Sustainable and Low-cost Electromagnetic Technologies for the Internet of Things: Experiences at Electromagnetic Labs in Lecce

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Abstract:

Research and industrial activities related to the Internet of Things (IoT) are growing up faster and faster, and the related enabling technologies play nowadays a very important role. Most of these technologies are electromagnetic-based. In this talk, we focus on some of the most important electromagnetic (EM) enabling technologies for the IoT, specifically referring to the research performed at the Electromagnetic Labs in Lecce (EML2). A special attention is put on some important issues for smart devices, such as 1) energy autonomy 2) identification 3) sustainability in terms of costs and safety related to human exposure to EM fields.

In the area of energy autonomy, two important issues are i) the design of systems and devices for Wireless Power Transmission (WPT) and ii) EM energy harvesting. The discussed research activities are related both to the design of low-power long-range links based on the use of rectennas (rectifying antennas) and to the design of high-power mid/low-range links based on the use of magnetically coupled resonant systems (WREL-Wireless Resonant Energy Links). In both cases, the interest is mainly focused on the design of WPT links for wearable and implantable devices. In particular, it is investigated the possibility of using a WREL operating in the MHz-GHz range for recharging medical devices implanted in the chest [1]-[3]. As per WPT for wearable and portable devices, the focus is on the design of WREL and rectennas fabricated by using non-conventional materials (conductive fabrics, textile materials, etc.). For instance, a portable charger fabricated on leather and optimized for integration in a bag has been proposed in [4]-[5], while a textile wearable rectenna has been presented in [6]. Further activities are related to the theoretical analysis of WREL implemented by using either a capacitive or an inductive coupling [8]-[12]. Useful design formulas have been derived for links using multiple transmitters and/or multiple receivers [9]-[11] and for multi-hop links [12].

As for identification, the reference enabling technology is of course RadioFrequency Identification (RFID). Design, prototyping and characterization of innovative tag and reader devices is addressed in a variety of applications, such as RFID-assisted robot navigation [13], segmented loop reader antennas enabling the behavioral analysis of lab animals [14], miniaturized label-type RFID tags [15], design of tags specifically designed for the pharmaceutical supply chain [16], and measurement systems for the over-the-air characterization of tags. A dedicated attention is paid to the integration between RFID systems and sensors and, more in general, to the design of fully passive tags with *augmented* capabilities, such as sensing, reasoning, and alerting, capable to render "smart" the objects they are applied to. Three main categories of augmented RFID tags have been introduced during the last past years. The sensor-tag [17], based on a so-called multi-ID strategy. RAMSES (RFID Augmented Module for Smart Environmental Sensing) [18], which guarantees passive RFID-sensing up to 10 m from a standard RFID reader, and SPARTACUS (Self Powered RFID Tag for Autonomous Computing and Ubiquitous Sensing) [19], which adds reasoning and pro-activity to the sole sensing and it is also provided with haptic functionalities. Finally, a recent activity has begun based on the joint use of 3D-printing in the RFID (and not only) domain, which promises new solutions paving the way to the new RFID-based devices suitable in the context of the IoT.

As for the sustainability in terms of costs and environmental issues, both for energy autonomy, and for RFID technologies, the proposed solutions are usually extremely effective, as discussed specifically in the talk.

As for sustainability in terms of safety related to human exposure to EM fields, specific research is performed, and will be discussed in the talk, ranging from the use of microdosimetric bioelectromagnetic models at cell membrane levels (and even smaller scales) [20], to the use of dosimetric numerical models (usually based on Finite-Difference Time-Domain -FDTD- methods) so to attack and solve the complex and critical issue of human interactions with EM fields generated by wireless systems [21-22].

