A Wireless Communication System for UWSNs Based on Guided Acoustic Waves

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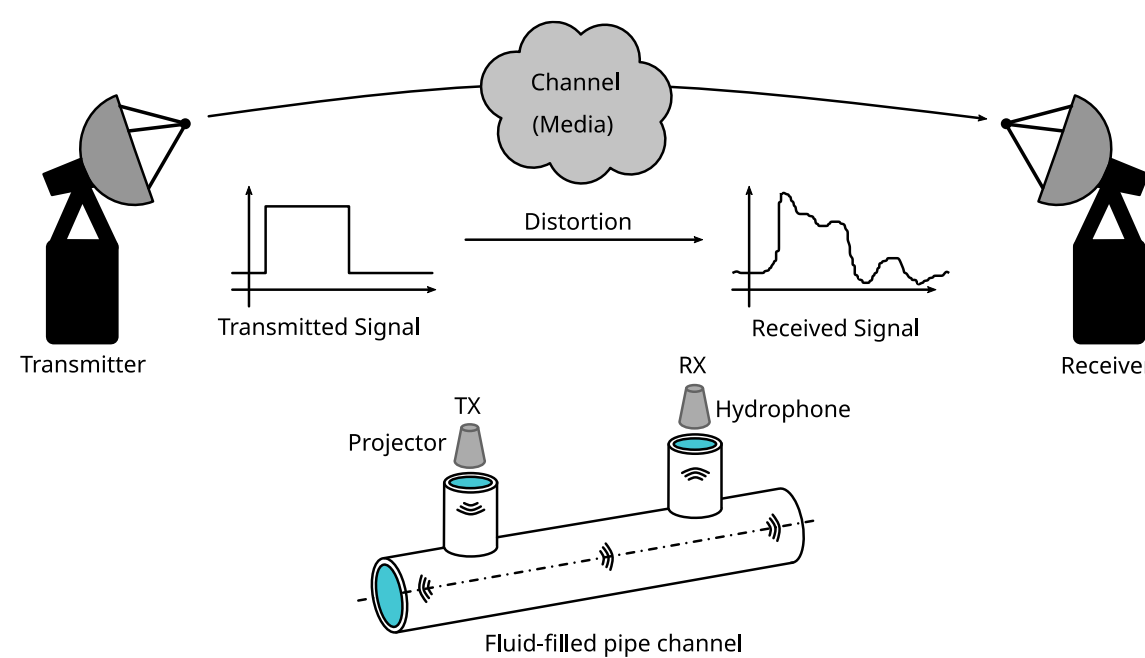WHAT YOU ARE, TAKES YOU FAR

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Research context and motivation

- Communication systems based on non conventional channels are increasingly used as an alternative for data transmission in scenarios where traditional wireless or wired channels cannot be used because unavailable or ineffective.
- Recently, in-pipe data transmission has acquired increasing interest from researchers, since Urban Water Supply Networks (UWSNs) provide a readily available infrastructure made of pipes, which has a large spatial extension and can reach areas not covered by traditional communication infrastructures.
- Among the underwater communication methods, the acoustic wave-based one is by far the most popular, thanks to its resilience to absorption and the reach over long propagation distances.
