Final Publishable JRP Summary for IND51 MORSE
Metrology for optical and RF communication systems

Overview

Society relies on reliable and efficient data communications; the sending of data through the air and point to point. However there are many interdependent technologies that are needed to ensure reliability and efficiency, ultimately providing a seamless experience for the user. This project developed a traceable measurement infrastructure and modelling techniques for mobile, satellite and optical communications.to minimise the time it takes to test and improve new devices, and therefore reduce time to market. Traceable measurement of signal and power output from devices ensures conformity to standards and safeguards end users. New measurement techniques for rapid characterisation of optical components allows industry to monitor device performance.

Need for the project

Traffic on telecommunication networks is currently growing by around 40 % each year, which will soon lead to a capacity crunch unless new technologies are introduced to maintain quality and prevent disruption to the networks on which the modern world relies. This project will support the work of the European Telecommunications Standards Institute (ETSI) and the International Electrotechnical Commission (IEC), and will result in new measurement procedures and services to support the introduction of new multiple antenna systems, satellite system testing and the next generation of optical communications equipment. It aims to help instrument, component and satellite manufacturers to develop and implement new systems, minimise test and measurement costs and reduce the time to market for new products and services.

Technologies such as reconfigurable and multiple antennas can increase the capacity and quality of wireless communications, however they also make testing more complex and time consuming. When building a satellite, antenna testing happens during a high-risk stage of development, therefore more complicated antennas could potentially disrupt the satellite companies' tight delivery schedules. State-of-the-art satellites can simultaneously create multiple transmission beams that cover different areas on the earth's surface and this increased complexity extends the test duration and makes it more complex. Reliable and robust methods to cut the test-time are needed to maintain the tight delivery-schedules. During the development of each next-generation system general-purpose test equipment is needed to determine the performance. Good metrology that extends the capability of this test-equipment will help the research, and improve service quality.

No single National Measurement Institute can address all of these challenges and so the project consortium includes several universities that have major test-bed facilities, as well as industry through component and test-equipment manufacturers. The project address the metrology of three areas of technology: terrestrial wireless, satellite antennas and optical communications.

Scientific and technical objectives

Wireless systems are difficult to characterise, but while RF measurements made over-the-air provide a realistic test for mobile communications it is difficult to ensure reproducible results at different facilities. Systems using several antennas cooperatively, known as Multiple-In-Multiple-Out (MIMO), are quantified by end-to-end data throughput, rather than traditional RF measurement. An understanding of the relationship between these methods is essential to link traditional measurements with the whole system behaviour. Also, it is important for operator safety to be able to measure the RF power in these systems. Directable antennas

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have great potential to increase battery life for the “Internet of Things” but these need low-cost and efficient test methods. Robust, traceable test methods will be developed in collaboration with test equipment manufacturers to reduce costs.

Objective 1: Terrestrial wireless communication

- Develop traceable RF power measurement for over-the-air (OTA) Multiple In-Multiple-Out (MIMO) systems.
- Develop and verify a sound methodology that qualifies the measurement and associated uncertainties for OTA testing of MIMO and adaptive antenna systems.
- Develop accurate, efficient and cost-effective metrological solutions for smart, adaptive reconfigurable and wearable antennas. Establish with quantified uncertainties the rapid measurement of pattern, gain and efficiency in anechoic environments, and total radiated power/gain diversity in multi-path environments.

The antenna systems are becoming more complicated so a key challenge is to determine whether modelling and measurement can be used together to speed up the design and prototyping process. This means understanding the relationship between reduced measurements and uncertainty. The antennas are normally tested in large facilities, and the project compared designs using conventional design techniques and then using the modelled and measured design techniques. In addition it developed methods to improve calibration efficiency of Compact Antenna Test Range (CATR) with a measurement probe that does not disturb the antennas. Avionics antennas operate in harsh environments with a range of temperatures. The project examined the behaviour of these antennas in different conditions to help improve future design.

Objective 2: Improved antenna measurement techniques using sub-Nyquist sampling and EM modelling

- Develop and validate a sound methodology for the testing of antennas over a range of temperatures.
- Develop and validate a sound methodology that links antenna modelling, sub-Nyquist spatial-sampling measurement-strategies with Electromagnetic-Modelling (EM) based interpolation to give a quantified uncertainty for the result. Validate the methods against traditional technique using both small and large antenna structures. Provide a rule-based approach that relates the measurement throughput improvement to the degradation of the uncertainty, allowing an optimum solution (WP2).
- Develop Optoelectronic Low-reflectivity Field-Sampling Probe for operation at 60 GHz.
- Improve the efficiency of Compact Antenna Test Range (CATR) by reducing the number of measurements needed to achieve the required uncertainty. The RF field variations in the measurement region “quiet zone” will be predicted and verified for 60 GHz operation using a scanning system and the OLFSP developed in this project.