References

1. G. Monti, L. Tarricone, C. Trane, "Experimental Characterization of a 434 MHz Wireless Energy Link For medical Applications," *Progress In Electromagnetics Research C* published by EMW Publishing (Cambridge, Massachusetts, USA), Vol. 30, pp. 53-64, DOI: 10.2528/PIERC12032606, ISSN: 19378718, May 2012.
2. G. Monti, P. Arcuti, L. Tarricone, "Resonant Inductive Link for Remote Powering of Pacemakers," *IEEE Transactions on Microwave Theory and Techniques* published by IEEE (Piscataway, NJ, USA), Vol. 63, Issue 11, pp.: 3814 – 3822, Nov. 2015.
3. G. Monti, V. De Paolis, L. Tarricone,"Wireless Energy Link for Deep Brain Stimulation", Microwave Conference (EuMC), 2015 European, Paris, 7-10 Sept. 2015, pp.64-67, DOI: 10.1109/EuMC.2015.7345700.
4. Monti, G., L. Corchia, E. De Benedetto, and L. Tarricone (2016), Compact resonator on leather for nonradiative inductive power transfer and far-field data links, Radio Science, 51, doi:10.1002/2016RS006030.
5. Giuseppina Monti, Laura Corchia, Egidio De Benedetto and Luciano Tarricone, "A Wearable Wireless Energy Link for Thin-Film Batteries Charging", *International Journal of Antennas and Propagation*, 2016, doi:10.1155/2016/9365756.
6. G. Monti, L. Corchia, L. Tarricone, "UHF Wearable Rectenna on Textile Materials," *IEEE Transactions on Antennas and Propagation* published by IEEE (Piscataway, NJ, USA), Vol. 61, Issue 7, pp. 3869–3873, DOI: 10.1109/TAP.2013.2254693, ISSN: 0018-926X, 2013.
7. Giuseppina Monti, Wenquan Che, Qinghua Wang, Marco Dionigi, Mauro Mongiardo, Renzo Perfetti, and Yumei Chang, "Wireless Power Transfer Between One Transmitter and Two Receivers: Optimal Analytical Solution," Wireless Power Transfer, March 2016, Vol. 3, Issue 1, doi: 10.1017/wpt.2016.3.
8. A. Costanzo, M. Dionigi, D. Masotti, M. Mongiardo, G. Monti, L. Tarricone, R. Sorrentino, "Electromagnetic Energy Harvesting and Wireless Power Transmission: A Unified Approach," *Proceedings of the IEEE* published by IEEE (Piscataway, NJ, USA), Vol. 102 , Issue 11, pp. 1692–1711, DOI: 10.1109/JPROC.2014.2355261, INSPEC Accession Number: 14682530, ISSN: 0018-9219, Oct. 2014.
9. Giuseppina Monti, Mauro Mongiardo, Qinghua Wang, Wenquan Che and Yumei Chang, "Wireless power transmission from two transmitters to one receiver: optimal design for power maximization," *2016 IEEE International Workshop on Electromagnetics*, May 16-18, 2016, Nanjing, China.
10. A. Costanzo, M. Dionigi, F. Mastri, M. Mongiardo, G. Monti, J.A. Russer, P. Russer, "The Basic Cell Operating Regimes for Wireless Power Transfer of Electric Vehicles," *2016 Wireless Power Transfer Conference, IEEE WPTC 2016*, May 5-6, 2016, Aveiro, Portugal.
11. G. Monti, A. Costanzo, F. Mastri, M. Mongiardo, L. Tarricone, "Power maximization in a WPT link using three transmitters and a single receiver," *Microwave Conference (EuMC), 2015 European*, 3-7 Oct. 2016, ExCel London (UK).
12. G. Monti, L. Tarricone, M. Dionigi, M. Mongiardo, "Magnetically Coupled Resonant Wireless Power Transmission: An Artificial Transmission Line Approach," *in proceeding of 42th European Microwave Conference (EuMC2012)*, Amsterdam, pp. 233-236, Oct. 28th – Nov. 2nd 2012.
13. L. Catarinucci, S. Tedesco, and L. Tarricone, "Customized ultra high frequency radio frequency identification tags and reader antennas enabling reliable mobile robot navigation," *IEEE Sensors Journal*, vol. 13, pp. 783-791, 2013.
14. L. Catarinucci, R. Colella, L. Mainetti, L. Patrono, S. Pieretti, I. Sergi, and L. Tarricone, "Smart RFID antenna system for indoor tracking and behavior analysis of small animals in colony cages," *IEEE Sensors Journal*, vol. 14, pp. 1198-1206, 2014.
15. L. Catarinucci, R. Colella, and L. Tarricone, "Design, development, and performance evaluation of a compact and long-range passive UHF RFID tag," *Microwave and Optical Technology Letters*, vol. 54, pp. 1335-1339, 2012.
16. L. Catarinucci, R. Colella, M. De Blasi, L. Patrono, and L. Tarricone, "Experimental performance evaluation of passive UHF RFID tags in electromagnetically critical supply chains," *Journal of Communications Software and Systems*, vol. 7, pp. 59-70, 2011.
17. L. Catarinucci, R. Colella, and L. Tarricone, "Enhanced UHF RFID sensor-tag," IEEE Microwave and Wireless Components Letters, vol. 23, pp. 49-51, 2013.
18. D. De Donno, L. Catarinucci, and L. Tarricone, "RAMSES: RFID augmented module for smart environmental sensing," *IEEE Transactions on Instrumentation and Measurement*, vol. 63, pp. 1701-1708, 2014.
19. R. Colella, L. Tarricone, and L. Catarinucci, "SPARTACUS: Self-Powered Augmented RFID Tag for Autonomous Computing and Ubiquitous Sensing," *IEEE Transactions on Antennas and Propagation*, vol. PP, pp. 1-10, 2015

