Metrology for optical and RF communication systems

Introduction

We are pleased to welcome you to the fourth and final newsletter for the “MORSE” Joint Research Project. The aim of this letter is to give a summary of the work that has been performed across this project over the last three years. More detail is available on all of the topics covered in this newsletter through our webpage

The underlying aim of this work was to support the ambitious challenges set out by the EU “2020 Digital Agenda for Europe”. This challenge has had an impact on all areas of the communication network. Clearly, as a group of National Measurement Institutes we cannot tackle all issues so we have focused on key areas that impact health and safety or where there is a pressing industrial need. The project is not limited to NMIs and we have collaborated with Universities Rennes 1 in France, TU Delft in the Netherlands and Chalmers University in Sweden to ensure that we also have cutting-edge and timely research contributions.

The terrestrial measurement work, such as MIMO Over-The-Air, provides essential underpinning for the current MET5G which, as the name suggests, is focused on 5G-communications, currently a hot topic. Optical communications has progressed from 100 Gb/s to over 400 Gb/s over the project lifetime and our work with state of the art facilities at Chalmers has greatly improved our understanding of the measurement issues that industry is currently facing.

It is my sincere hope that the outputs from this project will benefit European industry and that the consortium members are well-positioned to work with industry on future projects.

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(1) Terrestrial wireless communication

The first work-package addressed essential metrology issues for terrestrial wireless communications. These are grouped in three different topics.

Over the air testing of MIMO antenna

Characterisation of multiple-input and multiple output (MIMO) antennas, a system that uses multiple antennas and multiple RF paths to improve the channel capacity, is a challenging task. It is necessary to include both antenna and propagation characteristics at the same time when testing MIMO systems. At NPL, the two-stage method has been chosen to perform the characterisation in an efficient way using a real-time signal processing software-defined-radio (SDR) platform. With the two-stage method, the antenna angular sensitivity is first measured in terms of complex transmission coefficients and then this is combined with a channel-model to emulate a real-world environment. For MIMO system, the change is to represent the performance in terms of throughput, rather than an antenna characteristic.

Power metrology of Long Term Evolution (LTE)

Traceable measurements of mobile base-stations are important for protection against non-ionizing radiation. Within this project, a setup for measuring LTE signal has been realized and algorithms have been developed to determine the power of LTE reference signals (see LTE grid of Fig. 1) in a way that it is traceable to the International System of Units (SI). Experimental results have shown that the uncertainty of the LTE reference signal measurements is 0.05 dB (k=2). Moreover, the robustness of the power measurements has been demonstrated with a fading simulator.

This calibration capability is now available at METAS and the first certificates for calibration of LTE receivers have been issued. Reports and best practice guides are available for download from the project’s website.

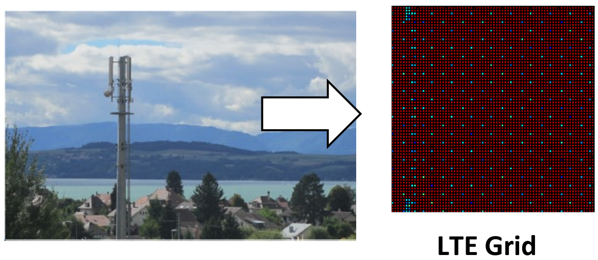
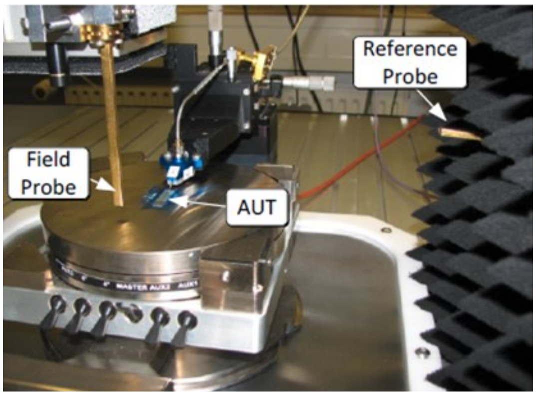


Fig. 1: The LTE grid of mobile base station can be reconstructed and the power of each resource element measured in a traceable way.

Metrology of adaptive antennas

This part of the project addressed two different approaches on adaptive beamforming antenna measurements. In Approach 1, we have developed and evaluated a millimetre-wave planar near-field system to characterise antennas operating in the 60 GHz and 94 GHz band. In addition, to reduce the measurement time for phased-array front-ends we have developed a quick method determine the compliance to specification aimed at reducing the measurement time of the phased array front-ends. The software can find the projected error bounds to the nominal pattern for a given fabrication error (i.e., mapped as a phase/delay mismatch). The software takes into account the maximum allowed phase-error for each array-element in order to determine a pass/fail pattern.