Optical communications now use similar modulation schemes to mobile communications but at vastly higher data rates, typically 100 Gb/s per channel. Higher data rates require measurement systems that are able to respond faster with minimal introduction of errors into the measurement. There are two aims in this objective: firstly to characterise the differential photodiodes that form the core of the coherent optical communication receiver and secondly to understand the relationship between bit-error and optical Error Vector Magnitude as this identifies which components are in need of improvement.

A faster optical core network needs to carry more data per channel, so that there is enough network capacity in the future. New terminal and test equipment is being developed by industry to achieve up to 1 Tbits in a single channel, this needs to be characterised. The supporting metrology for the transmitters and receivers is important to ensure that they are able to respond fast and accurately.

Objective 3: Optical Communications

- Develop traceable characterisation of the vector frequency response of a single photodiode over the range of approximately 1 GHz to >100 GHz complete with uncertainty budget.
- Develop traceable techniques to characterise differential photodiode pairs that form the core of a coherent receiver system. The common-mode and differential-mode vector frequency responses and uncertainty budgets are required over the range <1 GHz to >50 GHz, complete with uncertainty budgets.

- Develop measurement and analysis techniques for high spectral-efficiency modulation strategies such as QAM, traceable to electrical-waveform standard primary standards, to underpin the optical test instrumentation and commercial portable secondary reference standards required for terabit coherent optical transport. The technique must provide uncertainties for key parametric measures, such as Error-Vector-Magnitude (EVM).

Results

Objective 1: Terrestrial wireless communication

The current and future RF mobile communication systems cooperatively use multiple antennas and advanced coding algorithms to improve the number of calls that can be handled and the transmission quality. This MIMO configuration achieves a higher throughput and “bit-efficiency” than would be possible using traditional transmit and receive antennas. There are several implications of these changes, for example the interaction between the transmitter, receiver and the surrounding environment means that RF radiation hazards, which depend on the proximity to the transmitter, may also depend on the direction.

This objective has been achieved, and validated and traceable “over the air” (OTA) measurements of RF power for MIMO communication systems have been developed. METAS is now offering a calibration service and methodology for the fourth generation (4G) systems known as LTE (long-term-evolution) based on the results of the project. Validated MIMO systems are now available within NPL and METAS and these are enabling future research projects with European industrial collaborators. These measurement facilities did not exist before this project.

Measurements made by direct connection and OTA have been compared, and although the work set out was achieved the results show that it is a complex area and more work is needed. This is an ongoing problem that has been a key subject in COST IC1004 (European Co-operation in Science and Technology); a European intergovernmental framework for cooperation in science and technology, COST has been contributing to closing the gap between science, policy makers and society. As part of this work NPL has been invited to join the OTA testing standards group of the US Cellular Telecommunications Industry Alliance (CTIA) by an industrial partner within this project. This has provided insights to support similar European activities.

Objective 2: Improved antenna measurement techniques using sub-Nyquist sampling and EM modelling

Reducing test-times is essential to providing sophisticated products at an affordable cost. This theme has been core to several parts of the project but is particularly acute in the satellite industry where the systems are of increasing complexity but the test-times are long. This work is also important for smart antennas that will support development of the Internet of Things (IoT) operating at the free to access industrial, scientific and medical (ISM) frequencies, at higher frequencies and for the 5G systems.

The computing power available to designers has increased greatly over the years and part of this work was to evaluate the use of models to support sparse measurements. Test-times can be drastically cut if the required number of measurements is reduced.

This objective found that modelling of simple horn-antenna designs worked well to about -50 dB, but the approach failed for more complex designs. Also, the modelling had to be sufficiently detailed to avoid interpolation errors. This work was carried out with input from an antenna company.

Across Europe there are several major antenna facilities serving industry and academia. The Compact Antenna Range at the Institut d'Électronique et de Télécommunications de Rennes (IETR), the near-field scanner at TU Delft or the extrapolation range at NPL are examples. These systems map the results using planar (x and y, like graph paper) or polar (angle, like longitude and latitude coordinates) coordinate systems. The project prepared validated software to map data between these two coordinate systems.

This objective was achieved, and improved antenna measurement techniques are available. This work has resulted in a measurement facility which is available at Rennes for R&D phase of antenna design, together with a best practice guide to inform researchers on how best to characterise antennas.

During flight, the external antennas on aircraft are subjected to a wide temperature variation. LNE and Dassault Aviation, have built and validated a test facility covering 0 °C to 50 °C that allows aircraft antennas to be tested over a realistic temperature range.

