

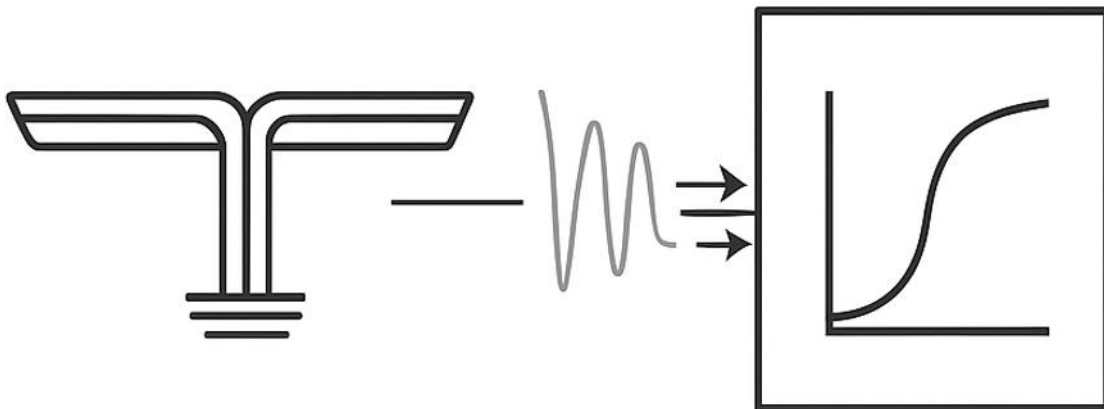
# SW8 - From RFID to Wireless Sensing and IoT: Antenna Innovations for Nonlinear Transponder Systems

## Abstract:

Nonlinear mechanisms are reshaping the landscape of passive wireless technologies from classical RFID to emerging harmonic and intermodulation backscatter-based sensors that operate without batteries or active components. These systems underpin a new generation of wireless sensing and IoT applications, enabling identification, localization, and environmental monitoring with ultra-low-power hardware. Antenna design is central to their performance: it governs energy transfer, harmonic generation, polarization behavior, impedance interaction, and system efficiency under varying, and sometimes extreme, constraints of size, bandwidth, and operating conditions. This workshop gathers researchers from antennas, microwave engineering, and applied sensing to discuss design, modeling, and integration challenges for antennas in nonlinear and passive wireless systems bridging communities in RFID, harmonic radar, chipless sensing, and sustainable IoT.

## Workshop outline:

The half-day workshop will comprise two 1h40 sessions combining invited technical presentations, a keynote talk, and a concluding round-table discussion. The first session will address the fundamentals of modeling and design of antennas for nonlinear passive wireless systems, featuring invited speakers from leading research groups. The second session will highlight integration, fabrication, and application examples across RFID, wireless sensing, and IoT domains. The workshop will conclude with an interactive round-table inviting end-users from applied fields to share their perspectives on current challenges, practical constraints, and emerging opportunities for antenna design for nonlinear technologies.



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## Agenda:

| Time Slot     | Speakers (Affiliation)                            | Topic   |
|---------------|---|---|
|               |   | Session 1: Foundations and Antenna Design Perspectives  |
| 08:00 – 08:10 | A. Lavrenko (UTwente)                             | Welcome and Workshop Scope  |
| 08:10 – 08:35 | M. Polivka (Czech Technical University in Prague) | Wearable Patch-Type Harmonic Tags: Step-by-Step Design Considerations   |
| 08:35 – 09:00 | A. Austin (University of Bristol)                 | Conversion Efficiency Is Not a Number: 3D Pattern Measurements for Harmonic Tags                                    |
| 09:00 – 09:25 | A. Lavrenko (UTwente)                             | To Match or Not to Match: Antenna Design Requirements and Constraints in Compact Harmonic Transponders              |
| 09:25 – 09:40 | All   | Discussion / Q&A  |
|               |   | Session 2: Materials, Fabrication, and System-Level Perspective   |
| 10:10 – 10:35 | V. Palazzi (University of Perugia)                | Design of Passive Wireless Sensors Using Harmonic Transponders: Architectures, Challenges and Technological Outlook |
| 10:35 – 10:55 | C. Li (Texas Tech University)                     | Printable Nonlinear Tags and Handheld Devices for Clutter-Resilient Contactless Monitoring and Tracking             |
| 10:55 – 11:20 | G. Marrocco (University of Rome Tor Vergata)      | The Laser-Induced Graphene Technology for Sustainable Radiofrequency Identification and Sensing                     |
| 11:20 – 11:40 | All   | Round-Table Discussion: What's Next for Antenna Design in Nonlinear Transponder Systems?                            |
| 11:40 – 11:50 | A. Lavrenko (UTwente)                             | Wrap-Up and Outlook   |

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### Speakers:

Dr. Milan Polivka is an Associate Professor at the Czech Technical University in Prague, specializing in advanced antenna systems, nonlinear backscatter transponders, and RF measurement techniques. He is internationally recognized for his contributions to harmonic and intermodulation tag design, including dual-band antenna architectures, characterization of nonlinear scattering mechanisms, and precision link-budget modelling for passive transponder systems. Dr. Polivka leads several research activities on nonlinear tag metrology, compact sensing antennas, and EMC-related measurements, and has co-authored numerous journal and conference papers in these areas. His group is among the leading European teams advancing nonlinear tag antennas and their practical evaluation.