In Approach 2, an adaptive beamforming code has been developed using simultaneous perturbation stochastic approximation (SPSA) algorithm where the maximum cross correlation coefficient (MCCC) algorithm (that provides the optimum weight during each SPSA iteration so to enable beamforming) is implemented. A series of smart antenna radiated measurements have been



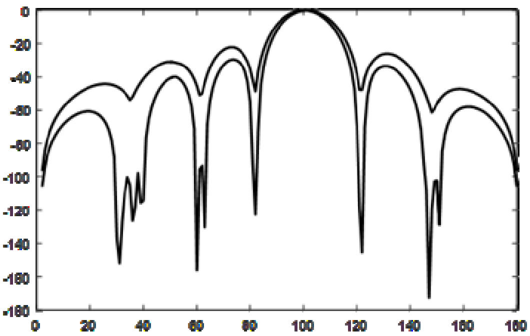


Fig. 2: (Upper) proposed near field measurement setup for system embedded antennas at mm-wave frequencies, (lower) bound for pass of a four element linear antenna array with maximum allowed error of ±5° at antenna

performed with the developed SPSA/MCCC adaptive beamforming algorithm. Fig. 3 shows some measurement results for a 12-element electronically steerable parasitic array radiator (ESPAR) smart antenna. Following beamforming functionality, the central shows the measured radiation pattern (Note: Red colour line for no interference and blue colour line for interference at Element 3 Direction) and the surrounding diagrams shows the histogram of the resulted weighted control vector over each parasitically coupling antenna element when interference exists.

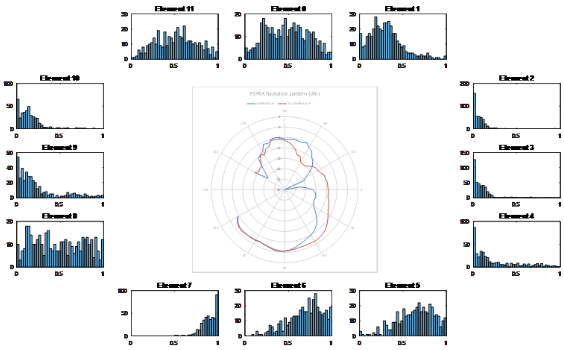


Fig. 3: Smart antenna adaptive beamforming functionality using the real-time FPGA software defined platform facilities.

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(2) Efficient Antenna Measurements

In the second work package we addressed metrology issues related to antenna characterization with a focus on the improvement of antenna measurement time using signal processing techniques, and the development of new electro-optic field sensors. A facility for the thermal study of antennas has also been developed.

Improving antenna measurement efficiency using Spherical Near-Field Ranges

The Spherical Near-Field antenna test range (SNF) is one of the most commonly employed systems used in antenna measurement, as it is both a versatile and accurate measurement system. However its performance is limited when a highly directive antenna is measured as it requires a fine sampling of the spatial near-field. In order to reduce the number of points required to measure a given antenna several methods have been tested within the project.

The subsampling methods developed and tested are mainly the iterative mode truncation and the kriging of data. Both were shown to be limited in their scope of application and to overcome the limitation highlighted in the research a compressive sensing approach has been developed and successfully tested [1]. The approach allows a quick and efficient testing of standard gain horn antennas and circular aperture in a spherical near-field range.

Improving antenna measurement accuracy using Compact Antenna Test Ranges

Testing antenna used in high-speed communication in the millimeter wavelength is also performed using Compact Antenna Test Range (CATR), which emulates far-field conditions in a quasi-optical approach.

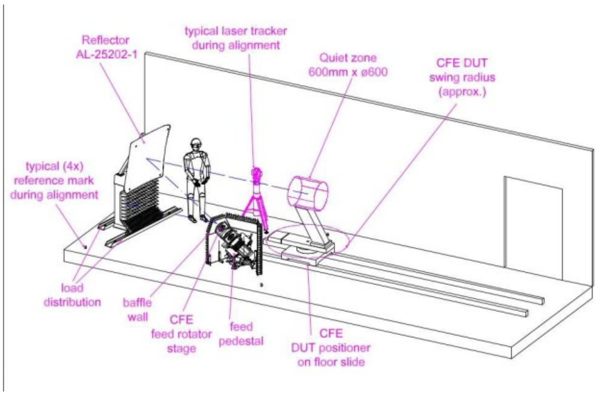

Fig. 4: Schematic view of the CATR installed at University of Rennes 1.

The performances of these types of systems are bounded to the quality of locally generated plain wave which is submitted to several distortion effects, due to the feeder radiation pattern, the stray radiation or the reflection from the chamber.