- Differently from the open-sea case, for in-pipe acoustic communication the distribution of the acoustic energy is affected by the pipe boundary, giving rise to a guided wave propagation, which can be described in terms of modal superposition
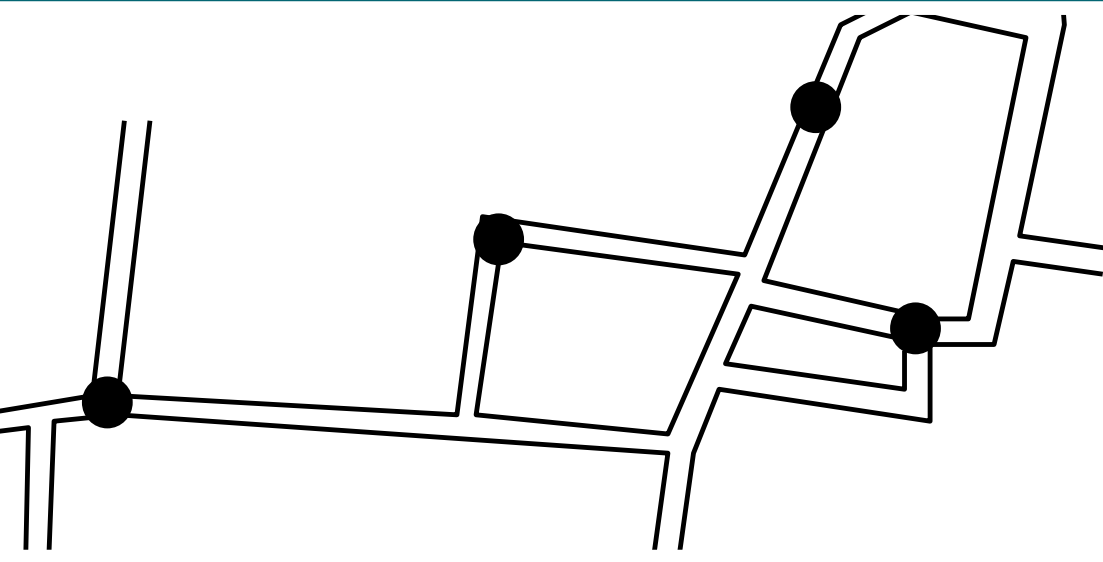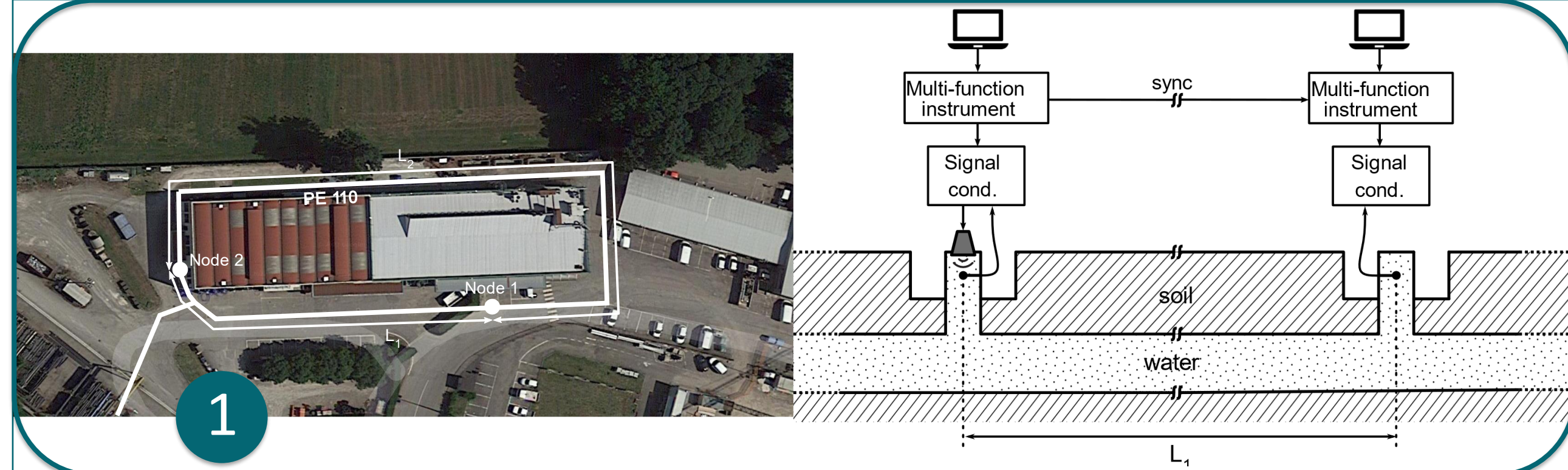
## Addressed research questions/problems

- Acoustic wave-based communication in fluid-filled pipes is an emerging technology and design methods for the communication system are not well established.
