Tommaso Campi
CV ai fini della pubblicazione

I – General Information

II – Education

2017	PhD, Industrial and Information Engineering and Economics (Dottorato di Ricerca in Ingegneria Industriale e dell'Informazione ed Economia), University of L'Aquila, Italy (2017), Thesis Title "Wireless Power Transfer System for Advanced Applications";
2013	M.Sc., Telecommunication Engineering (Laurea Magistrale in Ingegneria delle Telecomunicazioni), University of L'Aquila, Italy (2013) Thesis Title "Sistema di ricarica wireless per le batterie di dispositivi medici impiantabili attivi". Final mark: 110/110 *summa cum laude*;
2010	B.Sc., Engineering in Computer Science (Laurea Triennale in Ingegneria Informatica), Sapienza University of Rome, Italy (2010). Final mark: 110/110 *summa cum laude*.

III – Qualification

From 07/01/2021	RTDA in sector 09/E1 – "Elettrotecnica", disciplinary scientific sector ING-IND/31 - "Elettrotecnica", at the University of L'Aquila;
From 05/2020	Teaching assistant in Electrical Engineering, sector 09/E1;
05/2019	National Scientific Qualification (ASN) as Associate Professor in sector 09/E1, Electrical Science (Elettrotecnica);
04/2019 - 01/2021	Postdoctoral research fellow at the University of L'Aquila, Italy. Research title: "WPT (Wireless Power Transfer) systems for automotive, biomedical and consumer applications";
02/2017 – 01/2019	Postdoctoral research fellow at the University of L'Aquila, Italy. Research title: "Sviluppo di Modelli e Procedure per valutare la Conformità Elettromagnetica (EM) delle nuove Tecnologie Emergenti rispetto ai Limiti di Esposizione Vigenti".

IV – Expertise and Scientific Activity

The expertise and scientific activity of Dr. Tommaso Campi, is testified by more than 70 papers in international peer-reviewed journals and conference papers, and deals with innovative and advanced methodological aspects in the following topics:

- Models for electrical and electronic systems and devices;
- Wireless power transfer;
- Electromagnetic compatibility and Electromagnetic field safety;
- Numerical methods;

- Biomedical applications;
- Biological effects of electromagnetic fields.

V – Awards

Dr. Tommaso Campi received the following awards for his research activity and publications:

- *2020 - Moto Kanda Award for Most Cited IEEE Transactions on Electromagnetic Compatibility Paper in the Last Five Years* for the paper "T. Campi, S. Cruciani, F. Maradei, M. Feliziani, "Near-field reduction in a wireless power transfer system using LCC compensation", IEEE Trans. Electromag. Compat., vol. 59, no. 2, pp. 686-694, 2017". This is one of the most prestigious awards of the IEEE EMC Society for recognizing the outstanding research published on IEEE T-EMC with the most citations in a period;

- *2019 - Best Paper Award at the IEEE WPW 2019*, Wireless Power Week, London, U. K., 2019; organized by MTT and PEL IEEE Societies for the paper "Wireless Charging in Electric Vehicles: EMI/EMC Risk Mitigation in Pacemakers by Active Coils". The paper was the only winner out of more than 300 papers presented at the conference;

- *2018 - Best Poster Presentation Award at the IEEE CEFC 2018*, 18th Biennial IEEE Conference on Electromagnetic Field Computation, Hangzhou, China, for the paper "Comparison of Numerical Techniques for the Evaluation of Human Exposure from Measurement Data";

- *2017 - Best Poster Award at Annual meetings of the Electrical Engineering (ET) Group*, ET 2017, Milan, Italy, for the poster "Wireless Power Transfer System applied to Active Implanted Medical Device";

- *2014 - Best Student Paper Award at the IEEE CEFC 2014*, 16th Biennial IEEE Conference on Electromagnetic Field Computation, Annecy, France, 2014, for the paper "Wireless Power Transfer System in Medical Implants using Planar Spiral Coils". Only 6 papers on more than 400 that were submitted were awarded.

VI - Editorial Activity

Dr. Campi was ***Guest Editor*** of the following Special Issues of Energies (published monthly by MDPI, Impact Factor 3.252, ISSN 1996-1073;):

- "Research on Wireless Power Transfer Technology and Devices",2023;
- "EMC Issues and EMF Exposure in Wireless Power Transfer Systems for E-mobility", 2023;
- "Intelligent Wireless Power Transfer System and Its Application 2020", 2020;
- "Intelligent Wireless Power Transfer System and Its Application" 2018.

Dr. Campi was ***Guest Editor*** of a Special Issue published by Electronics (published monthly by MDPI, Impact Factor 2.690, ISSN 2079-9292) entitled

- "Wireless Power Transfer Systems for Biomedical Devices: Modeling, Simulation, Application", 2023.

Tommaso Campi is co-author of the book "Wireless Power Transfer for E-Mobility". The book will be published by the Elsevier starting from 01/11/2023.

Book website: [Wireless Power Transfer for E-Mobility - 1st Edition (elsevier.com)]

VII - Organization of Technical Sessions in International Conferences

Dr. Campi was the organizer of several workshops at international conferences in the field of wireless power transfer and electromagnetic compatibility:

- Role: ***Workshop Chair and Organizer***
  - Title: Impact of Automotive Wireless Power Transfer systems on EMC and EMF safety;
  - Contents: The workshop was focused on the electromagnetic emission of wireless charging systems for electric vehicles related to electromagnetic field (EMF) safety and electromagnetic compatibility (EMC);
  - Conference: "2021 Joint IEEE International Symposium on Electromagnetic Compatibility, Signal & Power Integrity, and EMC Europe, Virtual Event";
  - Workshop organizers: Tommaso Campi (University of L'Aquila) and Mauro Feliziani (University of L'Aquila).

- Role: ***Workshop Chair and Organizer***
  - Title: Low Frequency EMC in Next Generation Electrical Vehicles;
  - Contents: In this workshop EMC and EMF safety aspects on next generation electric vehicles (EVs) were discussed. The adoption of wireless power transfer (WPT) systems based on inductive coupling were considered. Advanced models for numerical simulations of shielding of composite structures, radiation, and human exposure were presented;
  - Conference: "International symposium and exhibition on electromagnetic compatibility (EMC EUROPE 2018), Amsterdam, NL, August 27-30, 2018".
  - Workshop organizers: Tommaso Campi (University of L'Aquila), Francesca Maradei (Sapienza University of Rome) and Mauro Feliziani (University of L'Aquila).

- Role: ***Workshop Chair and Organizer***
  - Title: EMC & EMF Safety Aspects of Wireless Power Transfer Technologies in Transportation Systems;
  - Contents: The goal of this workshop was to analyze the EMC and EMF safety aspects on electric vehicles (EVs) equipped with wireless power transfer (WPT) systems. Both numerical modeling and experimental validation were presented by the speakers;
  - Conference: "2018 Joint IEEE International Symposium on Electromagnetic Compatibility & Asia-Pacific Symposium on Electromagnetic Compatibility (IEEE EMC & APEMC 2018), Singapore, May 14-17, 2018";
  - Workshop organizers: Tommaso Campi (University of L'Aquila), Francesca Maradei (Sapienza University of Rome) and Mauro Feliziani (University of L'Aquila).

- Role: ***Session Organizer***;
  - Title: Computational Electromagnetics and Optimization;
  - Contents: The special session were focused on the numerical methods for the design and optimization of WPT system. Works related to both consumer and automotive applications were presented by the speakers;
  - Conference: "Computational Electromagnetics and Optimization" - International Annual Conference 2017 (AEIT 2017), Cagliari, Italy, September 20-22, 2017";

- Session organizers: Salvatore Alfonzetti (University of Catania) and Tommaso Campi (University of L'Aquila).

Dr. Tommaso Campi was a ***member of the Local Organizing Committee*** of the "International Symposium on Electromagnetic Compatibility Virtual Conference, September 23-25 (EMC Europe 2020)". This conference is worldwide recognized as a leading event in the field of the EMC.

VIII – International Conferences

Dr. Campi attended the following International Conferences:

- *IEEE Conference on Electromagnetic Field Computation* (CEFC), Annecy, France, May 25-28, 2014;
- *IEEE International Symposium on Electromagnetic Compatibility* (EMC), Tokyo, Japan, May 12-14, 2014;
- *IEEE International Joint EMC/SIPI and EMC Europe Symposium*, Dresden, Germany, Aug. 16-22, 2015;
- *IEEE 15th International Conference on Environment and Electrical Engineering* (EEEIC), Rome, Italy, June 10-13, 2015;
- *Applied Computational Electromagnetics Society* (ACES), Williamsburg, VA, USA, March 22-26, 2015;
- *IEEE Wireless Power Transfer Conference* (WPTC), Boulder, CO, USA, May 13-15, 2015;
- *Asia-Pacific International Symposium on Electromagnetic Compatibility (APEMC)*, Shenzhen, China, May 17-21,2016;
- EMC EUROPE 2016 - *International Symposium on Electromagnetic Compatibility*, Wroclaw, Poland, Sept. 5-9, 2016;
- *International Conference of Electrical and Electronic Technologies for Automotive*, Torino, Italy, June 15-16, 2017;
- *International Applied Computational Electromagnetics Society Symposium* (ACES), Florence, Italy, March 26-30, 2017;
- EMC EUROPE 2017 - *International Symposium on Electromagnetic Compatibility*, Angers, France, pp.1-4, 1-4 Sept, 2017;
- *IEEE International Symposium on Electromagnetic Compatibility & Signal/Power Integrity* (EMC&SIPI), Washington DC, USA, Aug 7-11, 2017;
- *AEIT International Annual Conference* (AEIT), Cagliari, Italy, Sept 20-22, 2017.
- *IEEE Wireless Power Transfer Conference* (WPTC), Montreal, Canada, Jun. 3-7, 2018;
- *International Symposium and exhibition on Electromagnetic Compatibility* (EMC EUROPE 2018), Amsterdam, Netherlands, Aug. 27-30, 2018;
- EMC EUROPE 2019 - *International Symposium and exhibition on Electromagnetic Compatibility,* Barcelona, Spain, Sept. 2 - 6, 2019.
- 22nd *Conference on the Computation of Electromagnetic Fields* (CONPUMAG), Paris, France, July 15 -19, 2019;
- EMC EUROPE 2020 - *International Symposium on Electromagnetic Compatibility*, Rome, Italy, Sept. 23 -25, 2020 (online);
- *IEEE Wireless Power Transfer Conference* (WPTC), Seoul, Korea (South), Nov 15-19, 2020 (online);

- *IEEE Wireless Power Transfer Conference* (WPTC), 2021, San Diego, CA, USA, Jun. 1-4, 2021 (online);
- *IEEE International Joint EMC/SIPI and EMC EUROPE Symposium*, July 27- Aug. 8, 2021 (online);
- *IEEE Wireless Power Week* (WPW), Bordeaux, France, July 5-8, 2022;
- EMC EUROPE 2022 - *International Symposium on Electromagnetic Compatibility*, Gothenburg, Sweden, Sept. 23-25, 2022.

