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A Maximum Efficiency Transfer Solution in Wireless Power Systems

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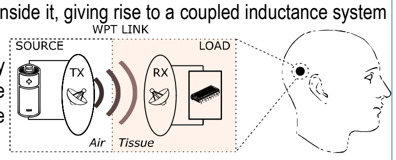
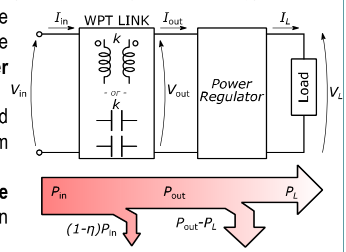
Research context and motivation

- **Wireless Power Transfer** (WPT) is an emerging technique that aims to replace standard wired power supply in an increasing amount of applications such as **biomedical implants**: it represents a viable alternative to overcome the issues related to the use of implanted batteries (e.g. size, longevity, and bio-compatibility).
- An example is given by the **cochlear implant** depicted in the Figure: WPT in cochlear implants usually relies on inductive coupling in which one coil is placed immediately outside the human body and the other inside it, giving rise to a coupled inductance system operating in the **near field**.
- Uncontrolled WPT systems are strongly **sensitive to variations** either in the **coupling factor** or in the **load** therefore a feedback mechanism is needed.



Addressed research questions/problems

- Investigation of a **primary-side control** of a WPT link, i.e., the capability of delivering the **optimal power level** to the load **without compromising system efficiency**, by only sensing quantities available at the primary side (i.e., by avoiding back telemetry).
- When adding a simple power regulator at the secondary side, we observe and analyze the existence of a **Maximum Efficiency Transfer point (MET)**, easily detectable at the primary.
- The MET point ensures both the desired power level $(\boldsymbol{P_L = P_N})$ and the maximum efficiency $(\boldsymbol{P_{out} = P_L})$
- The MET is identified by a **corner point in the** $\boldsymbol{I_{in} - V_{in}}$ characteristic (i.e., a discontinuity in its derivative)



Novel contributions

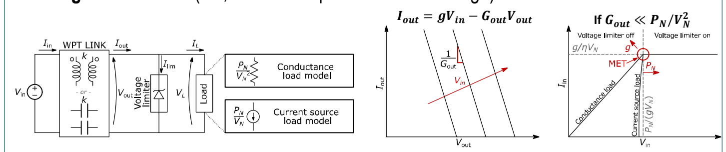
- Proposed Primary-Side approach with **NO need for advanced WPT system modeling**.
- Proposed Primary-Side approach with **NO need for system parameters estimation**.
- **K- and PN-agnostic procedure** capable of identifying the MET point around $V_{in} = V_{in}^{opt}$ by **avoiding back telemetry techniques**.

List of attended classes

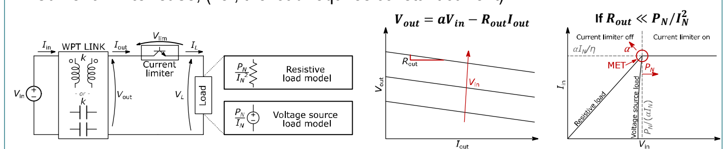
- 01DPIRO – Advanced Topics in Energy Storage System and Electric Vehicle Drivetrain Design (07/09/22, 4 CFU)
- 01UMNRV – Advanced deep Learning (15/06/21, 6 CFU)
- 01QTXRV – BIO/CMOS interfaces and co-design (31/08/21, 3 CFU)
- 01QFDRV – Photonics: a key enabling technology for engineering applications (16/07/21, 5 CFU)
- 02SFURV – Advanced scientific programming in Matlab (27/04/21, 6 CFU)
- 01QSXRU – The measurement of electrical impedance (10/03/21, 2 CFU)
- 02LGXRV – Environmental impact evaluation of magnetic and electric fields at industrial frequency (19/7/21, 4 CFU)
- 01TUFRV – All you need to know about research data management and open access publishing (08/04/21, 3 CFU)
- 02SINPQ – Anthropology of school and educational contexts (22/07/22, 6 CFU)
- 02SIOPQ – Teaching, technology and educational research (18/07/22, 6 CFU)
- EXT_ACT – Pedagogy of educational and formative relationship for secondary school (15/07/22, 6 CFU)
- 01UZHPQ – Psychological ed educational aspects of learning (23/06/22, 6 CFU)
- 02LWHRV – Communication (29/04/21, 1 CFU)
- 01SHMRV – Entrepreneurial Finance (28/04/21, 1 CFU)
- 01UNVRV – Navigating the hiring process (02/05/21, 1 CFU)
- 08IXTRV – Project management (28/04/21, 1 CFU)
- 01RISRV – Public Speaking (26/04/21, 1 CFU)
- 01SYBRV – Research integrity (03/05/21, 1 CFU)