- Existing approaches rely mostly on theoretical modeling of the communication channel. However, they are of limited practical utility due to the complex physical strucuture of real-world UWSNs, which can present joints, shafts, bends, branches.
- Furthermore, the signal propagation is largely dependent on the physical parameters of the pipe, as well as the properties of the surrounding soil, which can be unknown or have a large degree of variability.
- Hence, new design methodologies are needed, in order to guarantee robustness against parameter variability and avoid the initial modeling step.

List of attended classes

Submitted and published works

- Fishta, M.; Fiori, F., "*Decimation of Delta-Sigma-Modulated Signals Using a Low-Cost Microcontroller*", Circuits, Systems and Signal Processing, vol. 40, no. 12, 2021, pp. 6387–6400.
- Fishta, M.; Fiori, F., "*Investigation on the Susceptibility to EMI of Second-Order ΔΣ Modulators*", The 13th International Workshop on the Electromagnetic Compatibility of Integrated Circuits (EMC Compo 2021), 2022, pp. 75-80.
- Fishta, M.; Raviola, E.; Fiori, F.; Calza, F.; Tornaboni, A., "*Experimental Characterization of In-Pipe Acoustic Communication Channels Through Measurement of Pressure Transfer Functions*", 27th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA 2022), 2022.
- Cangemi, G.; Fishta, M.; Raviola, E.; Fiori, F., "*New Challenges on the Electromagnetic Compatibility of Electric Vehicles*", Annual Meeting Italian Electronics Society (SIE 2022), 2022.
- Fishta, M.; Raviola, E.; Fiori, F., "*A Baseband Wireless VNA for the Characterization of Multi-Port Distributed Systems*", submitted to IEEE Transactions on Instrumentation & Measurement, 2022.