IX - Review Activity

Dr. Campi served as ***reviewer*** for the following international journals:

- IEEE Transactions on Electromagnetic Compatibility;
- IEEE Transactions on Antennas and Propagation;
- IEEE Transactions on Microwave Theory and Techniques;
- IEEE Transactions on Power Electronics;
- IEEE Transactions on Industrial Electronics;
- IEEE Vehicular Technology Magazine;
- IEEE Access;
- International Transactions on Electrical Energy Systems;
- Electronics;
- Energies;
- Sensors.

X - Memberships

- Dr. Campi is a member of the IEEE EMC Society;

- Dr. Campi is a member of the Technical Committee "IEEE Electromagnetic Compatibility Society (EMC-S) Technical Committee 7 (TC-7) "Low Frequency EMC";

- Dr. Campi is a member of the IEEE WPT Initiative.

XI - Patents

Dr. Campi is the ***inventor*** of the patent "Carrello di atterraggio per aeromobili (droni); Campi, T & Feliziani, M". IT patent, priority number 102018000001311, 2018.
The patent describes an advanced drone cart capable of implanting a charging system based on WPT technology. The system allows the autonomous and rapid recharging of the drone without human intervention.

XII - Technological transfer activities

Tommaso Campi is a partner and co-founder of the academic spin-off of the University of L'Aquila "Zerowire", founded in 01/2022. Zerowire s.r.l. is an high tech company deals with the design and construction of low and high power WPT systems. The fields of application are mainly biomedical, robotic and automotive. This emerging technology is rapidly spreading today thanks to the numerous advantages it can provide in multiple fields of application. The novelty of technology means that there are still few companies that provide products and services in this sector. The proposed technology, based on innovative engineering, permits to design and build ad-hoc systems in order to fully satisfy possible customer requests.

XIII - Educational Activity

Academic year 2022/2023	Holder of the 6 CFU course "Principi di Ingegneria Elettrica Biomedicale" for the students of the 3-year Bachelor degree in Industrial Engineering – Biomedical engineering curriculum, University of L'Aquila, L'Aquila, Italy. Co-holder (3 CFU) of the 9 CFU course "*Environmental impact of electromagnetic fields*", in English language, for the students of the 2-year Master degree in Telecommunication Engineering, University of L'Aquila, L'Aquila, Italy. Co-holder (60 hours = 6 CFU): Prof. Mauro Feliziani.
Academic year 2021/2022	Holder of the 9 CFU course "Principi di Ingegneria Elettrica Biomedicale e complementi" for the students of the 3-year Bachelor degree in Industrial Engineering – Biomedical engineering curriculum, University of L'Aquila, L'Aquila, Italy. Holder of the 3 CFU course "Complementi di Elettrotecnica" for the students of the 3-year Bachelor degree in Industrial Engineering – Chemical engineering and Management engineering curricula, University of L'Aquila, L'Aquila, Italy. Co-holder (3 CFU) of the 9 CFU course "*Environmental impact of electromagnetic fields*", in English language, for the students of the 2-year Master degree in Telecommunication Engineering, Holder Prof. Mauro Feliziani, University of L'Aquila, L'Aquila, Italy. Holder of the 3 CFU course "Wireless Power Transfer", for PhD students of Industrial and Information Engineering and Economics course; University of L'Aquila, L'Aquila, Italy.
Academic year 2020/2021	Co-holder (2.5 CFU) of the 9 CFU course "Elettrotecnica", for the students of the 3-year achelor degree in Industrial Engineering – Chemical engineering and Management engineering curricula, University of L'Aquila, L'Aquila, Italy. Co-holder (6.5 CFU) Prof. Mauro Feliziani. Holder of the 3 CFU course "Wireless Power Transfer", for PhD students of Industrial and Information Engineering and Economics course; University of L'Aquila, L'Aquila, Italy. Teaching assistance for computer exercises and laboratory activities for the 9 CFU Course "*Environmental impact of electromagnetic fields*", in English language, for the students of the 2-year Master degree in Telecommunication Engineering, University of L'Aquila, L'Aquila, Italy, Holder Prof. Mauro Feliziani.

Academic year 2019/2020	Holder of the 3 CFU course “Wireless Power Transfer”, for PhD students of Industrial and Information Engineering and Economics course; University of L'Aquila, L'Aquila, Italy. Teaching assistance for computer exercises and laboratory activities for the 9 CFU Course “*Environmental impact of electromagnetic fields*”, in English language, for the students of the 2-year Master degree in Telecommunication Engineering, University of L'Aquila, L'Aquila, Italy, Holder Prof. Mauro Feliziani. Teaching assistance for exercises, laboratory activities and seminars of the 9 CFU course “*Elettrotecnica + Complementi*”, for the students of the 3-year Bachelor degree in Industrial Engineering Industrial Engineering – Chemical engineering and Management engineering curricula, University of L'Aquila, L'Aquila, Italy. Holder Prof. Mauro Feliziani.
Academic year 2018/2019	Holder of the 3 CFU course “Wireless Power Transfer”, for PhD students of Industrial and Information Engineering and Economics; University of L'Aquila, L'Aquila, Italy. Teaching assistance for computer exercises and laboratory activities of the 9 CFU course “*Environmental impact of electromagnetic fields*”, in English language, for the students of the 2-year Master degree in Telecommunication Engineering, University of L'Aquila, L'Aquila, Italy. Holder Prof. Mauro Feliziani. Teaching assistance for exercises, laboratory activities and seminars of the 9 CFU course “*Elettrotecnica + Complementi*”,”, for the students of the 3-year Bachelor degree in Industrial Engineering Mechanical Engineering curriculum, University of L'Aquila, L'Aquila, Italy. Holder Prof. Valerio De Santis. Teaching assistance for exercises, laboratory activities and seminars of the 9 CFU course “*Elettrotecnica + Complementi*”, for the students of the 3-year Bachelor degree in Industrial Engineering Industrial Engineering – Chemical engineering and Management engineering curricula, University of L'Aquila, L'Aquila, Italy. Holder Prof. Mauro Feliziani.
Academic year 2017/2018	Teaching assistance for computer exercises and laboratory activities for the 9 CFU Course “*Environmental impact of electromagnetic fields*”, in English language, for the students of the 2-year Master degree in Telecommunication Engineering, University of L'Aquila, L'Aquila, Italy. Holder Prof. Mauro Feliziani. Teaching assistance for exercises, laboratory activities and seminars of the 6 CFU course “*Elettrotecnica*”, for the students of the 3-year Bachelor degree in Industrial Engineering – Chemical engineering and Management engineering curricula, University of L'Aquila, L'Aquila, Italy. Holder Prof. Mauro Feliziani. Teaching assistance for exercises, laboratory activities and seminars for the students of the 6 CFU Course “*Elettrotecnica*”, 3-year

	Bachelor degree in Industrial Engineering – Mechanical Engineering curriculum, University of L'Aquila, L'Aquila, Italy. Holder Prof. Valerio De Santis.
Academic year 2016/2017	Teaching assistance for computer exercises and laboratory activities for of the 9 CFU course "*Environmental impact of electromagnetic fields*", in English language, for the students of the 2-year Master degree in Telecommunication Engineering, University of L'Aquila, L'Aquila, Italy. Holder Prof. Mauro Feliziani. Teaching assistance for exercises, laboratory activities and seminars of the 6 CFU course "*Elettrotecnica*", for the students of the 3-year Bachelor degree in Industrial Engineering – Chemical engineering and Management engineering curricula, University of L'Aquila, L'Aquila, Italy. Holder Prof. Mauro Feliziani.

Dr. Campi over the last ten years was ***Supervisor*** of N. 10 undergraduate students for short term projects (3 to 6 months), University of L'Aquila, L'Aquila, Italy. Academic years from 2013/2014 to 2022/2023.

XIV – Scientific collaborations

Dr. Tommaso Campi has collaborated with the following University, Research Centers and Institutions on the areas of wireless power transfer, electromagnetic compatibility, electromagnetic field safety and biomedical applications:

- Prof. Mauro Feliziani, Dept. of Industrial and Information Eng. and Economics, University of L'Aquila, L'Aquila, Italy;
- Prof. Valerio De Santis, Dept. of Industrial and Information Eng. and Economics, University of L'Aquila, L'Aquila, Italy;
- Prof. Francesca Maradei, Dept. of Astronautics, Electrical and Energetic Engineering, Sapienza University of Rome, Rome, Italy;
- Prof. Alessandra Costanzo, Department of Electrical, Electronic, and Information Engineering "Guglielmo Marconi", University of Bologna, Bologna, Italy;
- Prof. Luca Giaccone, Department of Energy "G. Ferraris," Polytechnic University of Turin, Turin, Italy;
- Prof. Akimasa Hirata, Dept. of Electrical and Electronic Engineering, Nagoya Institute of Technology, Nagoya, Japan;
- Prof. Ilkka Laakso, Department of Electrical Engineering and Automation Aalto University, Aalto, Finland;
- Dr. Giovanni Calcagnini, Technology and Health Dept., Italian National Institute of Health, Rome, Italy;
- Dr. Andrea Montalto, Department of Cardiac Surgery and Heart Transplantation, San Camillo Hospital - Rome, Italy;

- Prof. Francesco Musumeci, Department of Cardiac Surgery and Heart Transplantation, San Camillo Hospital - Rome, Italy;

- Prof. Luciano Tarricone, Department of Innovation Engineering, University of Salento, Lecce, Italy;

- Prof. Luigi Sciarra, Department of Clinical Medicine, public health, life and environmental sciences, University of L'Aquila, L'Aquila, Italy;

- Prof. Silvio Romano, Department of Clinical Medicine, public health, life and environmental sciences, University of L'Aquila, L'Aquila, Italy;

- Prof. Ernesto Di Cesare, Department of Clinical Medicine, public health, life and environmental sciences, University of L'Aquila, L'Aquila, Italy.

The collaborations are demonstrated by coauthorship of scientific papers and participation in research projects. T

he proposer is a member of the University of L'Aquila research unit of the
National Group in Elettrotecnica (ET Group):
http://www.gruppoelettrotecnica.it/index.php?who=dettunita&id=11

- From 06/2020 Dr. Campi is ***Coordinator*** of the "Electric mobility" section, within the research line "RL10: ICT for environmental sustainability" in the Center of Excellence DEWS (Design Methodologies of Embedded Controllers, Wireless Interconnect and Systems-on-chip), University of L'Aquila, Italy.
  Online: https://dews.univaq.it/index.php?id=dewshome&no_cache=1.
  Description: The DEWS Centre of Excellence of the University of L'Aquila was established in 2001, upon approval of the MIUR (Ministry of Education, University and Research). Among the wide variety of research areas in the sphere of high technology, DEWS has focused on the use of advanced electrical engineering models and methods in the interest of society.