The qualification of the field in the test area (or quiet zone) is a key input to the determination of uncertainty. In this project it has been brought a step further in order to compensate for distortion effects on the antenna pattern measurement. A correction method was implemented from the existing research and tested with a propagation of the measurement uncertainty. Tests were performed based on the qualification of a newly installed CATR at the University of Rennes 1, France [2]. The Quiet Zone was probed using a high precision near-field scanner at 60 GHz, with a control of the position based on a theodolite

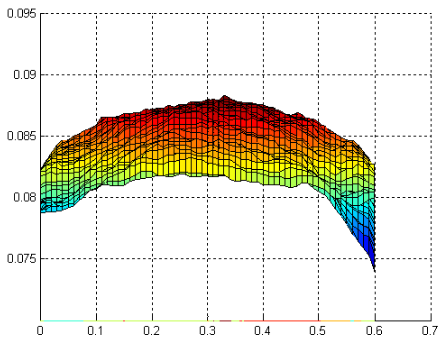

Fig. 5: measured QZ field (left) and calculated holography at +350mm (right).

measurement [3].

The measured data were used to calculate the local plane wave spectrum and apply a compensation algorithm on a reference antenna. In addition several processing methods have been developed to overcome some practical challenges regarding the sampling of plane wave field: (i) under sampling on a planar grid [4], (ii) interpolation of an irregular grid to map the measured antenna pattern to spectral components, and (iii) propagation of uncertainty using a specific implementation of the Monte-Carlo method to withstand the high number of data.

Developing a new field probe for low reflectivity sensing in the millimetre wavelength domain

The need for a compact electric field sensor with a low reflectivity has driven the development of an electro-optic based field sensor [5]. Within the project a small electro-optic field sensor has been used to perform the measurement of a standard gain horn at 90 GHz, see Fig. 6. The measured uncertainties were propagated to the far field radiated pattern and compared to that of the standard gain horn. The results are promising and show that an electro-optic based field sensor can be developed for the measurement of the electric field at GHz and THz frequencies.

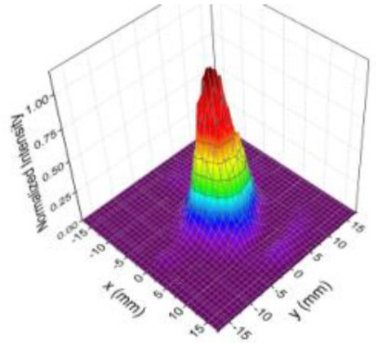

Fig. 6: Spatially resolved intensity map, 3 cm x 3 cm, 2.5 cm distance between horn and detector.

Contributing to antenna measurement reliability in the millimetric domain

The methods developed in the project have been tested using an antenna circulated among the partners, qualified both electrically and dimensionally. The antenna is an end-launch Tchebychev array tuned to achieve a perpendicular pointing direction of the beam at 60 GHz.

Developing low-cost antenna calibration method with a controlled temperature

The effect of outdoor conditions may affect the properties of an antenna and in some cases it is important to determine the actual performances under various conditions. A specific effort has been dedicated within the project to the development of a simple measurement method, that can be implemented in any particular measurement range and allowing the measurement of antenna gain over a temperature range of 0°C to 50°C. An enclosure made of low permittivity material was developed and tested on an aeronautical antenna at 950 MHz and it showed a good stability of the temperature over time [6].

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(3) Optical Communications

In this work-package we develop the supporting metrology and measurement capability for transmitters and receivers to achieve up to 1 Tbit/s in a single optical channel. The difficulty is that all the components and test instrumentation are stretching the current state-of-the-art.

Characterisation of photoreceiver systems

Photodetectors (PDs) constitute a stable interface between the optical and electronic devices. This property makes them an ideal reference point to identify failings of other components and develop new higher-frequency systems. Characterizing high-bandwidth photodiodes is not trivial as their frequency response may exceed the bandwidth of some traditional test-equipment.

We have recently developed laser-based vector network analyzer (VNA) [1]. With this instrumentation, we are able to accurately measure ultrashort voltage pulses and complex reflection coefficients on a coplanar waveguide (CPW). The latter allows us to obtain scattering parameters [1] with a dynamic range of more than 40 dB and a bandwidth of up to 500 GHz. We have used this facility to traceably characterize different PD designs.

We first employed the laser-based VNA to characterize a single high-speed PD with a nominal bandwidth of 100 GHz (*XPDV4120R, u2t/Finisar)* [2]. The amplitude and phase response in the frequency domain are shown in Fig 7.

