Title: Compressed sensing for dynamic and RF waveforms

Abstract

Both radio frequency (RF) waveforms, as used in automotive radar systems, and other industrially important dynamic waveforms, such as electromagnetic compatibility, terahertz spectroscopy and primary waveform standards, generate significant amounts of data. Therefore, a compressed sensing approach needs to be developed to decrease the amount of data recorded and to speed up the measurement time. Proposals against this SRT should include both theoretical and practical compressed sensing measurements designed to enable a reduction in testing costs e.g. in demonstrating compliance with the Radio Equipment Directive (RED) 2014/53/EU.

Keywords

Compressed sensing, antenna characterisation, electro-optic sampling, terahertz spectroscopy, waveform metrology, uncertainty propagation, automotive radar, electromagnetic compatibility, RF

Background to the Metrological Challenges

Compressed sensing is a well-known approach for data reduction and has the potential to speed up traceable measurements for dynamic and RF waveforms, such as primary waveform standards and automotive radar systems. Compressed sensing also has the potential to contribute to standards such as IEC 62754 (Computation of Waveform Parameter Uncertainties) and to the electromagnetic compatibility (EMC) compliance testing process though the RED 2014/53/EU. However, to use compressed sensing in metrological applications, e.g. calibration, a validated theoretical framework needs to be developed to assess the fundamental limits and the uncertainty propagation arising from frequency-domain and/or time-domain compressed sensing measurements.

Automotive radar has been available for high-end vehicles for some time and currently the validation of the safety of autonomous vehicle systems is undertaken on the road. Cost effective simulations and electromagnetic models of vehicles are being explored as alternatives and would allow the evaluation of external parameters like fences, rainfall, etc., however, these methods require data from the characterisation of radar parameters to feed into them. Such radar parameters are related to the antenna radiation pattern and to the modulation signal and the characterisation needs to be performed once the antenna is integrated on a vehicle. To address this, novel compressive sensing radar systems with embedded intelligence that can perform direct detection and classification are needed. Such systems would avoid signal reconstruction and its computational burden, and would lead to cognitive radar that is capable of real time decision tailored to the environment.

Primary waveform standards are realised using laser-based ultra-short electrical pulse generation and electro-optic sampling (EOS). Such metrological methods are routinely used for high-bandwidth oscilloscope and photodiode calibration, and current EOS systems can recover signal components larger than 500 GHz with the maximum frequency resolution depending on the length of the measured time trace. State of the art EOS systems can capture time traces over an epoch of several nanoseconds with a time resolution of several 100 femtoseconds and a frequency spacing of several 100 MHz. These waveforms may easily contain 1 000 - 10 000 data points, and in order to obtain traces with a signal to noise ratio of 60 dB or better a measurement time of > 10 hours may be required. Currently, two different methods (i.e. synchronous or asynchronous sampling) exist to capture these time-domain waveforms. For example, asynchronous sampling enables longer sampling times, however it results in larger amounts of data and hence needs the development of reliable compressed sensing approaches.

Commercial terahertz time-domain spectroscopy systems can be used for a variety of tasks including basic research, quality and production control. The systems function by generating and detecting ultrashort voltage pulses in free space, with the spectrum of the measured pulses typically ranging from several 100 GHz to several THz. For such THz traces it is often sufficient to measure them over ~100 picoseconds, however, all reflections need to be accurately considered. At present, there is no commercial system available with both a high dynamic range and a fast measurement rate and thus there is usually a trade-off between high time-resolution and the upper frequency limit. Therefore, in order to support the use of commercial terahertz time-domain spectroscopy systems improved and validated compressed sensing methods are needed.

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The JRP shall focus on the traceable measurement and characterisation of compressed sensing measurements for dynamic and RF waveforms.

The specific objectives are

1. To develop a validated theoretical framework for frequency-domain and/or time-domain compressed sensing measurements. This should include an estimate of the fundamental limits and an assessment of the uncertainties, such that the compressed sensing measurements can be used for calibration purposes.
2. To develop improved and validated methods for using compressed sensing in automotive radar. This should include (i) signal acquisition, (ii) signal recovery, and (iii) under-sampled signals. The target improvement is a fourfold increase in the measurement rate.
3. To develop improved and reliable methods for using compressed sensing in primary waveform electro-optic sampling (EOS) systems, used for high-bandwidth oscilloscope and photodiode calibration, where time-traces are captured over an epoch of several nanoseconds (>10 000 data points). Such methods should be validated in terms of using synchronous or asynchronous sampling schemes and the target is to reduce the measurement time by an order of magnitude.
4. To develop improved and validated methods for using compressed sensing in commercial terahertz time-domain spectroscopy systems. The target is to reduce the measurement time by a factor of 5, whilst maintaining the dynamic range.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (accredited laboratories, instrument manufacturers), standards developing organisations (e.g. IEC TC 58, IEC TC 77 and standards bodies associated with Radio Equipment Directive (RED) 2014/53/EU such as ETSI) and end users (the communications and automotive industries).

Proposers shall give priority to work that meets documented industrial needs and include measures to support transfer into industry by cooperation and by standardisation. An active involvement of industrial stakeholders is expected in order to align the project with their needs – both through project steering boards and participation in the research activities.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.5 M€, and has defined an upper limit of 1.8 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 30 % of the total EU Contribution to the project.

Any industrial partners that will receive significant benefit from the results of the proposed project are expected to be unfunded partners.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the communications and automotive sectors.

You should detail other impacts of your proposed JRP as specified in the document "Guide 4: Writing Joint Research Projects (JRPs)"

You should also detail how your approach to realising the objectives will further the aim of EMPIR to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of up to 3 years duration.