XV - Third Mission

Dr. Tommaso Campi is the ***<u>Leader</u>*** (responsabile scientifico) of the following research contracts:

2023	*Title:* "Estimation of the electromagnetic field produced by commercial WPT systems currently on the market and the assessment of the risks of electromagnetic interference in workers with pacemakers or implantable defibrillators"; *Committent:* National Institute of Health (Istituto Superiore di Sanità) ; *Funding*: 20 k€; *Description*: Aim of the project was the investigation of the influence of the magnetic field produced by new technologies such as WPT systems on active implantable medical devices.

2021	*Title*: “Design, implementation and optimization of a wireless power supply system for medium power mobile devices”; *Committent*: Engineering & Economics Consulting Solutions s.r.l. ; *Funding*: 24.2k€; *Description*: The project was focused on design optimization and construction of a WPT system for medium power applications.

XVI - Research projects

Dr. Tommaso Campi was ***<u>Principal Investigator</u>*** of the following research projects:

2023	University Projects for Basic Research funded by the University of L’Aquila; *Title*: “Wireless power transfer technology applied to a leadless pacemaker”; *Funding*: 13.5 k€.
2023	University Project of Interest of the University (Ricerca di Interesse di Ateneo), funded by the University of L’Aquila; *Title*: “Sistemi di alimentazione wireless per dispositivi di assistenza ventricolare (LVAD)”. *Funding*: 1.5 k€.
2022	University Project of Interest of the University (Ricerca di Interesse di Ateneo), funded by the University of L'Aquila; *Title*: “Sistemi di alimentazione wireless per dispositivi di assistenza ventricolare (LVAD)”; *Funding*: 1.5 k€.
2021	University projects "Avvio alla ricerca" funded by the University of L'Aquila. Project *Title*: “Wireless power transfer technology applied to a leadless pacemaker”. *Funding*: 2.7 k€.

Dr. Tommaso Campi has participated with different roles at the research activities of the following projects:

2012/2015	Research contract "Sensor networks and distributed architectures for communications and control", funded by Thales Italia S.p.a. under a program supported by MiUR - Art.10. Contract between Thales Italia S.p.a. and DIIIE- University of L’Aquila. *Description*: The Project activities were divided into 8 distinct research lines. Dr. Campi was the Leader of the research line "RFID system design oriented to maximum efficiency and with integration of active and passive sensors" in phase 3 (1/1/2015 - 12/31/2015), and he supervised the related report (supply document) called "DF31_OR2". *Funding*: 138 k€

2018	Research contract "Jacket for the wireless charging of wearable devices by Wireless Power Transfer technology" Contract between Siralab Robotics s.r.l and DIIIE- University of L'Aquila. *Description*: Dr. Campi was the technical leader of the project focused on the design, optimization and realization of WPT system for recharging the soldier's equipment inside the transport vehicle. *Funding*: 20 k€.
2020	Research contract "Design wireless charging systems with advanced features for jackets equipped with devices rechargeable in vehicles" Contract between Siralab Robotics s.r.l. and DIIIE- University of L'Aquila. *Description*: Dr. Campi was the technical leader of the project focused on the optimization and the integration of advanced features in a WPT system for recharging the soldier's equipment inside the transport vehicle. *Funding*: 40 k€.
2019-2022 (ext 2023)	Italian Ministry of Education, Universities and Research (MIUR), Projects of national interest – PRIN 2017, Project title "WPT4WID: Wireless Power Transfer for Wearable and Implantable Devices", Project no. 2017YJE9XK. *Description*: The project is focused on the development of WPT technologies for wearable and implantable biomedical devices. Dr. Campi was a researcher member of the Research unit of the University of L'Aquila (UNIVAQ), responsible for the development of wireless power transfer system for active implantable medical devices. *Funding for UNIVAQ*: 127 k€
2021	Research contract "Wireless charging system for light electric vehicles in high density urban area, and demonstrator for a kick scooter". Consulting contract between BluHub s.r.l. and DEWS- University of L'Aquila. *Description*: Dr. Campi was the coordinator for the development of wireless power transfer system for a kick scooter. *Funding*: 45 k€.

XVII – Brief description of the research activity

The research activity of Dr. Tommaso Campi can be summarized in three main topics:

A) Models for electrical and electronic systems and devices
   1) WPT for implanted biomedical devices
   2) WPT system for robotics.

B) Electromagnetic compatibility and EMF safety:
   1) EMC in automotive WPT
   2) Active shielding for WPT applications
   3) EMC in biomedical devices
   4) EMF safety

C) Numerical methods

1) Modeling of thin conductive shields
2) Litz wire

A brief description of each research topic is given below. Citations are numbered as reported in the "all publications" section.

A) Models for electrical and electronic systems and devices

The research activity of Dr. Tommaso Campi is mainly focused on the development of models for the Wireless Power Transfer (WPT) technology based on resonant inductive coupling between one or more transmitting coils and one or more receiving coils. This technology is used to transfer electricity without using wired connections. There are several ways to make a wireless connection, however inductive resonance coupling is the most popular technology today. WPT technology based on magnetic fields is also known as inductive power transfer (IPT). The principle is the same as for the electrical transformer according to Faraday's law of induction. However, while in electrical transformers the primary and secondary coils are strongly coupled through a ferromagnetic core that channels the magnetic flux along a specific path, in a WPT system the presence of an air gap leads to a weak magnetic coupling between the transmitter (primary) coil and the receiving (secondary) coil. The advantages of this technology are many such as safety, comfort, simplicity for the user, etc.. There are many areas that can benefit from WPT technology which can be used to transfer low or very low power, such as in implanted biomedical devices, up to high power applications, such as automotive WPT systems for electric vehicles. However, there are many aspects that still need major innovation or in-depth study, such as the magnetic field mitigation in the environment, efficiency improvement, system miniaturization, etc..
The activity carried out by Dr. Campi concerned the development of models for electrical and electronic systems used in WPT in two main fields of application: biomedical and robotics.

A1) WPT for implanted biomedical devices

The research activity of Dr. Campi on WPT systems for biomedical devices has been focused on both low power ($P < 1$ W) active implantable medical devices (AIMDs) such as pacemakers (PMs) and implantable cardioverter-defibrillator (ICDs), and high power ($P > 5$ W) AIMDs such as ventricular assist devices (VADs).
In recent years, AIMDs have undergone a significant technological breakthrough that has enabled them to spread enormously. There are many devices classified as AIMDs, but the most popular are PMs and ICDs. Technological development has made these devices extremely effective and reliable, with a useful life after installation of 4 - 10 years, after which it is necessary to replace them. The main factors determining the lifetime of the device is the battery. When the battery level falls below a certain threshold, the entire device must be surgically replaced, exposing the patient to some risks (for example, the risk of infection is in the range 2 - 5%). Furthermore, in recent years, technological evolution has enabled the introduction of increasingly sophisticated cardiac signal analysis, data storage and telemetry transmission functions making these devices extremely sophisticated and with important monitoring and diagnostic functions. The remote sensing is already available: many AIMDs on the market can wirelessly transmit the collected data to an external reader. However, the exploitation of the wireless reading function significantly reduces the battery life, which currently represents the main limitation for a full exploitation of monitoring and diagnostic functions. Thus, the possibility to equip AIMDs with a wireless charging system can improve both device lifetime and functionality. Also, the battery size can be reduced as it will be rechargeable. Applying WPT technology to AIMDs is a major technological challenge that requires system miniaturization and maximization of the electrical performance of the WPT system. In addition, the devices must comply with regulations of electromagnetic field (EMF) and thermal safety.

aDr. Campi, through studies on the electromagnetic field and circuits considering anatomy of the human body and the frequency-dependent physical constants of the biological tissues, has proposed very innovative WPT system architectures for AIMDs which have allowed the construction in the laboratories of the University of L'Aquila of WPT system prototypes and demonstrators mounted on commercial AIMDs which have been used for the experimental validation of the simulation results. In many WPT applications the WPT transmitter is placed outside the human body with the coil mounted on the skin, while the receiver is integrated into the implanted device inside the human body. In [A37, A38, C28, C39] the application of the WPT system to recharge the battery of a pacemaker has been investigated proposing innovative different architectures of the WPT system. The integration of the receiving coil inside the device has been proposed using a considerable low operational frequency (20 kHz). The usage of such a low frequency is an original aspect and permits a good magnetic field penetration through the pacemaker case reducing at the same time the EMF exposure and temperature rise risks, as presented in [C33]. The integration of the receiving coil inside the PM case is essential to improve the biocompatibility of the device. Different secondary coil configurations have been analysed by numerical simulations and experiments revealing the feasibility of the proposed technology, also considering different operational conditions of the device [C29]. The results obtained were validated through prototypes and demonstrators. This research activity has received a high number of citations and is very appreciated for the original solutions by the biomedical and WPT technical communities**.** Subsequently, the research activity of Dr. Campi was focused on the application of inductively-based WPT technology applied to power a deep implant with no fixed position inside the human body. An example of deep implant can be the leadless pacemaker, that is an innovative miniaturized device that is implanted directly inside the heart chamber, without the use of pacing or sensing leads. The main difficulty to apply a wireless charging on these systems is due to the significant implant depth, thus the gap between transmitter and receiver coils is significant and the coupling factor between coils can be very small due to the field attenuation produced by biological tissues and large separation distance. To overcome these problems, a large primary coil, derived by the Helmholtz coil, was proposed to obtain a nearly uniform magnetic field inside the human body at intermediate frequencies (IFs) [A19, C19]. Then, a detailed analysis was carried out to assess the compliance with EMF safety standards. General guidelines on the design of primary and secondary coils were provided for powering or charging a deep implant of cylindrical shape with or without metal housing (e.g., leadless pacemaker). To validate the proposed method several demonstrators of the WPT systems have been fabricated and tested.
In recent years the research activity on biomedical devices has been moved on high power biomedical devices, such as artificial organs. Actually, the most diffused device of this categories is the left ventricular assist device (LVAD) which is an electric pump surgically attached to the heart and used to treat the advanced heart failure. The LVADs were initially designed for a short operational period (< 2 years) for those people who were waiting for a heart transplant, but currently, with the poor availability of donor organs, a lot of studies and research are aimed to extend the LVAD life to several years as a long-term treatment. However, the diffusion of the LVAD is strongly related to the solution of some problems that affects this device. The infection is one of the main adverse events that may be associated with the use of the LVAD. The presence of the percutaneous driveline cable, used to connect the on-body powering system with the in-body controller to power the device, is the main cause of infection. Aim of the research activity was the development of a WPT system that can eliminate the driveline and replace the galvanic connection with a wireless power link. If the application of the WPT technology applied to recharge the battery of low power biomedical devices (e.g., pacemakers, etc.) is well known in literature, the application of the WPT technology to directly power battery-free LVADs represents a very innovative scientific challenge. The main critical points are:

- Clinical, geometric and weight requirements for integrating the WPT system on the LVAD;

- High power (up to 50W during peaks in pulsatile mode) continuously required by the device without any interruption which can be critical for the patient's life;
- Compliance with the EMF and thermal safety limits;
- Biocompatibility of adopted materials.

