Publishable JRP Summary Report for JRP SIB59 Q-WAVE
A Quantum Standard for sampled electrical Measurements

Quantum voltage standards based on the Josephson effect currently ensure the traceability to DC and low-frequency AC voltages. The aim of JRP SIB59 Q-WAVE is to provide direct and efficient traceability for precision devices generating or measuring arbitrary waves at frequencies up to 10 MHz. The demand for these significant improvements of high-precision voltage measurements is caused among other things by the rapid progress of semiconductor industry offering analogue-to-digital converters (ADC) and digital-to-analogue converters (DAC) with higher and higher sampling rates and accuracy.

Background

Digital metrology is now the method of choice in the instrumentation sector with sensing and measurement becoming increasingly dependent on analogue-to-digital conversion of sampled measurements. One example is dynamic measurement where sensor-electrical signals are digitised and then processed using digital algorithms to recover the measured parameters. Another is electrical power measurement in the presence of harmonics where signal-processing techniques are used to extract the measured power. The scale of digital metrology is already large and is expected to continue to increase. A key benefit is that once the electrical signal has been digitised, quantities such as the basic root mean square (RMS) value, peak value, crest factor and harmonic content can all be calculated from one data set whereas previously, each quantity required a special instrument feature or range and each of these ranges had to be separately calibrated.

Need for the project

Recent industrial R&D in precision integrated circuits and measurement equipment has brought about a step change in the sampling rates and potential accuracy available. However, the present methods for disseminating the SI volt for non-stationary or alternating waveforms (AC) are not keeping pace with requirements. They rely on the equivalence of direct and alternating current (DC and AC) via a thermal transfer device with the consequence that DC and AC are seen as separate quantities. Whilst DC measurements have enjoyed a quantum basis for many years, AC measurements have not. Furthermore, AC measurements are based on single frequency waveforms and the thermal transfer methods give no information on harmonic content or phase.

Scientific and technical objectives

The challenging aim of this project is to provide direct and efficient traceability to the SI volt for ADC and DAC operating in the frequency range from DC to 10 MHz. These procedures comprise the investigation and measurement of arbitrary waveform signals. Therefore, the project addresses the following scientific and technical objectives:

- To realise a measurement system based on the Josephson effect for the dynamic calibration of analogue-to-digital converters.
- To establish dissemination methods based on state of the art instrumentation and converters, as used in national metrology institutes and the next tier of users in the calibration and test sectors, including techniques for both repetitive and single shot waveforms.
- To improve digital signal processing techniques and evaluate their contribution to the measurement uncertainty.

Expected results and potential impact

The project will result in a new capability for the provision of traceability for sampled electrical measurements directly to the SI using the voltage references based on the Josephson effect. The dissemination methods

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developed in the project will have an impact on the specification, calibration and testing of the latest generation of analogue-to-digital and digital-to-analogue converters according to the published IEC and IEEE standards. The modeling of sampled electrical measurements and estimation of measurement uncertainty will enable proper traceability for converters used in research, test and calibration and the instrumentation sector. Converters recently released to the market have a performance at the limit of what can be measured with currently available test instrumentation. This project, through investment in the development of the SI for sampled electrical measurements, will unlock the door to direct traceability for this fast moving sector.

The project has made a good scientific progress in the first year. Suitable test arrays for operation by photodiodes have been developed and fabricated at PTB. Commercially available InGaAs photodiodes with a 20 GHz bandwidth have been selected. NPL, JV, and PTB have jointly developed and fabricated special high-frequency carriers for the photodiodes and mounted some photodiodes on the carriers for further investigations. INRIM and PTB have demonstrated preliminary measurements of cryocooler operation of Josephson arrays; first results were published and presented at the international conference EUCAS 2013. Josephson arrays of the first generation (single arrays) were also designed and fabricated at PTB, and some arrays were selected after characterisation for further investigations. JV has measured that the selected photodiode provide sufficient current to drive an array, when operating at room temperature. NPL has configured an opto-electronic system to deliver a GHz rate optical pulse stream imaged to a spot size approaching 10 µm in diameter. NPL also measured the temporal response of the photodiode, in under-filled mode, to GHz rate pulses.

Several sampling strategies to enable estimation of the frequency response of ADCs based on the step response were tested at MIKES and an optimal solution was found. At MIKES, a new semiconductor DAC based arbitrary waveform generator prototype has been designed and built, and it has shown excellent short-term stability below 1 kHz frequencies. This high stability allowed the optimisation of the usage of the AC Quantum Voltmeter at PTB. Three mercury-wetted step generators have been built and evaluated at MIKES and a first version of the filter for the Delta-Sigma Programmable Josephson Voltage Standard has been built and evaluated at SP. A list of synchronous and asynchronous sampling techniques was compiled by SIQ and VSL; it contains some yet unused but promising techniques amongst others. TUBITAK, CMI, SIQ and VSL have prepared a detailed list of identified error sources. Based on this list, further investigations have been started to identify those error sources that result in most dominant effects in generating and sampling systems. VSL and SIQ have compiled a list containing identified cable resonance phenomena and possible solutions.

RMG(TUBITAK) has been working for about 3 months at PTB, where a number of experiments have been performed to investigate uncertainties in the time domain and related effects in the frequency domain especially of the combined Josephson system consisting of programmable and pulse-driven voltage standards. REG(HBV) started on 1 November 2013. REG(HBV) is presently focused on the mounting of photodiodes and optical fibres in a robust way. This work will allow cooling of the photodiodes to 4 K without destroying the electrical connections or misaligning the laser. In addition to this, the Instituto Nacional de Tecnologia Industrial (INTI), Argentina, the National Measurement Institute of Australia (NMIA), and the Mendeleyev Institute for Metrology (VNIIM), Russia have all joined the JRP as collaborators.

The project will ensure that the work carried out within it is of relevance to the widest possible range of stakeholders and potential end-users. The project results will be shared through a combination of knowledge transfer, training and dissemination activities. Knowledge transfer includes activities like the set-up of a Stakeholder Group, publications of scientific papers, conference presentations, and a JRP website. In addition, practical trainings and demonstrations will be performed. Furthermore, new procedures will furthermore be disseminated via good practice guides.

In the first year, 5 presentations were given at international conferences and workshops. In addition, a paper on pulse-driven arrays operated in a cryocooler has been published. Several papers describing first achievements of the project have been submitted to the international Conference on Precision Electromagnetic Measurements (CPEM 2014) and will be presented at the conference in Rio de Janeiro, Brazil, 24 - 29 August 2014.

JRP start date and duration:	1 June 2013, 36 months
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