Adopted methodologies

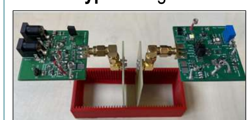
- **Voltage limiter case** (i.e., the load requires constant voltage)



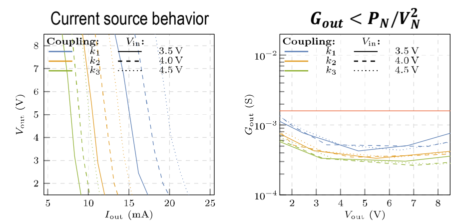
- **Current limiter case**, (i.e., the load requires constant current)



- **Prototype**: Design and Characterization



Class-E DC-DC SPECIFICATIONS			
Vin	3 V	k	0.16
Vout	6 V	L1=L2	1.47 uH
Iout	10 mA	Q	50

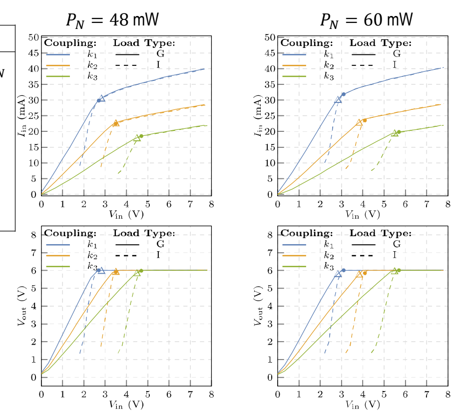


- **MET Point Identification**

Algorithm: MET Point Id.

Result: $V_{in} \approx V_{in}^{opt}, P_{out} \approx P_L \approx P_N$
Apply V_{in} ensuring the regulator is on
Estimate the intercept $I_{in}^0|_{ON}$
Repeat
| Reduce V_{in}
| Estimate I_{in}^0
Until $I_{in}^0 > 0.5\, I_{in}^0|_{ON}$

- **Bullet** highlights the **theoretical MET** point.
- **Triangle** highlights the **identified MET point** according to the previous Algorithm.



Future work

- Development of an Online MET point tracking algorithm.
- Design and Control of WPT systems that are not based on Class-E DC-DC (e.g., LLC).
- Design and Control of WPT systems achieving a higher power level.

Submitted and published works

- A. Celentano, C.Paolino, F. Pareschi, V. Valente, R. Rovatti, W. A. Serdijn and G. Setti, "A Maximum Efficiency Transfer Solution in Wireless Power Transfer Systems: Theory and Validation," submitted in IEEE Transactions on Power Electronics.
- A. Celentano, F. Pareschi, R. Rovatti and G. Setti, "A Zero-Transient Dual Frequency Control for Class-E Resonant DC-DC Converters," accepted for publication in IEEE Transactions on Power Electronics.
- A. Celentano, F. Pareschi, V. Valente, R. Rovatti, W. A. Serdijn and G. Setti, "A Comparison between Class-E DC-DC Design Methodologies for Wireless Power Transfer," 2021 IEEE International Midwest Symposium on Circuits and Systems (MWSCAS), 2021, pp. 71-74, doi: 10.1109/MWSCAS47672.2021.9531712.
- A. Celentano, F. Pareschi, V. R. Gozalez-Diaz, R. Rovatti and G. Setti, "A Methodology for Practical Design and Optimization of Class-E DC-DC Resonant Converters," in IEEE Access, vol. 8, pp. 205568-205589, 2020, doi: 10.1109/ACCESS.2020.3035507.
- F. Pareschi, A. Celentano, M. Mangia, R. Rovatti and G. Setti, "Through-The-Barrier Communications in Isolated Class-E Converters Embedding a Low-K Transformer," 2020 IEEE International Symposium on Circuits and Systems (ISCAS), 2020, pp. 1-5, doi: 10.1109/ISCAS45731.2020.9180486.
- A. Celentano, F. Pareschi, V. Valente, R. Rovatti, W. A. Serdijn and G. Setti, "A Wireless Power Transfer System for Biomedical Implants based on an isolated Class-E DC-DC Converter with Power Regulation Capability," 2020 IEEE 63rd International Midwest Symposium on Circuits and Systems (MWSCAS), 2020, pp. 190-193, doi: 10.1109/MWSCAS48704.2020.9184689.

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PhD program in
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