The attention has been focused on the development of methods, circuits and architectures that allows the realization of a WPT system able to transfer a significant amount of power (> 10 W) while respecting the EMF and thermal safety limits. In [A15] two different solutions have been proposed. The first uses a subcutaneous secondary coil and has been revealed to be very efficient and easy to implement in LVADs, even if it requires a new subcutaneous implant for the receiver and an internal driveline to connect the receiver to the LVAD attached to the heart. The second is based on the integration of the secondary coil in the LVAD, but it requires a new design of the LVAD itself and the WPT efficiency is lower than that of the first solution. For both systems the coil geometry and equivalent circuits have been optimized to find the best tradeoff between size and performances. For each configuration the operational frequency has been also optimized. Several studies were addressed to design a system that can be easily integrated in the LVAD itself [C10, A10]. A deep investigation and optimization of the subcutaneous configuration is presented in [A7, C8]. One of the main innovations is represented by the integration of a rechargeable battery pack in the receiving coil. This configuration provides the following benefits: no-break power supply for the LVAD; peak load management; enhanced system reliability; elimination of the driveline infection; enhancement of patient's quality of life. The measured coil currents were used as sources for dosimetric analysis to assess the compliance of the system with the EMF safety and thermal regulations. Numerous experimental tests have been carried out on a prototype WPT system mounted in a real LVAD, with excellent results. An evolution of the system is presented in [A6, C5] where the use of a subcutaneous WPT system has been proposed to power two or more different devices. This feature can be very useful, for example, for severe heart patients, when the LVAD is implanted together with an ICD. The electromagnetic configuration of the implanted system has been redesigned to allow for higher power output, and the secondary circuitry has been improved to power multiple loads with different characteristics. The development of WPT systems for LVAD has led to numerous experimental tests. ***The latest version of the WPT system for LVAD was adopted for an in-vivo test conducted in collaboration with an outstanding cardiac surgical team of 8 people led by Prof. Francesco Musumeci, San Camillo-Forlanini Hospital, Rome. The design of these highly innovative systems required extensive knowledge of electrical, electromagnetic and biomedical models and methods.***

The research activity on the biomedical WPT systems also concerned the possibility of powering implantable bio-robot organs (IBROs). The most widespread IBROs are endoscopic capsules, however also robotic capsules are under development and will be adopted in the near future. These devices are used to apply therapy or to perform diagnostic functions. IBROs might have a lot of features, but they are limited by the available power. When energy demand is limited and energy storage is available, battery integration into the device is the traditional approach but for some applications the battery charge lasts only a few hours. In addition, many features of implanted devices are often not used for energy savings. To overcome the limited energy available, WPT technology may show great promise for recharging batteries or directly powering IBROs. In [A5, C3] a new architecture for the transmitting coil, based on a combination of a Helmholtz coil and a birdcage coil, was proposed. This configuration generates a magnetic field with all nonzero field components at any point within the human torso. In [A2] an innovative excitation system has been proposed to allow wireless recharging of the capsule equipped with a monoaxial winding for the receiver, so reducing weight and size of the implant. The new transmitting coil consists of four rectangular coils with independent excitations to produce a non-zero magnetic field in any direction. The results obtained demonstrate that the proposed WPT configuration can transfer at least 250 mW in a capsule that travels the entire gastrointestinal tract.

A2) WPT systems for robotics

The use of lightweight Unmanned Aerial Vehicles (UAVs) and drones is becoming increasingly popular in various application areas such as surveillance, monitoring and couriers. One of the most critical limitations of battery powered drones is the poor autonomy of the battery, typically between 20 and 60 minutes. In applications where the drone should be fully autonomous the reduced flight time is a real problem. To permit continue operations a suitable solution is to create base stations where the drone lands to automatically recharge its battery. The use of the WPT technology based on magnetic resonant coupling is very suitable for this kind of problem. The WPT technology can be applied to a drone placing the transmitting coils on a ground base station and equipping the drone with a receiving coil. However, there are several problems to be solved. First the on-board WPT system must be very lightweight to avoid payload reduction. Moreover, the weight increase leads to a significant reduction of the flying time. For this reason, the on-board components of the WPT system must be minimized and miniaturized. The second aspect regards the compatibility of the WPT charging system with on-board electronics. The magnetic field produced by the coils does not have to interfere with the high-speed communications inside on-board systems and between drone and ground systems. Finally, the WPT technology must guarantee efficient power transfer with high tolerance to coil misalignment due to always possible poor landing precision. In the studies proposed by Dr. Campi several solutions able to overcome these issues have been presented minimizing the number and the weight of the on-board components [C12, C32]. In [A30] the receiving coil has been placed on the drone landing skid to reduce the vertical gap between the transmitting and the receiving coils to only few millimeters. The base station dimensions are chosen in function of the landing precision that depends on the accuracy of the GPS or other automatic landing assistance techniques.. The performance of the system obtained by a numerical simulation has been validated through measurements on a demonstrator. A system for small size drone is presented in [C22] where the receiving coil is integrated into the propeller protection.

In [A23] the main idea was the use of a structural element of the drone as a secondary coil, without adding any new coil. In all past works, the receiving system is a separate part that is added to the drone, while with the proposed configuration the receiving coil is integrated in a pre-existent part of the drone. This makes possible to use the drone landing gear with a suitable (closed loop) shape as a single-turn secondary coil. Obviously, the landing gear must be realized in a light, highly conductive material and must have low AC impedance at the WPT operational frequency that is usually in the range 150 kHz–13.56 MHz. The configuration that perfectly meets the required electrical and mechanical characteristics is an aluminum pipe that is therefore adopted for the drone landing gear in the proposed experimental work. Numerical methods were developed to optimize both the primary and secondary coils. The primary coil must be well designed to achieve good electrical performance also in the case of imperfect landing. Also, the electric configuration must be selected to allows a transfer of the power considering a single turn on board coil. The proposed method and simulations were validated by measurements in a WPT system demonstrator mounted in a commercial lightweight drone demonstrating a very high efficiency with a negligible extra weight on the drone. This solution has been patented.

B) Electromagnetic compatibility and EMF safety

B1) EMC in automotive WPT

To achieve the goal of producing zero CO2 emissions, significant growth in battery-powered electric vehicles (EVs) is expected in the near future. There are two ways to charge EV batteries: i) plug-in charging via galvanic connection; ii) wireless charging via inductive link. The latter technology is very attractive as it is safer and more comfortable than plug-in charging, but requires a wireless charging infrastructure. Currently, the WPT technology is the most mature solution. The WPT technology used for automotive is mostly based on the magnetic resonant coupling between inductively coupled coils, which are loosely coupled due to the presence of an air gap between them. The primary coil is usually mounted on the road, while the secondary coil is placed in the car underbody. SAE J2954 standard for stationary vehicles defines the criteria for interoperability, EMC, EMF safety, performance and testing for the WPT system of light-duty electric vehicles. The standard is intended for stationary vehicles and unidirectional charging, from grid to vehicle, and defines the operating frequency at 85 kHz and various levels of charging power. Since WPT relies on a strong magnetic field, there are some concerns about EMC and EMF issues, where the potential victims are electronic devices and humans, respectively. Thus, is very important to develop adequate solutions to mitigate the magnetic field emission in the environment. Dr. Campi provided an extensive analysis of the shielding systems based on conductive and magnetic materials in [C40, A31, A28]. A WPT system can be considered as an intentional source of electromagnetic field, therefore the use of traditional conductive shields can lead to a drastic reduction in the electrical performance of the WPT due to power losses on the shield itself. On the contrary, the use of magnetic shields allows to improve the magnetic coupling between the coils with good shielding results due to the deviation of the magnetic flux from the area to be shielded; however, these materials are usually expensive and heavy. Several works [C36, C34, C15, C16] were addressed to provide general guidelines for the design of shielding structure for WPT system in automotive. The methods for obtaining the best compromise between shielding efficiency, electrical efficiency and reduction in size and weight are deeply described. Using a combination of conductive and magnetic shields provides good magnetic field reduction, however requires additional materials for the shield construction, which increases cost and weight. One possible solution is based on source mitigation by reducing the current flowing in the coils instead of using shields. In [A31, C35] a very innovative method for magnetic field mitigation has been proposed adopting an LCC compensation topology for the resonant WPT system. A tuning of the parameters of the LCC compensation circuit allows to reduce the currents on both transmitting and receiving coils with a consequent mitigation of the magnetic field emission. Adopting this approach there is a negligible reduction of the WPT electrical performance. The proposed method has been also applied in [A21] to coil configurations defined by the international standard SAE J2954. The parameters of the electric circuit and the compensation network have been chosen to minimize the magnetic field without reducing the electrical performance of the WPT and without any modification to the original coil structure.

Part of the research activities on the WPT system for electric vehicles was focused on the design of an innovative configuration for a dynamic wireless power transfer (DWPT) system for electric vehicles in motion, which is the future of mobility. DWPT often relies on a series of short track pads embedded in the road pavement that transfer electrical power wirelessly to electric vehicles equipped with a pick-up coil for battery charging. An open problem with this technology is the variation of the coupling factor as a vehicle switches from one transmitting coil to another during its motion. This can cause a significant change in power with possible power spikes and holes with negative effects also from the EMC point of view. To overcome these issues, a new architecture is proposed in [A12] based on two pick-up coils mounted in the vehicle underneath. These identical receiving coils are placed in different positions under the vehicle (one in front and the other in the rear) and are activated one at a time so that inductive coupling is always good enough. This innovative configuration has two main advantages: i) it maintains a nearly constant coupling factor, as well as efficiency and transferred power, as the vehicle moves along the electrified road; ii) it significantly reduces the cost of road infrastructure. The results of the investigation show the significant improvement achieved in terms of maximum power variation which is nearly stable with the proposed two-coil architecture (only 2.8% variation) while there are many power holes with the traditional single pick-up coil architecture. In addition, the number of the required transmitting coils is significantly reduced due to a larger separation between adjacent coils. Also, the EMC/EMI issues are strongly reduced due the elimination of many transients.

