'Aquila, Italy)
- TS8-3 Wireless Torque Transfer Using Multiple Coils With Different Phases.....164  
WPTC Jaewon Rhee, Yujun Shin and Haerim Kim (Korea Advanced Institute of Science and Technology, Korea (South)); Jongwook Kim (KAIST(Korea Advanced Institute of Science and Technology), Korea (South)); Changmin Lee (Korea Advanced Institute of Science and Technology, Korea (South)); Sungryul Huh (Korea Advanced Institute of Science and Technology(KAIST), Korea (South)); Seongho Woo, Seokhyeon Son and Seungyoung Ahn (Korea Advanced Institute of Science and Technology, Korea (South))
- TS8-4 Physical Bounds on Implant Powering Efficiency Using Body-Conformal WPT Systems.....167  
WPTC Icaro V Soares (Institut do Électronique et des Technologies du Numérique & Université de Rennes 1, France); Mingxiang Gao (Swiss Federal Institute of Technology in Lausanne, Switzerland); Anja K. Skrivervik (EPFL, Switzerland); Zvonimir Sipus (University of Zagreb, Croatia); Maxim Zhadobov (University of RENNES 1, France); Ronan Sauleau (University of Rennes 1, France); Denys Nikolayev (Institut d'Électronique et des Technologies du Numérique (IETR) - UMR CNRS 6164, France)

- TS8-5 Resonant Coupler Designs for Subcutaneous Implants.....171  
WPTC Sen Bing, Khengdauliu Chawang and Jung-chih Chiao (Southern Methodist University, USA)
- TS8-6 An Implantable Wireless Charger System With  $\times 8.91$  Increased Charging Power Using Smartphone and Relay Coil.....175  
WPTC Hankyu Lee, Seungchul Jung, Yeunhee Huh and Jaechun Lee (Samsung Advanced Institute of Technology, Korea (South)); ChiSung Bae (Samsung Electronics, Korea (South)); Sang Joon Kim (Samsung Advanced Institute of Technology, Korea (South))
- TS8-7 Design of a Wireless Power and Data Transfer System for pH Sensing Inside a Small Tube.....179  
WPTC Fatemeh Mohseni, Paul Marsh and Filippo Capolino (University of California, Irvine, USA); Jung-chih Chiao (Southern Methodist University, USA); Hung Cao (University of California, Irvine, USA)
- TS8-8 Magnetolectric Versus Inductive Power Delivery for Sub-mm Receivers.....183  
WPTC Adam Khalifa (Massachusetts General Hospital & Harvard Medical School, USA); Mehdi Nasrollahpour, Neville Sun, Mohsen Zaeimbashi, Huaihao Chen and Xianfeng Liang (Northeastern University, USA); Milad Alemohammad Alemohammad (Johns Hopkins University, USA); Ralph Etienne-Cummings (Johns Hopkins University, USA); Nian Sun (Northeastern University, USA); Sydney Cash (Massachusetts General Hospital, USA)
- TS8-9 Demonstration of Healthcare-Specific Li-Ion Battery Charging Using Ultrasound Power Delivery.....187  
WPTC Inder Raj S Makin (A. T. Still University, USA); Harry Jabs (Piezo Energy Technologies, USA); T. Douglas Mast (University of Cincinnati, USA); Leon Radziemski (Piezo Energy Technologies, USA)

Keynote 9, Chairs: Chris Mi, Naoki Shinohara

## **Worldwide Standardization of Wireless Power Transfer for EVs, SAE J2954**

Jesse Schneider, Chair; CEO/ CTO, SAE Wireless Power Transfer Taskforce, J2954; ZEV Station

Electric and Plug-in Electric vehicles are just beginning to be commercialized in large scale production which are charged through conductive charging with multiple plug types. There are numerous advantages which wireless power transfer (WPT) offers, effectively charging without cables, related to improved customer acceptance of the charging and automatic charging of autonomous electric vehicles. In order to establish a worldwide standard, to ensure a smooth implementation of the WPT to 11kW related to safety, performance, interoperability vehicle alignment SAE published the J2954 standard. The standard establishes a specification for the vehicle & infrastructure EVSE coils, EMC/EMF limits and a common methodology for validation and testing WPT. An overview of the newly published Standard, SAE J2954 will be given including some background for the testing with automaker and supplier systems to validate. In addition, plans for the next phase of standardization for both light and heavy-duty electric vehicles will be given.

### **Technical Session TS9: Low Power Inductive and Ultrasound Methods**

Chairs: Naoki Shinohara, Jenshan Lin

- TS9-1 Pre-Charged Collapse-Mode Capacitive Micromachined Ultrasonic Transducer (CMUT) for Broadband Ultrasound Power Transfer.....191
- WPTC Shinnosuke Kawasaki, Youri Westhoek, Indulakshmi Subramaniam and Marta Saccher (Delft University of Technology, The Netherlands); Ronald Dekker (Philips Research, The Netherlands)
- TS9-2 A Novel Magnetically Coupled Resonant Wireless Power Transfer Technique Used in Rotary Ultrasonic Machining Process.....195
- WPTC Xianpeng Qiao and Wu Yongbo (Southern University of Science and

Technology, China)

- TS9-3 Selective Receiver Charging Using Acoustic Vibration Modes.....199  
WPTC Victor F.f G. Tseng (US Army Research Laboratory, USA)
- TS9-4 Design of Ultrasonic Transducer Structure for Underwater Wireless Power Transfer System.....203  
WPTC Yufei Zhao, Yuwei Du and Zhenxing Wang (Xi'an Jiaotong University, China); Jianhua Wang (Xi'an Jiaotong University, China); Geng Yingsan (Xi'an Jiaotong University, China)
- TS9-5 A Novel Hybrid Class E Topology With Load-Independent Output for WPT.....N/A  
WoW Houji Li, Ming Liu and Wang Yong (Shanghai Jiao Tong University, China)
- TS9-6 Design and Development of a Test Rig for 13.56 MHz IPT Systems With Synchronous Rectification and Bidirectional Capability.....N/A  
WoW Nunzio Pucci (Imperial College, United Kingdom (Great Britain)); Juan Arteaga and Paul Mitcheson (Imperial College London, United Kingdom (Great Britain))
- TS9-7 Modularized and Reconfigurable Wireless Power Transfer Architecture, Modeling and Analysis.....N/A  
WoW Huan Zhang, Chengbin Ma and Ming Liu (Shanghai Jiao Tong University, China)