- Fishta, M.; Raviola, E.; Fiori, F., "*A Wireless Communication System for Urban Water Supply Networks Based on Guided Acoustic Waves*", submitted to IEEE Access, 2022.
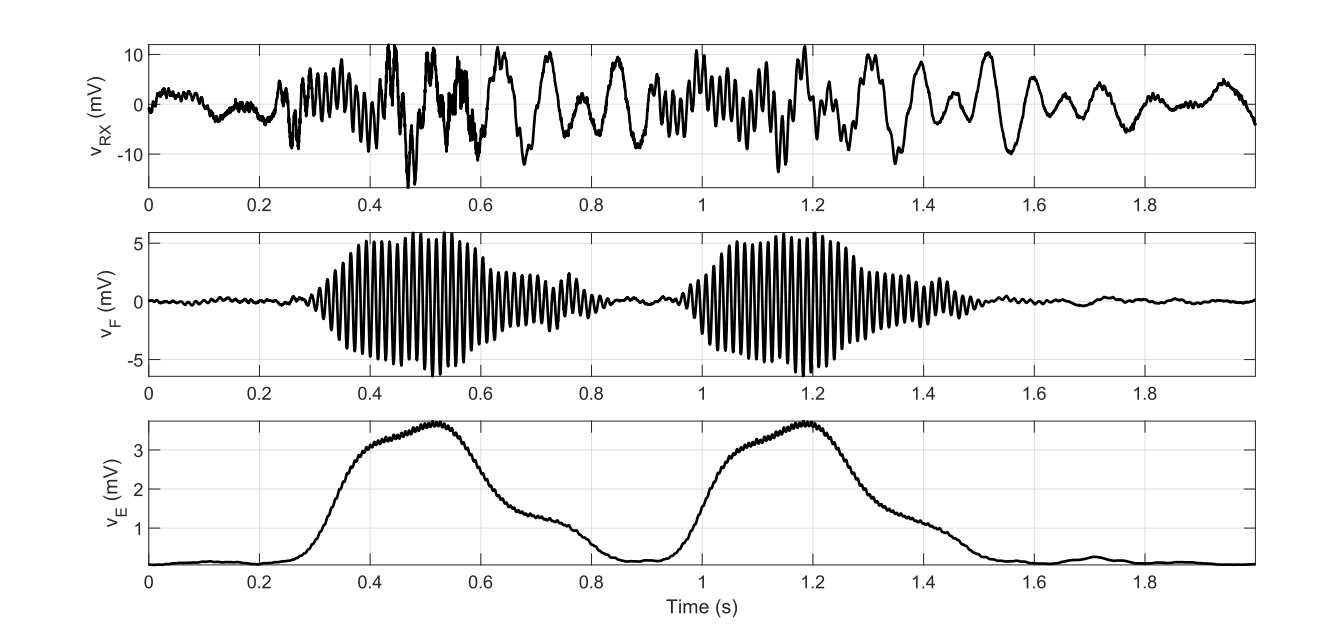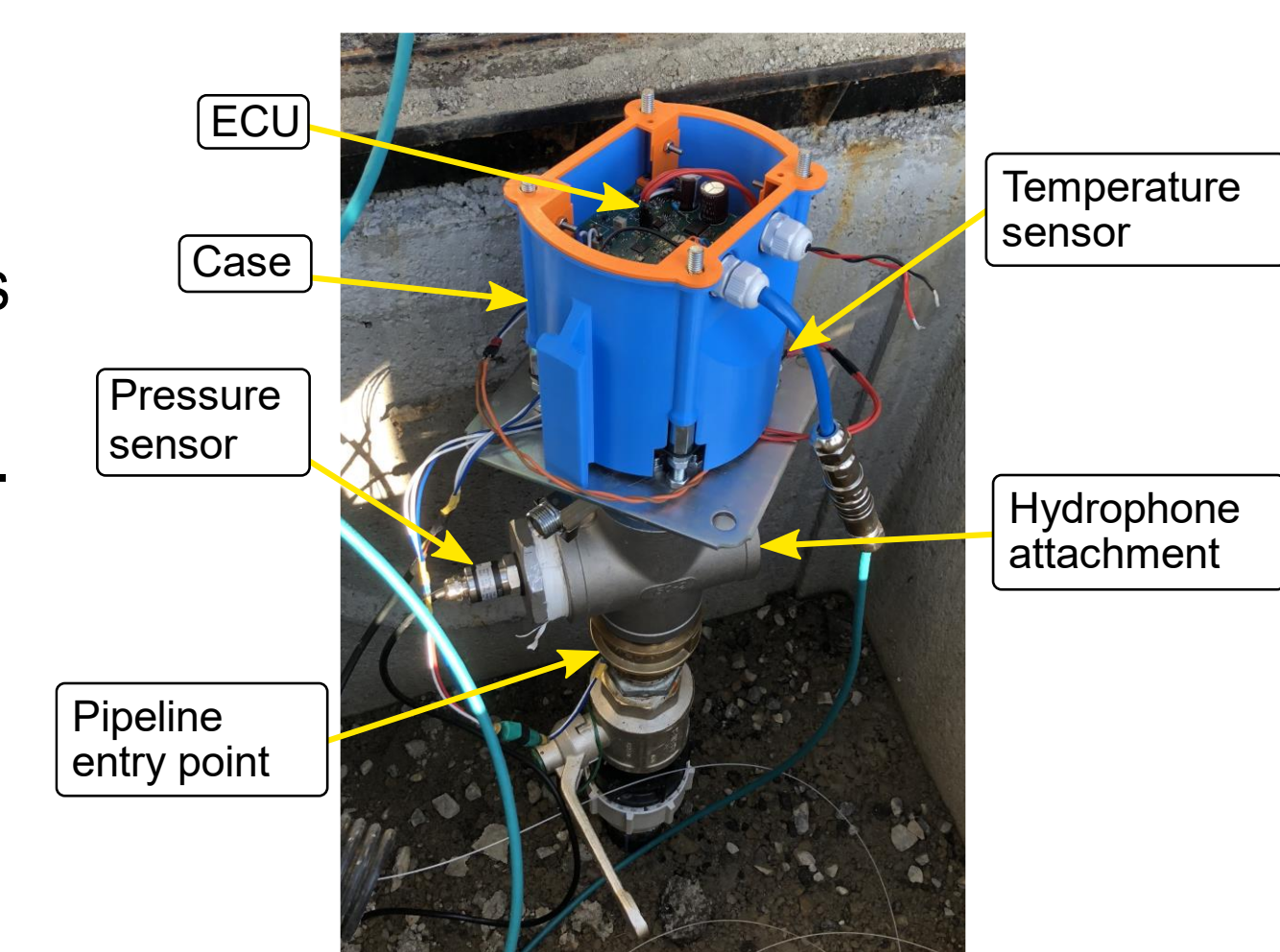
Adopted methodologies

1. The first step of the proposed system design methodology consists in the experimental channel characterization. The complex response of the channel is measured in a chosen set of frequencies. The channel is excited by a CW signal and its response is acquired.
2. Model building from experimental data and model validation. Synchronous acquisition at the ports of the channel allows modeling by means of black-box modeling techniques, such as vector fitting. The derived model is validated by comparison of simulation and measurement, with modulated signal.