Another relevant EMC issue of automotive WPT systems concerns the conducted emission (CE). Due to the presence of multiple power converters, problems related to CE can arise both in the power supply network and in the vehicle's susceptible electronic equipment which includes audio systems, car alarm and security, door switch modules, GPS navigation system, engine control units, antilock braking system, airbag control, etc... This is very critical due to the coexistence of signal interfaces and electric power systems in the relatively small volume of a car. The main source of noise is the onboard rectifier that is the power electronic circuit used to convert the AC current transferred to the secondary coil of the WPT system at the nominal frequency $f = 85$ kHz into a DC current used to charge the battery. The rectifier should be located in proximity of the receiving coil. The connection between the rectifier and the battery is realized by a DC power bus. Although the power bus is composed of shielded cables, the conducted electromagnetic noise can couple onto susceptible circuits through crosstalk, or it can generate radiated emission (RE) in the resonating structure of the metallic chassis.
The CE in the vehicle power bus produced by a WPT charger with different compensation networks is studied by simulations in [C25] highlighting advantages and disadvantages of different compensation network topologies. The SPICE simulations were based on the analysis of the whole electric/electronic system which is modeled using a circuit representation of each single subsystem. The CE of a DWPT system was analyzed in [C1]. In DWPT applications the main criticality is the high variability of the power absorbed by EVs and supplied by the AC power grid. This is due to the continuous variation of the coupling factor of the Tx and Rx coils due to vehicle movement. The fast transients related to the activation and deactivation of the coils when the EV is in or out of the charging zones (i.e., just above the Tx coils) can also lead to significant EMC problems.

B2) Active shielding for WPT applications

Traditional shielding based on conductive shields is not suitable to mitigate the magnetic field produced by WPT coils which are an intentional source. However, the combined use of conductive and magnetic shields allows good shielding and electrical performance, but with an increase in weight and cost. Another well-known passive shielding technique is based on reactive coils, i.e., passive loops that are excited by time-varying magnetic fields. The main advantages of passive loops are low cost, lightness and simplicity. A further advantage is given by the field-controlled effect as the electromotive force is exactly proportional to the time derivative of the incident magnetic flux. Increasing the intensity of the incident field, there is an increase of the induced current that can exactly compensate the increase of the incident field. Despite the great simplicity, the shielding performances of reactive coils are limited. To overcome this limitation, active coil shielding technique can be adopted. Active coils are similar to passive loops, but they are independently powered. By this way it is possible to inject a current of any waveshape and intensity into the active coil that is able to produce a magnetic field opposite to the incident one obtaining a good shielding performance. Thus, active coils can be very good for shielding, but they require independent feeding and control systems that increase the system complexity and cost. When a single active coil is not enough to obtain a satisfactory field reduction, it is possible to use a more complex configuration based on multiple active coils. In this case, the main issue is the definition of the electro-geometrical configuration of each coil (i.e., shape, dimension, orientation, and position), as well as the current to be injected.
The active shielding technique is a promising solution to reduce the strong magnetic field produced by automotive WPT system in critical areas, typically beside the electric vehicle. In the proposed active shielding method [C14, C11, C9, A13], the active coil is controlled by the same voltage source used to power the WPT coil system. By this approach, it is possible to compensate any variation of the source, e.g., due to vertical and lateral misalignment of the coils, only adjusting the current on the active shield in real-time. General guidelines have been provided for the design of an active shield using a single coil. The proposed active shielding method has been validated through measurements. To this aim two active shield demonstrators

have been built and tested: the first is adopted to shield the source (very innovative), and the second to shield the victim. The results obtained demonstrate the validity of the method, obtaining a good shielding effectiveness without reducing the WPT performance. In [A16] this procedure has been extended to a configuration of multiple active coils to better mitigate the field in a three-dimensional region.
Active shielding technique was applied to mitigate the magnetic field produced by a WPT system designed according to SAE J2954, which is the standard for applying WPT to stationary EVs, obtaining very good results [A13, A17]. Active shielding coils were also proposed to mitigate the magnetic field in DWPT systems for road transport. Contrary to stationary WPT systems, the DWPT systems are far from a real application and are not yet standardized, but some research projects have been carried out. Mainly, there are two kinds of primary coils: long-track pads that are quite similar to excitation rails, or multiple short-track pads that are quite similar to a series of relatively small primary coils studded on the road. The first architecture is better for vehicles, since they have a quite uniform excitation during their motion, but it is not very efficient from an energetic point of view, and the electromagnetic pollution is quite relevant around the long track. The second architecture is more complex, and the vehicles have different excitation during motion, but it is more efficient and the pollution is limited, since the short-track pads are excited one at a time; only when an EV is just above a pad. The second solution is therefore preferred and selected for possible application of active shields in the research of Dr. Campi. The goal of the active shielding is to mitigate the field in order to be compliant with the EMF safety standards and regulations for human exposure inside and beside EVs where pedestrians can stay. Since the area where the field must be mitigated is very large, the active shields must be simple, low cost, and easy to install. A possible solution was presented in [A16].

B3) EMC in biomedical devices

A significant part of the research activity of Dr. Campi was addressed to study the EMC of AIMD equipped. Specifically, devices as PMs and ICDs are equipped with special wires (also called "leads") that are used to connect the device, implanted in subcutaneous position, with the heart chamber. An external time-varying magnetic field can induce current and voltage on the pacing leads, which in turn can generate interference in the circuitry of the pacemaker itself and, above all, can inject current in the heart. The attention has been focused on the possible interaction with the magnetic field produced by WPT systems, that are intentional source of strong magnetic field. The main coupling mechanism between the pacemaker and the magnetic field generated by the WPT system is due to the loop formed by the lead through the human tissues. The lead loop area depends on the electro-geometrical configuration of the pacing leads. Studies reported in [A35, C30] are addressed to verify the interference on the AIMDs provoked by the wireless charging system of the pacemaker itself. Due to the complexity of the configuration composed by the human body, pacing leads, WPT coils, and pacemaker housing, a full numerical investigation is not practicable. To overcome this difficulty, a circuit-field co-simulation tool is proposed to evaluate the voltage induced at the input port of the pacemaker. In the proposed approach, the configuration of the pacemaker with a unipolar lead is modelled by an equivalent circuit obtained applying the transmission line (TL) theory, while the numerical approach is used to derive the circuit parameters. In [A19, C11] the influence of the automotive WPT system on people with AIMD was investigated. The strong magnetic field produced by the WPT coils can significantly interfere with the normal operation of the medical devices, that can be very dangerous for the patient. Calculating induced voltage can be very complex when a non-planar lead (implanted within the body in the venous system) is immersed in a non-uniform magnetic field, such as the field generated by automotive WPT coil currents. To reduce the calculation effort, the standard ISO 14117 defines a standardized lead loop of semicircle shape with area equal to 255 cm^2. A computational procedure was developed to find the maximum induced voltage in the lead loop area in the critical regions. The volume of the region under consideration has been discretized into a cloud of equally spaced points. In each of these points the induced voltage was calculated for any orientation of the lead loop. In the proposed method the rotation of the lead loop along three orthogonal directions was performed by post-processing of the field solution [A19, A3]. With the proposed procedure it is possible to quickly calculate the electromagnetic interference in the pacemaker during the wireless charging of an electric vehicle battery.

B4) EMF safety

Emerging new technologies, such as Wireless Power Transfer (WPT) and Radio Frequency Identification (RFID), are placing humans increasingly exposed to electromagnetic fields (EMF) and also to frequencies rarely used in the past such as intermediate frequency (IF), typically rated from a few kilohertz to a few megahertz. In order to prevent the general public from excessive EMF exposure, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) has established several guidelines (last update in 2020) which are non-binding to the several countries following them. The assessment of the electromagnetic field according to ICNIRP guidelines is based on compliance with two different limits known as reference levels (RLs) and basic restrictions (BRs) which are different for workers and general public. The RLs are based essentially on magnetic field limits at low frequency (LF)/IF in the air without taking into account the presence of the exposed human body which could alter the distribution of the field. Therefore the RL are quantities measurable in air and the measurements are well established. The BRs are instead limits of physical quantities inside the human body (induced electric field at LF/IF) which can never be exceeded. The guidelines provide that when the fields measured in the air exceed the RL it is necessary to verify compliance with the BR, but to date this is not possible.

Since 2016 every employer within the European Union (EU) will have to evaluate the exposure of their workers in accordance with the requirements of Directive 2013/35/EU. This is a legally-binding and very challenging task for EU employers, who may lack the resources and expertise required to show compliance with EMF limits. For a large number of workplaces at industries utilizing EMFs, such as in the power electronics, automotive and metal fabrication, the current instrumentation used for EMF evaluation is insufficient to fully demonstrate compliance with exposure limits. This is particularly true in LF and IF range, where exposure limit values (ELVs) are specified in terms of induced electric fields in the body (ELVs are like BRs in the ICNIRP guidelines), which can only be calculated as the measurements are expected to be invasive and therefore risky for humans. The challenges in this area are therefore many, from the modeling of the human body exposed to IF magnetic fields considering the frequency behavior of biological tissues to the development of new sensors and instrumentation for the direct or indirect measurement of physical quantities inside the human body.

The research of Dr. Campi was addressed to solve some EMF safety and dosimetric problems. In order to facilitate the compliance assessment against Directive 2013/35/EU, novel sensor concepts have been proposed in [C21, C31]. In particular, different prototypes of electric field (E-field) sensors measuring the induced fields rather than the incident fields are proposed. In this way, even non-EMF-experts will be able to interpret the results and easily demonstrate compliance of their workplaces. The practical realization of these sensors is not so trivial as developing a miniaturized electric field sensor working at such low frequencies within liquid gels emulating the biological tissues is a very challenging task.

An alternative way to demonstrate compliance with Directive 2013/35/EU for LF-IF magnetic sources would be measuring the B-field in free-space around the source where the worker is going to be and then numerically reconstruct the magnetic vector potential (A-vector) in order to evaluate the induced E-field. To this aim, a mathematical procedure capable to reconstruct the A-vector from measurements of B-fields on a coarse grid has been proposed in [A33]. An automated scanning system for the acquisition of nonuniform time-varying magnetic fields has been also developed [A22].

Further research has been done on numerical dosimetry problems, such as how to model skin in computer codes. Skin is a very complex tissue that requires sophisticated frequency-

dependent models [C28]. To simplify the study, a homogeneous model was successfully proposed [A38].
Numerical dosimetric analyzes were performed to predict field levels in different fields of application. The WPT automotive systems scenario was thoroughly investigated using numerical simulations to predict magnetic field levels inside and beside an EV during wireless charging, considering different EV chassis materials such as iron, aluminum, and carbon fibers [A29, A32 , C16, C24, C26, C27]. For some configurations the induced electric field has also been predicted using very sophisticated models of the human body.
EMF safety has also been studied for RFID and WPT applications to wearable [C37] and implantable [C33] electronic devices. A multiphysics analysis has been performed for pacemakers equipped with the WPT system to predict not only electromagnetic dosimetric quantities, but also temperature rise [A36].