Objective 3: Optical Communications

Fibre-optic communication is the workhorse that shifts huge quantities of data across Europe. At its heart is a coherent optical detection system, this is a hybrid module that detects the modulated signal and separates the two key signal components for each polarisation. Within this module, a key element is pairs of matched photodiodes that separate the desired signals from the unwanted signals that are present on both photodiodes. The degree of rejection of these unwanted signals, the Common-Mode Rejection Ratio, is an important parameter that affects the system sensitivity.

PTB developed a measurement strategy based on Electro-Optic Sampling that operated over more than 50 dB dynamic range and covered frequencies up to 200 GHz, well in excess of the capability of commercial instrumentation. As this equipment is not readily available in industry, NPL developed test methods using commercial instrumentation for components and instruments in a comparable dynamic range. PTB also modified its Electro-Optic Sampling system to provide traceable calibration of single photodiodes from less than 2 GHz to more than 100 GHz. The company Finisar collaborated on this.

Bit-Error-Ratio (BER) and Error-Vector-Magnitude (EVM) are important metrics used in communication systems both to qualify the components and as diagnostic tools. Working with Chalmers University, CMI and NPL developed a link between these two parameters. Also, NPL developed test algorithms for Digital Real-Time Oscilloscopes (DRTO) that are used to acquire the optical waveforms in the testbed, and highlighted options that allow the waveform to be studied in greater detail to isolate component nonlinearities.

This objective was achieved, and the supporting metrology for the transmitters and receivers has been developed to ensure that they are able to respond fast and accurately. This is important for the testing and essential maintenance of these devices. It has also provided the communications research industry with valuable insights into key metrics used by the industry as well as a better understanding of how to use DRTOs to calibrate devices.

Actual and potential impact

Future telecommunications growth depends on the development and delivery of new technology. This project developed the underlying metrology for both research and deployment activities, and advanced the test facilities to enable industry and research to provide a competitive edge within Europe. In addition, it generated a first-hand appreciation within the NMIs and universities of the measurement issues. An advisory board comprising members from ESA, ETSI, Keysight, Finisar and NEC has ensured good industrial focus throughout the project.

This project developed traceable measurement infrastructure and modelling techniques for mobile, satellite and optical communications to minimise the time it takes to test and improve new devices, and therefore reduce time to market. Traceable measurement for signal and power output from devices ensures conformity to standards and safeguards end users. New measurement techniques for rapid characterisation of optical components allows industry to monitor device performance.

Dissemination of results

In addition to 19 conference presentations, seven full papers were published in leading journals. Two full-day workshops allowed the scientists to interact directly with industry. There were around 30 further publications, including best-practice guides, newsletters, workshop presentations and trade journals. This material is available electronically through the project website, the NPL website and the Euramet repository in addition to widely used sources such as Linked-In and personal ResearchGate accounts.

Impact on standards

The results of the project have been communicated to ITU, ETSI and IEEE standards bodies, so that the knowledge from this project can be used to advance the standards.

One of the partners played an active role with ITU in the group SG15 Networks, Technologies and Infrastructures for Transport, Access and Home which relates to several optical transport standards, such as Contribution on EVM calculation methods according to amendment G.698.2. This has an ongoing and worldwide impact.

PTB has contributed to IEC TC85 WG22 through the preparation of a technical annex for standard IEC62754 "Computation of Waveform Parameter Uncertainties". This has an ongoing and worldwide impact.

NPL has contributed to the ETSI mWT pre-standard in areas of use-cases for mm-wave in a future telecommunication system.

Early impact

This project developed facilities within European measurement institutes and universities that are now available for use by industry to train future engineers and to provide NMIs with a better insight into practical measurement issues in the field.

Key highlights from the project were:

- Development of traceable RF power for 4th generation mobile communications by METAS in Switzerland, ensuring that base-stations can be safely deployed. An early impact is direct take-up by industry and so far, four commercial calibrations have been carried out.
- METAS developed validated LTE algorithms to underpin this new calibration service
- LNE developed a system to measure antennas in different temperature environments. This is being used by the aviation industry
- Development of software correction algorithm enhanced compact-range antenna facility at the University Rennes 1, in France using technology developed in this project
- PTB Electro-Optic probe system that is almost invisible to the system being tested
- Development of state-of-the-art measurements for optical communications at PTB and at NPL
- Development of a 2x2 MIMO Software-Defined Radio facilities at NPL, now creating impact for 5G research in the UK.
- The relationship between two key parameters (Error Vector Magnitude and Bit Error Ratio), has been established by CMI and NPL. This will be included in submissions to the IEEE P1765 Group.
- An SME specialising in antenna hardware joined the project to evaluate and apply the undersampling algorithms in their production process.