20. F. Apollonio, G. D'Inzeo, M. Liberti, L. Tarricone: "Integrated Models for the Analysis of Biological Effects of EM Fields Used for Mobile Communications", IEEE Trans. on Microwave Theory and Techniques, pp. 1804-1815, November 2000
21. L.Catarinucci, P. Palazzari, L. Tarricone: "Human exposure to the near field of radiobase antennas - a full-wave solution using parallel FDTD", Microwave Theory and Techniques, IEEE Transactions on , Volume: 51 Issue: 3 , Pages 935-940, Mar 2003
22. L.Catarinucci, P. Palazzari, L. Tarricone: "On the Use of Numerical Phantoms in the Study of the Human-Antenna Interaction Problem", IEEE Antennas and Wireless Propagation Letters, Vol. 2 , Issue: 1, Pagg:43-45, 2003

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Luciano Tarricone is a Full Professor of Electromagnetic (EM) Fields at the Department of Innovation Engineering, University of Lecce, Italy. He received a Laurea degree with honors in Electronic Engineering at the University of Rome La Sapienza, Italy, in 1989, and his PhD from the same university in 1994, with a thesis on biological effects of EM fields.

In 1990 he was a research fellow at the National Institute of Health in Rome, Italy, involved in EM compatibility of implanted pacemakers, and contributing to the first European draft of safety standards. Since late 1990 up to 1994 he has been with IBM Research. He was first with the Scientific Center in Rome (speech recognition group), later on with European Center for Scientific and Engineering Computing (ECSEC), dealing with high performance computing and mathematical methods and simulation models.

Between 1994 and 1997 he was a Researcher of EM Fields at the University of Perugia. Between 1997 and 2001 he was a Senior Researcher and a Professore Incaricato of EM Compatibility at the same university. At the University of Perugia he started a research group in the area of EM compatibility which achieved interesting scientific results. In 2001 he moved to the University of Lecce, where he was an Associate Professor (2002-2011) and is currently a Full Professor and coordinates the Electromagnetic Labs and a research group. Holder of the Chair of EM Fields, he is also Professore Incaricato of Applied Electromagnetics. He has authored more than 130 papers in international journals, 300 papers in international conferences, and 3 books. He is a reviewer for all the most important international journals in electromagnetics, coordinates or coordinated several research and industrial projects at national and international level, and is a consultant for several academic and industrial institutions in Italy and abroad.