C) Numerical methods and models

C1) Modelling of thin conductive shields

The research activity of Dr. Campi has also been dedicated to the development of original numerical methods for modeling thin conductive layers such as shields that are often present in the magnetic couplers of WPT systems, or for modeling the metal chassis of vehicles in automotive WPT . The most significant scientific results have been obtained by the Artificial Material Single-Layer (AMSL) method which allows a significant reduction of the computational cost. The finite-element method (FEM) is very efficient to solve electromagnetic (EM) field equations in many frequency domain applications, but it is not efficient to model thin conductive regions without using small elements size. Indeed, numerical analysis of EM field penetration through a shield may require a very fine mesh as the element size in the conductive regions must be much smaller than the penetration depth to achieve good accuracy. The use of a very fine mesh discretization can lead to a large number of unknowns and therefore large memory and computational time requirements. At higher frequencies, when the penetration depth tends to very small values, spatial discretization within the shielding region is impractical. Many methods have been presented in the past to solve this type of problem using subcells or by eliminating the shield region from the computational domain by applying equivalent boundary conditions on the new boundary surfaces created by shield elimination. To this end, impedance network boundary conditions (INBC) or transition boundary conditions (TBC) have been proposed in the past to analyze conductive shields. However, there are many application cases where it is of paramount importance to keep the geometric configuration of the shield within the computational domain without doing any region elimination. Indeed, the shield can be thin from an electromagnetic point of view, i.e., when the shield thickness is smaller than the penetration depth, but not geometrically. Furthermore, the INBC/TBC approximation is not available in all commercial software tools for electromagnetic field solution. Therefore, it can be very relevant to develop a method that can be easily implemented in any commercial software tool and this is the main goal of this research. Dr. Campi has proposed the new AMSL method, to simulate the field discontinuity produced by the shield. The original idea of the AMSL method is to synthesize an artificial layer that exhibits the same electrical performance as a real conductive shield, but without the need for fine discretization. In the AMSL method, described in [A14, A25, A26, A27], the artificial material region is discretized, in the direction perpendicular to the shield, by a single layer of finite elements having artificial physical constants obtained by equivalence with the equations of a lossy transmission line (TL) in the frequency domain.
The AMSL element can approximate the field using first-order [A25] or second-order [A26] 1-D finite element equations. The application of the AMSL method leads to a strong reduction of the computation time compared to the traditional FEM codes which use a very fine discretization in the shield region. Furthermore, the implementation is very simple as it is sufficient to replace the real physical constants of the shield region with the artificial ones. The

AMSL method, proposed initially for a solid thin conductive shield, has been also extended for the numerical simulation of anisotropic materials [A25] and multilayer shields [A14]. The results obtained with the AMSL method were validated through measurements and calculations with other numerical methods. This method has been successfully applied to predict model conductive regions such as the vehicle chassis in automotive WPT applications [C17, C20].

C2) Litz wire

Litz wire is a multi-stranded wire made up of many thin strands, individually insulated and twisted together. It is used extensively in power electronics at frequencies up to a few megahertz to reduce the AC losses produced by skin effect and proximity effect. There is currently a growing interest in litz wires due to their extensive use in the emerging WPT technology based on inductive resonant coupling. Modeling litz wire is not easy as the number of strands can be very high (>1000). In the past, complex analytical formulations have been provided to evaluate the AC resistance of a litz wire using simplifying hypotheses, which are not always valid, while the numerical calculation using 3-D codes has proved to be long and very complex, often impracticable. Dr. Campi therefore developed an innovative and very simple numerical method for predicting the AC resistance of a single-bundle litz wire with a large number of strands [A1]. The main assumption is that a multi-strand litz wire can be viewed as a multi-conductor transmission line (MTL) since all strands are electrically isolated [C4]. The MTL can be modeled by cascading a series of MTL segments by applying a strand transposition from one MTL segment to the next. The original and revolutionary idea of this work is that, instead of considering several cross sections, all different, of a discretized MTL, we consider only a single cross section of a parallel multiwire line whose series impedance matrix is calculated from a 2-D finite element analysis (FEA). So instead of serially cascading MTL sections with different cross sections, a large number of discrete transpositions are mathematically applied to the same cross section to simulate an ideal model of a litz wire, i.e. all strands are assumed to have the same impedance and current as occurs in real litz wires with many strands. The new procedure is very efficient and accurate, as demonstrated by the excellent agreement of the numerical results with those obtained by experiments or with 3-D FEA solutions. The error in terms of AC-to-DC resistance ratio is less than 10% in the tested configurations. Furthermore, the computational cost of the proposed method is very low and comparable with a simple 2-D FEA. The method has been applied to litz wire with perfect [C2] or unperfect strand pattern [A1].

Part – XVIII – Summary of Scientific Achievements

Product type	Number	Data Base	Start	End
Papers [international]	78	Scopus	2014	2023

Total Impact factor[1]	92,459
Mean Impact factor	2,801
Total Citations [2]	1303
Average Citations per Product	16,70

Hirsch (H) index[2]	20
Normalized H index*	2,222

*H index divided by the academic seniority.
[1] Calculated as the sum of each article with Impact factor. For recent articles, the last available IF is considered. Source: Journal Citation Report.
[2] Source: Scopus.

Part – XIX Academic assignments

Dr. Tommaso Campi has been a member of the Commission for cultural aspects - Course of Studies of the 3-year Bachelor Degree Course in Industrial Engineering (I3D), University of L'Aquila since 2021;

Dr. Tommaso Campi is member of the CAD "*Consiglio Area Didattica*" of the Course of Studies of the 3-year Bachelor Degree Course in Industrial Engineering (I3D), University of L'Aquila since 2021;

Dr. Tommaso Campi is member of the CAD "*Consiglio Area Didattica*" of the Course of Studies of the 2-year Master degree course of Telecommunication Engineering (I4T), University of L'Aquila, L'Aquila, Italy.

Part – XX Selected Publications

List of the publications selected for the evaluation. For each publication is reported authors, title, reference data, journal IF (if applicable), citations and a brief description. Labels refer to the full publications list in section "XXI All Publications". In the attached list of publications file are reported from (1) to (12).

1. [A1] S. Cruciani, T. Campi, F. Maradei, and M. Feliziani, "Numerical Modeling of Litz Wires based on Discrete Transpositions of Strands and 2-D Finite Element Analysis," *IEEE Trans. Power Electron.* , vol. 38, no. 5, pp. 6710-6719, May 2023 doi: 10.1109/TPEL.2023.3240338.

   Journal I.F. [5.967] (2021) Citations [0];

   The article proposes an innovative numerical method to model the electric behaviour of a single bundle litz wire with a large number of strands. This type of cable are widely used in power applications such as WPT systems and induction heating. The challenge in litz wire design consists in adopting complex bunching architectures to obtain an approximately identical path for all strands which therefore occupy all possible positions in the litz wire sections. In an ideal pattern model, the impedance of all the strands is the same and the current flowing through each of them is also the same. Therefore, the distribution of the current in any cross section of litz is quite uniform and insensitive to skin and proximity effects. The proposed method is first based on a two-dimensional (2D) finite element analysis (FEA) to evaluate the series impedance matrix of a multistrand cable with parallel strands. Then a mathematical algorithm for a discrete transposition of all strands is applied to simulate the bunching and twisting of the strands. The new procedure is very efficient and accurate, as demonstrated by the excellent agreement of the numerical results with those obtained by experiments or with 3D FEA. The error in terms of AC-to-DC resistance ratio is less than 10% in the tested configurations. The computational cost is not expensive and comparable with a traditional 2D FEA which is much lower than a complex 3D simulation, while the simple 2D FEA without strand transposition algorithm proposed in this work is not accurate. The contribution of Dr. Campi can be distinguished from the order of authors. However he participated to develop the original formulation of the theory. Furthermore, Dr Campi carried out all the measurements for the experimental validation of the method.

2. [A6] T. Campi, S. Cruciani, F. Maradei, A. Montalto, F. Musumeci and M. Feliziani, "Centralized High Power Supply System for Implanted Medical Devices Using Wireless Power Transfer Technology," *IEEE Trans. Med. Rob. Bionics*, vol. 3, no. 4, pp. 992-1001, Nov. 2021, doi: 10.1109/TMRB.2021.3123404.

   Journal I.F. [NA] Citations [6];

   This study deals with the development of a new power supply system implanted in the human body to feed several implantable medical devices (IMDs). The idea is to implant a centralized power system inside the human body in a subcutaneous position to power the implants or to recharge their batteries. The energy supplied by the implanted power system comes from outside via a transcutaneous WPT connection. The power system is energized from outside the human body via a transcutaneous wireless power transfer (WPT) link implanted in a subcutaneous pocket. The internal power system is equipped with a backup battery and can continuously power multiple IMDs for a maximum power of 25 W. An implanted centralized UPS system is designed for a test case consisting of several IMDs. As test case, the use of a left ventricular assisted device (LVAD) and an ICD were investigated. These well-known and life-saving devices are implanted simultaneously because an ICD implant with an LVAD statistically produces a significant survival advantage. The technological challenge in designing the system was significant, given the high transmitted power and the need to comply with electrical and thermal safety constraints. A demonstrator of the power supply system proposed for the considered test case was made and tested in the laboratory to verify its feasibility and efficiency. The proposed configuration permits to obtain excellent results from an electrical point of view while respecting the EMF safety and thermal limits. The contribution of Dr. Campi can be distinguished from the order of authors. However he was the main proposer of the centralized power system. He also physically built the demonstrator and performed all laboratory tests on the system.

3. [A7] T. Campi, S. Cruciani, F. Maradei, A. Montalto, F. Musumeci and M. Feliziani, "Uninterruptable Transcutaneous Wireless Power Supply for an LVAD: Experimental Validation and EMF Safety Analysis," *IEEE Trans. Electromagn. Compat*., vol. 63, no. 5, pp. 1717-1725, Oct. 2021, doi: 10.1109/TEMC.2021.3102036.