3. System simulation and selection of suitable communication layer parameters. Different data modulation schemes can be tested. Also, a suitable set of communication parameters, such as the carrier frequency and the bitrate can be chosen.
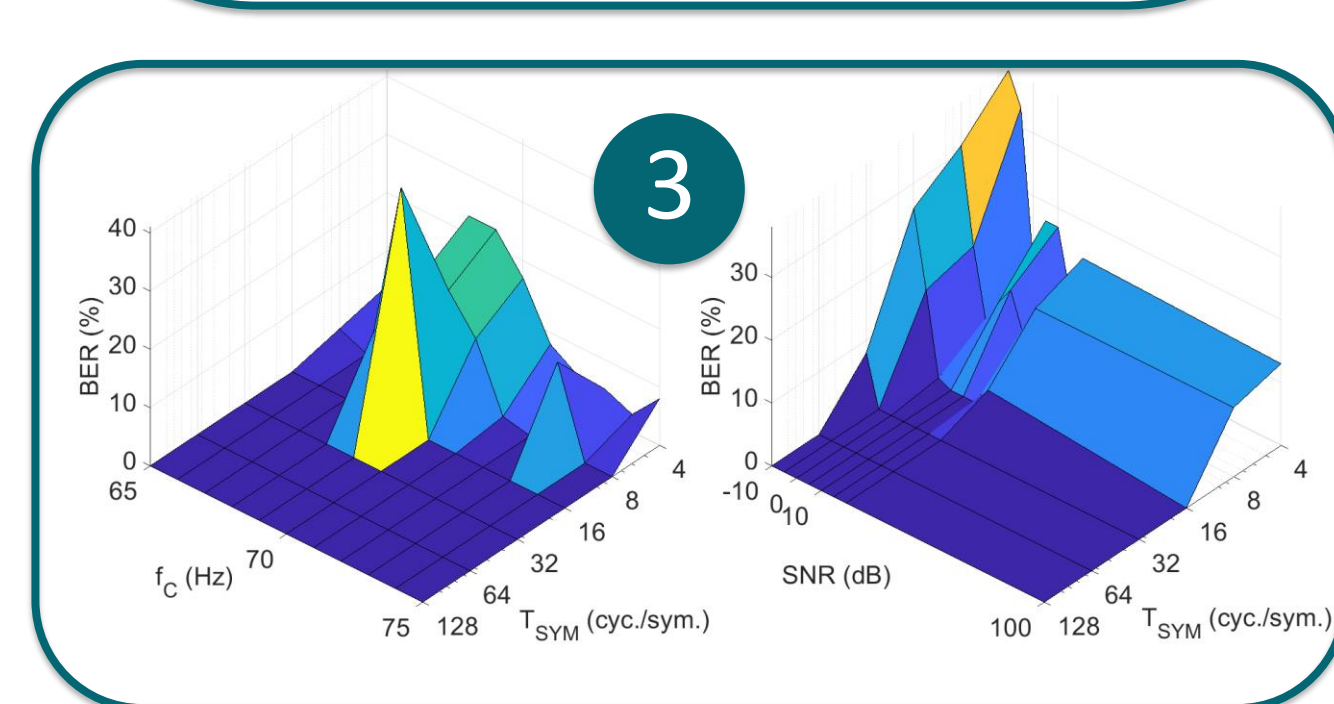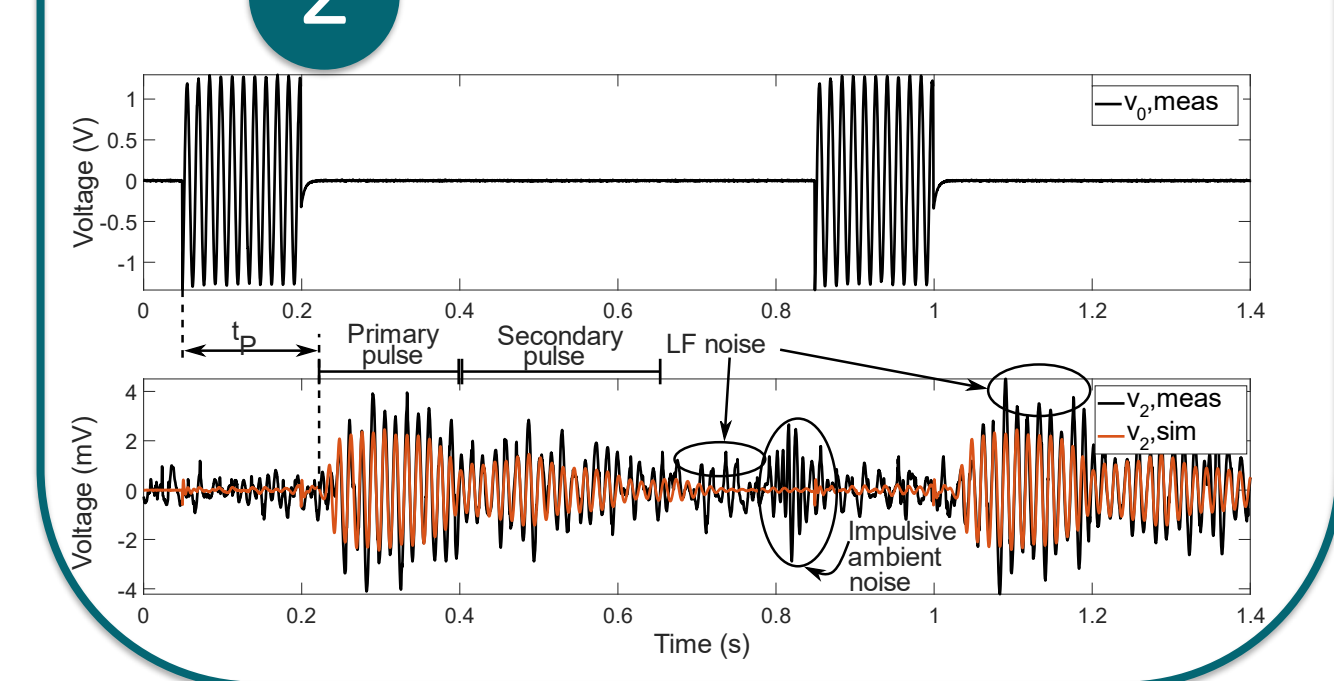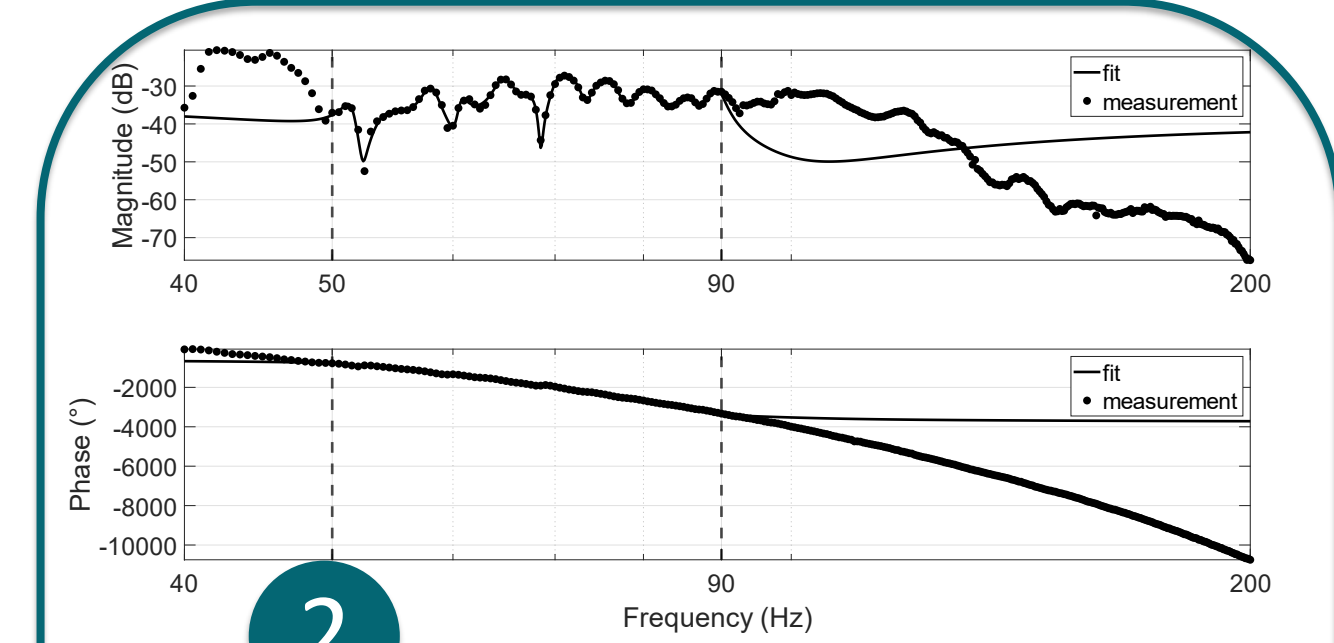
Novel contributions

- The proposed design methodology is based on the experimental characterization of the channel.
- Frequency-domain characterization allows to account for additional effects such as multi-path propagation, losses, reflections.
- A complete communication system has been designed and implemented in order to validate the proposed design flow.
- Two identical nodes attach directly to the pipeline and can operate as transmitter or receiver.
- For the considered channel, a real-world UWSN, the optimal carrier frequency was found to be 71 Hz.
- Bidirectional data communication was successfully achieved over a 75 m distance, using OOK modulation with a rate of 2.5 bps.

Future work

- The designed system can be optimized for different applications such as Structural Health Monitoring and Water Quality Monitoring by adding different sensing elements to the node.
- The system can be expanded in order to constitute a network of multiple nodes that exchange information amongst them through the water supply network of a city.
- More sophisticated data modulation schemes can be investigated, with the aim of increasing the data-rate of the link, which is limited by the small coherence bandwidth of the channel.

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Electrical, Electronics and Communications Engineering