Common-Mode Rejection-Ratio is an important parameter for the dual photodiodes and hybrid detectors used in coherent optical receivers. Using the laser-based

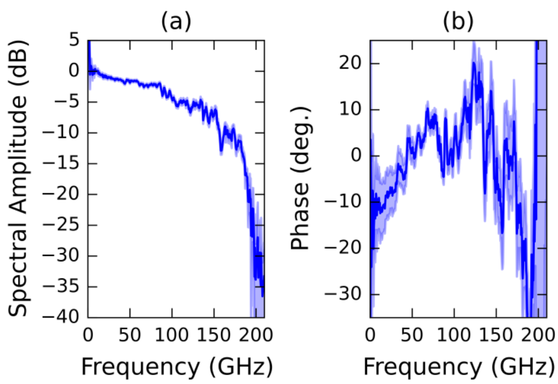

Fig. 7: Amplitude (a) and phase (b) spectrum of the single PD at its coaxial connector. The 95% confidence intervals are marked by the light semi-transparent color.

VNA we have also characterized a balanced high-speed PD with a nominal bandwidth of 43 GHz (*BPDV2150R, u2t/Finisar*) [2]. A CMRR of better than 30 dB at up to ~85 GHz was obtained. Similar results achieved with conventional equipment and might even be further improved with additional optimization.

Digital Real-Time Oscilloscope calibration for high-speed optical communications

Digital real-time oscilloscopes (RTDOs) are very versatile instruments that have the ability to capture single events is vital for many applications including optical and RF communications to support the increased data rates and modulation complexity and for nonlinear measurements. Our motivation is to provide traceable calibration and insights to avoid errors arising from the instrument architecture.

Measurements made at Chalmers University used two RTDO at 100 GSa/s and an Arbitrary Waveform Generator at 56 GSa/s (Variable). At 28 GBaud (DAC rate is 56 GBaud, with 2 points per cycle) the RTDO is cyclic (25 points correspond to 7 symbols). For certain PRBS sequences this allows the acquired data to be folded to give a detailed representation of the waveform.

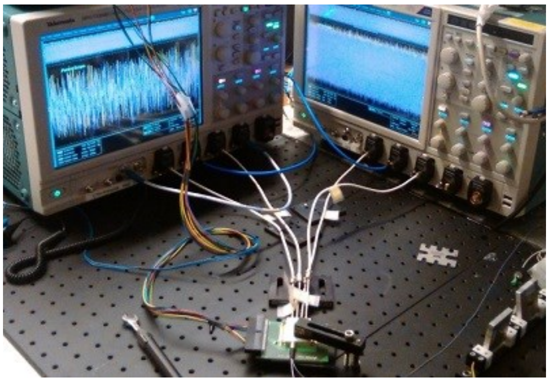

Fig 8: Optical receiver at Chalmers University Photonics Laboratory.

EVM relationship with Quadrature Imbalance

It becomes apparent that the Error vector magnitude (EVM) is more suitable for measurement of a digital signal quality for multidimensional modulation formats than the traditional bit error rate (BER). It is a figure of merit to characterise imperfections in the transmitter and receiver. First results show that there exists a clear link between the EVM and other quantities, such as the optical signal-to-noise ratios (OSNR) and bit-error ratio (BER) [3]. A number of numerical analyses have been performed on the data acquired during a short measurement campaign in the Photonics Laboratory (Chalmers University of technology, Sweden) in March 2015. Two different optical receivers were used in one test bench, namely a commercial Keysight optical modulation analyzer (OMA) and an in-house setup comprised of two high-speed real-time oscilloscopes. QPSK and 16-QAM pseudo-random 28 GBaud sequences with various artificial impairments have been considered. Collaborative work of researchers from CMI, NPL and Chalmers resulted in a conference paper [4]. The relationship between EVM and quadrature error is shown in Fig. 9.

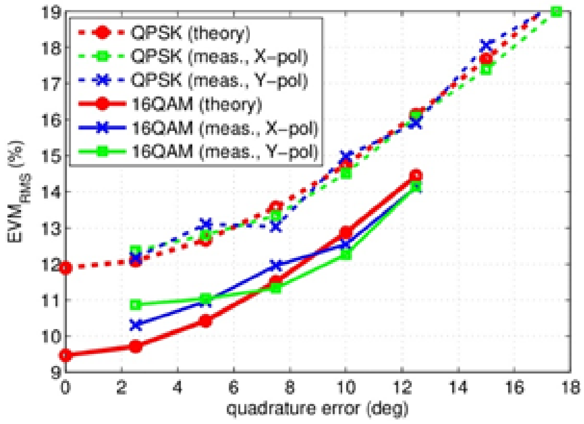

Fig. 9 EVM versus quadrature error.

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