   Journal I.F. [2.036] Citations [1];

   An uninterruptable wireless power supply was developed for am LVAD, which is an implanted, electrically driven centrifugal pump used to treat advanced heart failure (HF) pathologies. The LVADs are currently powered through a cable driveline (DL) that exits the patient's body through the skin. The proposed configuration is based on a hybrid wireless/wired architecture: the electric power of 10 W is transferred by the near field wireless power transfer (WPT) technology operating at 300 kHz, from outside the human body to an implanted subcutaneous receiver, and then by an internal driveline cable to the LVAD. A significant improvement of the subcutaneous receiver is here proposed, based on the integration in the receiving coil of a battery pack providing the following benefits: no-break power supply for the LVAD; peak load management; enhanced system reliability; elimination of driveline infection (DLI); enhancement of patient's quality of life. The proposed system was first designed, then a demonstrator was made and tested in a laboratory using the latest LVAD generation on the market. The measured coil currents were used as sources for dosimetric analysis to assess the compliance of the system with the EMF safety and thermal regulations. The proposed configuration was successively adopted for an *in-vivo* test of the system conducted in collaboration with the cardiac surgery team led by Prof. Francesco Musumeci. Dr. Campi is the first author, and his contribution was fundamental for the design and optimization of the proposed WPT system to meet the requirements given by the medical team. He also conducted all the experimental engineering tests.

4. [A8] T. Campi, S. Cruciani, F. Maradei, A.Montalto, F. Musumeci and M. Feliziani, "EMI in a Cardiac Implantable Electronic Device (CIED) by the Wireless Powering of a Left Ventricular Assist Device (LVAD)", *IEEE Trans. Electromagn. Compat*., vol. 63, no. 4, pp. 988-995, Aug. 2021, doi: 10.1109/TEMC.2020.3047465.

   Journal I.F. [2.036] Citations [14];

   Aim of the proposed article is the electromagnetic interference (EMI) calculation in a cardiac implantable electronic device (e.g., implantable cardioverter-defibrillator or cardiac resynchronization therapy) generated by an LVAD powered by a WPT system. The wireless power supply of LVADs, not yet available on the market, is currently being studied as many aspects of electronics, hydraulics, power supply, mechanics, etc., are to be investigated. Of great importance is the study of EMI on other implantable devices, such as implantable electronic cardiac devices (CIEDs) with unipolar leads that form a closed loop susceptible to incident fields. The induced effects on a CIED produced by a subcutaneous WPT system powering an LVAD have been numerically calculated and measured. The investigation has demonstrated as the induced voltage at the CIED input port was well below the limit of the ISO 14117 standard, assuming the worst case position for the subcutaneous implant in the abdomen and the maximum transferred power of 20 W. Also the measured magnetic field was well below the ICNIRP and ISO limit. The obtained results demonstrate that the proposed transcutaneous WPT system does not interfere with CIEDs tested in accordance with the ISO standard. The contribution of Dr. Campi can be distinguished from the order of authors. Dr. Campi had a primary role in the conceptualization, design and optimization of the engineering system. It also built the demonstrators and performed the experimental validation of the proposed system.

5. [A9] T. Campi, S. Cruciani, F. Maradei and M. Feliziani, "Innovative Wireless Charging System for Implantable Capsule Robots," *IEEE Trans. Electromagn. Compat*., vol. 63, no. 5, pp. 1726-1734, Oct. 2021, doi: 10.1109/TEMC.2021.3078846

   Journal I.F. [2.036] Citations [5];

   In this article, an innovative system to wirelessly power implantable biorobot organs (IBRO) has been proposed. The most widespread IBROs are endoscopic capsules, however also robotic capsules are under development and will be adopted in a near future. These devices are used to apply therapy or to perform diagnostic functions. IBROs might have a lot of features, but they are limited by the available power. To overcome the limited energy available for implanted medical devices (IMDs), wireless power transfer (WPT) based on inductive electromagnetic coupling can be a very promising solution. In the proposed architecture the Tx coil is given by a combination of a Helmholtz coil and a birdcage coil. Some guidelines have been provided to design the excitation system to ensure a good magnetic coupling with a single-axis receiving coil for any position of the capsule. The proposed Tx coil configuration can generate a magnetic field inside the human body which has a good spatial uniformity and all field components different from zero at any point. The performances of the system have been verified considering a capsule with a length of 2 cm and a diameter of 1 cm. The obtained results demonstrate the capability of the system to transfer at least 1W to the load for any position and inclination of the capsule, respecting the EMF safety limits. Finally, a simple experimental validation of the adopted numerical calculation has been provided. The results obtained are exceptional and very important for a significant evolution of the IBROs in a near future. Dr. Campi is the first author of the paper and had a primary role in modeling the proposed excitation system. He devised the configuration of the electronic ballast and conducted all the experimental tests.

6. [A15] T. Campi, S. Cruciani, F. Maradei, A.Montalto, F. Musumeci and M. Feliziani," Wireless Powering of Next Generation Left Ventricular Assist Devices (LVADs) without Percutaneous Cable Driveline", *IEEE Trans. Microw. Theory Techn*., vol. 68, no. 9, pp. 3969-3977, Sept. 2020, doi: 10.1109/TMTT.2020.2992462;

   Journal I.F. [3.599] Citations [14];

This article deals with the design of a wireless powering system for an LVAD. The modern LVAD is mainly a miniaturized blood pump attached to the heart and is driven by an electric motor powered by a cable driveline that exits the patient's body through the skin to be connected with an external battery. The driveline is a portal to the exterior environment and this can cause frequent and severe infections. The goal of this article is to analyse the possible configuration that can be used to eliminate the cable link between the interior and the exterior of the human body. To this aim, two innovative powering design of the LVAD were proposed adopting the WPT technology based on magnetic resonant coupling. The main challenges in the design of a WPT system for LVAD application are the considerable implantation depth (5−10 cm) and the relatively high power (>5 W) required by the device to operate continuously. Two different solutions were proposed. The first uses a subcutaneous secondary coil and has been revealed to be very efficient and easy to implement in LVADs, even if it requires a new subcutaneous implant. The second is based on the integration of the secondary coil in the LVAD, but it requires a new design of the LVAD itself and the WPT efficiency is lower than that of the first solution. Furthermore, the compliance with the EMF safety limits has been also verified. Dr. Campi was the first author of this article, he had a primary role in the design of the proposed innovative WPT system. Both demonstrators were built and tested by Dr. Campi.

7. [A13] T. Campi, S. Cruciani, F. Maradei and M. Feliziani, "Magnetic Field Mitigation by Multicoil Active Shielding in Electric Vehicles Equipped With Wireless Power Charging System," *IEEE Trans. Electromag. Compat*, vol. 62, no. 4, pp. 1398-1405, Aug. 2020, doi: 10.1109/TEMC.2020.2988463;

Journal I.F. [2.006] Citations [25];

This paper presented a novel configuration of an active shielding system for automotive WPT applications. The adopted multicoil active shield permits to significantly reduce the magnetic field in critical areas near the WPT assembly. The active shielding of the magnetic field produced by the WPT coils was based on four independent active coils placed at the sides of the transmitter and receiver coils. An original mathematical formulation was developed to find out the excitations of the multicoil system suitable to achieve an acceptable field reduction while maintaining satisfactory WPT efficiency. Finally, the impact of the shielding coils on the electrical performance of the system was evaluated. The obtained results were very good and showed a significant reduction of the magnetic field in a target area where the field was shielded. The contribution of Dr. Campi can be distinguished from the order of authors. He had a primary role in the modelling of multicoil active shielding for WPT automotive.

8. [A14] S. Cruciani, T. Campi, F. Maradei and M. Feliziani, "Finite-Element Modeling of Conductive Multilayer Shields by Artificial Material Single-Layer Method," *IEEE Trans. Magnetics*, vol. 56, no. 1, pp. 1-4, Jan. 2020, doi: 10.1109/TMAG.2019.2949737.

Journal I.F. [1.7] Citations [5];

The AMSL method, previously proposed by the same authors, has been extended to model multilayer shields. First, the admittance matrix of a multilayer shield is analytically derived by the transmission line (TL) theory. Then, considering that the field through conductive shields propagates normally to the shield surface, the TL admittance matrix is equated to that of a 1-D finite element to extract the physical constants of a homogenized artificial material. These constants are adopted to model the multilayer shield region in the finite-element method (FEM) calculations by using only one layer of finite elements in the direction of the field propagation. By the AMSL-FEM, the field propagation through the multilayer shield is accurately modelled taking into account the skin effect and avoiding the fine discretization of the shield. The obtained results have been validated by a comparison through experimental tests. The contribution of Dr. Campi can be distinguished from the order of authors. His contribution was very important for the numerical modelling and experimental tests.

9. [A18] S. Cruciani, T. Campi, F. Maradei and M. Feliziani, "Active Shielding Design for Wireless Power Transfer Systems," *IEEE Trans. Electromag. Compat*, vol. 61, no. 6, pp. 1953-1960, Dec. 2019, doi: 10.1109/TEMC.2019.2942264.

Journal I.F. [1.882] Citations [43];

An innovative shielding technique by active coils was proposed to mitigate the magnetic field produced by a WPT system based on near field coupling. General guidelines were provided for the active shielding design to shield the source to reduce the emission or to shield the victim to improve the immunity. Then, an original circuit-approach was proposed to find the optimum powering of the active coil to minimize the magnetic field in a point or in a specific area. Furthermore, the influence of the active shielding on the performance of a WPT system was also investigated. Finally, the proposed solution for active shielding was validated by measurements. Very good results were obtained with a shielding efficiency (SE) of about 20 dB on the considered area with a negligible degradation of the WPT system efficiency. The contribution of Dr. Campi can be distinguished from the order of authors. Dr. Campi had a significant role in the conceptualization of the theory and in the numerical and experimental tests.

10. [A19] T. Campi, S. Cruciani, F. Maradei and M. Feliziani, "Pacemaker Lead Coupling With an Automotive Wireless Power Transfer System," *IEEE Trans. Electromag. Compat*, vol. 61, no. 6, pp. 1935-1943, Dec. 2019, doi: 10.1109/TEMC.2019.2906328.

Journal I.F. [1.882] Citations [4];

The pacemakers are equipped with special wires (also called “leads”) that are used to connect the device, implanted in subcutaneous position, with the heart chamber. An external time-varying magnetic field can induce current and voltage on the pacing leads, which in turn can generate interference in the circuitry of the pacemaker itself and, above all, can inject current in the heart. In the first part of the work, the magnetic field distributions inside and outside an EV equipped with WPT technology is carried out by finite element (FE) simulations using the AMSL method. In the second part, the calculated magnetic field is used as electromagnetic source of a unipolar pacing lead implanted in the human body. Some original calculation methods were proposed to assess the induced voltage in the loop area formed by a lead. By the proposed procedure it was possible to quickly calculate the electromagnetic interference in the pacemaker during wireless battery recharging of an EV. The numerical results demonstrated a major concern for the region beside the car close to the ground where the induced voltage is more than twice the limit and where a patient can stay for an accidental fall, to pick some objects up, or for other reasons. On the contrary, inside the cabin the magnetic field is well shielded by the EV metallic bodyshell, thus the induced voltage in the pacemaker is fully compliant with the limits. The contribution of Dr. Campi can be distinguished from the order of authors. Dr. Campi had a significant role in the conceptualization of the theory and in the experimental tests.