Prof. Valentina Palazzi is an Associate Professor at the University of Perugia, Italy, with research interests spanning RFID systems, chipless and harmonic transponders, and passive wireless sensors. She is widely recognized for her work on antenna-circuit co-design, dual-band and nonlinear tag architectures, and electromagnetic modelling of passive sensing platforms. Her contributions include innovative chipless sensing schemes, compact tag antennas for low-power applications, and analytical methods for characterising nonlinear backscatter mechanisms. Prof. Palazzi has published extensively in leading RF and antenna journals and plays an active role in the European RFID and wireless sensing research community.

Prof. Changzhi Li is a Professor of Electrical and Computer Engineering at Texas Tech University, internationally recognized for pioneering contributions to noncontact RF sensing, nonlinear radar, and harmonic signal processing. His research focuses on Doppler and harmonic radar architectures, nonlinear transceiver design, and high-sensitivity motion and vital-sign detection using low-power microwave systems. Prof. Li has published extensively in IEEE Transactions, delivered numerous invited talks and tutorials, and his work has strongly influenced emerging applications in biomedical sensing, smart environments, and low-power IoT. He is a Fellow of the IEEE and a leading figure in advanced nonlinear RF sensing technologies.

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## ABSTRACTS:

### **Wearable Patch-Type Harmonic Tags: Step-by-Step Design Considerations:**

This contribution presents a step-by-step methodology for designing wearable patch-type harmonic tags, with an emphasis on efficient harmonic generation, and a compact design. The choice of diode is determined based on the selected operating frequencies. An analytical model is used to identify the level of incident power at which these losses are minimal. A dual-band, differentially fed, dual-quarter-wave patch antenna topology is selected, which provides broadside radiation, and self-resonant operation without the need for external matching circuits. Impedance matching is further improved by the use of tuning slots, whose effect on resonance tuning is investigated. Finally, selected prototypes are experimentally characterized, demonstrating achievable performance in terms of conversion efficiency, and robustness in wearable scenarios.

### **Conversion Efficiency Is Not a Number: 3D Pattern Measurements for Harmonic Tags**

The radiation efficiency of harmonic radar tags is typically measured and reported at a single incidence angle. However, the radiation efficiency is a three dimensional (re-)radiation pattern. In this presentation, the setup for three dimensional measurements of harmonic radar tags operating at 9/18 GHz will be presented, along with experimental results, interpretation, and future improvements.

### **To Match or Not to Match: Antenna Design Requirements and Constraints in Compact Harmonic Transponders**

The design of compact harmonic transponders introduces unique challenges that go beyond conventional antenna matching paradigms. In these systems, the antenna must be co-designed with the nonlinear element, where impedance matching, radiation efficiency, and conversion efficiency are tightly interdependent. This talk revisits the role of matching in harmonic transponders, questioning when traditional approaches remain valid and when they become limiting. Emphasis is placed on practical design constraints arising from miniaturization, low-power operation, and integration. Through representative examples, the talk highlights key trade-offs and proposes guidelines for antenna–nonlinearity co-design in next-generation passive sensing systems.

### **Design of Passive Wireless Sensors Using Harmonic Transponders: Architectures, Challenges and Technological Outlook**

This talk will describe some of the most recent design strategies both at component and system level to develop energy-autonomous harmonic transponders with sensing capabilities, while maximizing the read range of the transponders. Practical examples with a case study related to automotive applications will be shown as well. This talk will also focus on the open challenges of this field and will highlight some promising technologies for future advancements in the field.

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### ABSTRACTS:

#### **Printable Nonlinear Tags and Handheld Devices for Clutter-Resilient Contactless Monitoring and Tracking**

This talk presents printable, battery-free nonlinear tags and compact harmonic radar systems for clutter-resilient, contactless sensing and tracking. Operating at 4–8 GHz and 8–16 GHz, the systems exploit second-harmonic generation from diode-based printed tags to suppress linear reflections and enable reliable detection in complex environments. Scalable fabrication methods, including inkjet printing on flexible substrates, produce lightweight, conformal tags. Two compact high-linearity radar platforms ensure strong harmonic isolation and sensitivity. Demonstrations include accurate, noninvasive respiratory monitoring and object localization, establishing a scalable approach for healthcare, tracking, and nonlinear IoT sensing applications.

#### **The Laser-Induced Graphene Technology for Sustainable Radiofrequency Identification and Sensing**

This talk discusses nonlinear RFID transponders as a new frontier in antenna-enabled wireless systems, where the backscattered response is governed not only by tag geometry, but also by chip dynamics, mutual coupling, interrogation power, and material imperfections. Within this perspective, self-tuning chips enable environment-aware sensing, interacting transponders reveal equilibrium phenomena, and power-dependent responses generate distinctive electromagnetic signatures for physical unclonable functions. Additional nonlinear features may arise from imperfect graphene-based materials, further enriching the transponder behavior. The overall picture shows how nonlinear backscatter can extend RFID well beyond identification, opening new directions toward sensing, authentication, and physics-inspired IoT devices.

#### **Round-Table Discussion: What's Next for Antenna Design in Nonlinear Transponder Systems?**

This round-table will explore emerging directions and open challenges in antenna design for nonlinear and passive transponder systems. Moving beyond conventional matching and efficiency-driven approaches, the discussion will address how antennas can be co-designed with nonlinear elements, materials, and system architectures to enable robust operation in realistic environments. Topics include compact and wearable implementations, advanced fabrication techniques, measurement methodologies, and the role of antennas in shaping system-level performance. By bringing together perspectives from design, materials, and applications, the session aims to identify key research priorities and opportunities for the next generation of RFID, sensing, and IoT systems.