11. [A30] T. Campi, S. Cruciani, and M. Feliziani, “Wireless Power Transfer Technology Applied to an Autonomous Electric UAV with a Small Secondary Coil,” Energies, vol. 11, no. 2, p. 352, Feb. 2018, doi: 10.3390/en11020352.

Journal I.F. [2.707] Citations [89];

The proposed article was focused on the design of a WPT system applied to an electric vertical take-off and landing UAV. The application of this technology to UAV is very challenge since the on-board WPT systems must be very lightweight to avoid significant reduction of the payload (in general between 0.5 kg and 10 kg depending on the size of the lightweight UAV). Furthermore, the WPT systems must not interfere with the electronic systems of the UAV and with the communications between UAV and ground systems. All on-board components have been designed to be very light and compact in order to reduce weight and size as much as possible. By the design procedure, a small secondary coil with only two turns has been proposed and installed on a drone landing skid. This installation with a small air gap between primary and secondary coils leads to a high efficiency of the WPT system. A procedure has been also proposed to design an array of independent primary coils for the ground station of a WPT charging system. Thanks to this approach, it is possible to mitigate the inconveniences produced by possible coil misalignment due to an imperfect landing of the drone. Numerical and experimental results have been presented in terms of electrical performances to demonstrate the validity of the proposed WPT application. In particular, the proposed solution allows for the achievement of good electrical performances combined with an excellent tolerance to coil misalignment. This aspect is of fundamental importance for the automatic recharge of the drone battery. Finally, the proposed solution reduces the weight and size of the onboard WPT systems without altering the flight capabilities of the drone, maintaining almost unchanged the payload and the vision of the on-board apparatuses such as cameras and sensors. Dr. Campi is the first author of the article, and his contribution was fundamental for the design of the proposed WPT for UAV.

12. [A26] S. Cruciani, T. Campi, F. Maradei, M. Feliziani, "Artificial Material Single Layer Method Applied to Model the Electromagnetic Field Propagation Through Anisotropic Shields," *IEEE Trans. Microw. Th. Techn.*, vol. 66, no. 8, pp. 3756–3763, Aug. 2018, doi: 10.1109/TMTT.2018.2840975.

Journal I.F. [3.756] Citations [4];

An evolution of the first release of artificial material single-layer (AMSL) method is presented. The AMSL permits to model electromagnetically a thin conductive material using the finite-element method (FEM), to the more general case of transversally anisotropic shields. The analogy between the field equations and the multiconductor transmission line (MTL) equations is here used to calculate the admittance matrix of a thin anisotropic material. This admittance matrix is then imposed to be that of an equivalent circuit with lumped parameters. Thus, it is possible to synthetize the AMSL tensors containing the specific constants to be used in commercial software tools. The adoption of the AMSL method in FEM simulations avoids a fine discretization inside the thin conductive anisotropic material required at high frequency. The proposed method leads to a considerable simplification in the calculation and a dramatic decrease of the computational cost. The obtained results have been validated by a comparison. with those obtained by numerical methods and experiments in simple test configurations. The contribution of Dr. Campi can be distinguished from the order of authors. Dr. Campi had a significant role in the conceptualization of the model and in the experimental tests.

Journal I.F. source: *Clarivate JCR*
Citations source: *Scopus*

Part – XXI All Publications

Article papers

2023

A1. S. Cruciani, T. Campi, F. Maradei, and M. Feliziani, "Numerical Modeling of Litz Wires based on Discrete Transpositions of Strands and 2D Finite Element Analysis," IEEE Trans. Power Electr., vol. 38, no. 5, pp. 6710-6719, May 2023;
A2. T. Campi, S. Cruciani, F. Maradei, and M. Feliziani, "A New Transmitting Coil for Powering Endoscopic Capsules Using Wireless Power Transfer," Electronics, vol. 12, no. 8, p. 1942, Apr. 2023;
A3. T. Campi, S. Cruciani, F. Maradei, and M. Feliziani, "Electromagnetic Interference in Cardiac Implantable Electronic Devices Due to Dynamic Wireless Power Systems for Electric Vehicles," Energies, vol. 16, no. 9, p. 3822, Apr. 2023.

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A4. T. Campi, S. Cruciani, F. Maradei, A. Montalto, F. Musumeci and M. Feliziani, "Thermal Analysis of a Transcutaneous Energy Transfer System for a Left Ventricular Assist Device," IEEE J. Electromag., RF Microw. Med. Biology, vol. 6, no. 2, pp. 253-259, June 2022;
A5. S. Cruciani, T. Campi, F. Maradei, and M. Feliziani, "Electromagnetic Interference in a Buried Multiconductor Cable Due to a Dynamic Wireless Power Transfer System," Energies, vol. 15, no. 5, p. 1645, Feb. 2022.

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A6. T. Campi, S. Cruciani, F. Maradei, A. Montalto, F. Musumeci and M. Feliziani, "Centralized High Power Supply System for Implanted Medical Devices Using Wireless Power Transfer Technology," IEEE Trans. Med. Rob. Bionics, vol. 3, no. 4, pp. 992-1001, Nov. 2021;
A7. T. Campi, S. Cruciani, F. Maradei, A. Montalto, F. Musumeci and M. Feliziani, "Uninterruptable Transcutaneous Wireless Power Supply for an LVAD: Experimental Validation and EMF Safety Analysis," IEEE Trans. Electromagn. Compat., vol. 63, no. 5, pp. 1717-1725, Oct. 2021;
A8. T. Campi, S. Cruciani, F. Maradei, A. Montalto, F. Musumeci and M. Feliziani, "EMI in a Cardiac Implantable Electronic Device (CIED) by the Wireless Powering of a Left Ventricular Assist Device (LVAD)", IEEE Trans. Electromagn. Compat., vol. 63, no. 4, pp. 988-995, Aug. 2021;
A9. T. Campi, S. Cruciani, F. Maradei and M. Feliziani, "Innovative Wireless Charging System for Implantable Capsule Robots," IEEE Trans. Electromagn. vol. 63, no. 5, pp. 1726-1734, Oct. 2021;
A10. T. Campi, S. Cruciani, F. Maradei, and M. Feliziani, "Coil Design of a Wireless Power-Transfer Receiver Integrated into a Left Ventricular Assist Device," Electronics, vol. 10, no. 8, p. 874, Apr. 2021;
A11. T. Campi, S. Cruciani, F. Maradei, and M. Feliziani, "Efficient Wireless Drone Charging Pad for Any Landing Position and Orientation," Energies, vol. 14, no. 23, p. 8188, Dec. 2021;
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A13. T. Campi, S. Cruciani, F. Maradei and M. Feliziani, "Magnetic Field Mitigation by Multicoil Active Shielding in Electric Vehicles Equipped With Wireless Power Charging System, " IEEE Trans. Electromag. Compat, vol. 62, no. 4, pp. 1398-1405, Aug. 2020;
A14. S. Cruciani, T. Campi, F. Maradei and M. Feliziani, "Finite-Element Modeling of Conductive Multilayer Shields by Artificial Material Single-Layer Method," IEEE Trans. Magnetics, vol. 56, no. 1, pp. 1-4, Jan. 2020;
A15. T. Campi, S. Cruciani, F. Maradei, A.Montalto, F. Musumeci and M. Feliziani," Wireless Powering of Next Generation Left Ventricular Assist Devices (LVADs) without Percutaneous Cable Driveline", IEEE Trans. Microw. Theory Techn., vol. 68, no. 9, pp. 3969-3977, Sept. 2020;
A16. S. Cruciani, T. Campi, F. Maradei, and M. Feliziani, "Active Shielding Applied to an Electrified Road in a Dynamic Wireless Power Transfer (WPT) System," Energies, vol. 13, no. 10, p. 2522, May 2020;
A17. S. Cruciani, T. Campi, F. Maradei, and M. Feliziani, "Active Shielding Design and Optimization of a Wireless Power Transfer (WPT) System for Automotive," Energies, vol. 13, no. 21, p. 5575, Oct. 2020.

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A19. T. Campi, S. Cruciani, F. Maradei and M. Feliziani, "Pacemaker Lead Coupling With an Automotive Wireless Power Transfer System,"IEEE Trans. Electromag. Compat, vol. 61, no. 6, pp. 1935-1943, Dec. 2019;
A20. T. Campi, S. Cruciani, V., F. Maradei, and M. Feliziani, "Near Field Wireless Powering of Deep Medical Implants," Energies, vol. 12, no. 14, p. 2720, July. 2019;
A21. T. Campi, S. Cruciani, F. Maradei, and M. Feliziani, "Magnetic Field during Wireless Charging in an Electric Vehicle According to Standard SAE J2954," Energies, vol. 12, no. 9, p. 1795, May 2019;

A22. E. Reticcioli, T. Campi and V. De Santis, "An Automated Scanning System for the Acquisition of Nonuniform Time-Varying Magnetic Fields," IEEE Trans. Instrumentation Measurement, vol. 69, no. 6, pp. 3216-3222, June 2020;
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A24. A. C. Gubernati, F. Freschi, L. Giaccone, T. Campi, V. De Santis, and I. Laakso “Comparison of Numerical Techniques for the Evaluation of Human Exposure From Measurement Data,” IEEE Trans. Magnetics, vol. 55, no.6, June 2019.

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A26. S. Cruciani, T. Campi, F. Maradei, M. Feliziani, “Artificial Material Single Layer Method Applied to Model the Electromagnetic Field Propagation Through Anisotropic Shields,” IEEE Trans. Microw. Th. Techn., vol. 66, no. 8, pp. 3756–3763, Aug. 2018;
A27. M. Feliziani, S. Cruciani, T. Campi, F. Maradei, “Artificial Material Single Layer to Model the Field Penetration Through Thin Shields in Finite-Elements Analysis,” IEEE Trans. Microw. Theory Techn., vol. 66, no. 1, pp. 56–63, Jan. 2018;
A28. T. Campi, S. Cruciani, V. De Santis, F. Maradei, and M. Feliziani, “Wireless power transfer (WPT) system for an electric vehicle (EV): how to shield the car from the magnetic field generated by two planar coils,” Wireless Power Transfer, vol. 5, no. 1, pp. 1–8, 2018;
A29. V. De Santis, T. Campi, S. Cruciani, I. Laakso, and M. Feliziani, “Assessment of the Induced Electric Fields in a Carbon-Fiber Electrical Vehicle Equipped with a Wireless Power Transfer System,” Energies, vol. 11, no. 3, p. 684, Mar. 2018;
A30. T. Campi, S. Cruciani, and M. Feliziani, “Wireless Power Transfer Technology Applied to an Autonomous Electric UAV with a Small Secondary Coil,” Energies, vol. 11, no. 2, p. 352, Feb. 2018;

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