Potential impact

There has been good collaboration between Finisar (formerly U^2T), PTB and NPL on the measurement of the high-bandwidth photodiodes used for optical communications, which has the potential to be used in new products.

There is potential for continued collaboration and direct uptake of Electro-Optic device calibration by PTB.

The knowledge-base and best-practice from this project is available for use by industry, and supports the future development of faster optical communication systems for the core network.

A project partner has contributed to the ETSI mWT pre-standard in areas of use-cases for mm-wave in a future telecommunication system.

A serendipitous impact that occurred during the development of the LTE RF power service was the invention of a new modulation scheme to increase the transmission bitrate with a given SNR.

List of publications

1. I. Fatadin, D. Ives, S. J. Savory, "Carrier-Phase Estimation for 16-QAM Optical Coherent Systems Using QPSK Partitioning With Barycenter Approximation ," IEEE J. Lightwave Tech., vol. 32, No 13 pp. 2420 – 2427, 1st July, 2014.
2. Humphreys, D.A.; Hudlicka, M.; Fatadin, I., "Calibration of wideband digital real-time oscilloscopes," Conference on Precision Electromagnetic Measurements (CPEM 2014), 2014, vol., no., pp.698 - 699, 24-29 Aug. 2014.
3. Yuqiang Deng; Fuser, H.; Bieler, M., "Absolute intensity measurement of a 100 GHz source using laser-based electro-optic sampling," Conference on Precision Electromagnetic Measurements (CPEM 2014), 2014 , pp.748,749, 24-29 Aug. 2014.
4. L. Le Coq, B. Fuchs, T. Kozan, T. Andersson and S. Burgos, "Compact antenna test range implementation in IETR millimetre wave antenna test facility," 2014 IEEE Conference on Antenna Measurements & Applications (CAMA), Antibes Juan-les-Pins, pp. 1-4., Nov. 2014.
5. L. Le Coq and B. Fuchs, "Design and manufacturing of a high accuracy planar scanner for millimeter wave applications," 2014 IEEE Conference on Antenna Measurements & Applications (CAMA), Antibes Juan-les-Pins, pp. 1-4., Nov. 2014.
6. M. Hudlicka, I. Fatadin, D. Humphreys, “Analysis of high-speed optical data transmission using advanced modulation formats,” (in Czech, original title: Analýza vysokorychlostních datových přenosů s vícestavovými optickými modulačními formáty), 41st meeting of the Czech electrotechnical society, subgroup Microwave technique, 19th Nov. 2014, Prague, Czech Republic, pp. 1-4
7. L. Le Coq, B. Fuchs, T. Kozan, S. Burgos and P. O. Iversen, "IETR millimeter-wave Compact Antenna Test Range implementation and validation," 2015 9th European Conference on Antennas and Propagation (EuCAP), Lisbon, 12-17 April 2015, pp. 1-5.
8. T. H. Loh and W. Qi, "A comparison of MIMO antenna efficiency measurements performed in Anechoic Chamber and Reverberation Chamber," 85th Microwave Measurement Conference (ARFTG), Phoenix, AZ, 2015, pp. 1-4, May 2015.
9. D. A. Humphreys, Martin Hudlička and Irshaad Fatadin, “Calibration of Wideband Digital Real-Time Oscilloscopes,” IEEE Trans. Instrumen. and Meas., vol. 64 no. 6, pp. 1716 – 1725, June 2015.
10. Y. Deng, H. Fuser, and M. Bieler, “Absolute Intensity Measurements of CW GHz and THz Radiation Using Electro-Optic Sampling,” IEEE Transactions on Instrumen. and Meas., vol. 64, no. 6, pp. 1734–1740, June 2015.
11. S. Dash, F. Pythoud, P. Leuchtmann and J. Leuthold, "Traceable Power Measurement of LTE Signals," 17th International Congress of Metrology, Paris France, 12005, 21 - 24 Sept. 2015.
12. Yannick Le Sage, Michael Charles, Jean-Marie Lerat, "Measurement of antenna parameters under a controlled temperature Mesure des paramètres d’une antenne sous une température controllée," 17th International Congress of Metrology, 12010, 21 - 24 Sept. 2015.
13. M. Bieler, H. Fuser, and K. Pierz, “Time-Domain Optoelectronic Vector Network Analysis on Coplanar Waveguides,” IEEE Trans. on Microwave Theory & Techniques, vol. 63, no. 11, pp. 3775–3784, 2015.
14. S. Dash, F. Pythoud, M. Hudlicka, “RF Power Metrology in LTE Systems (original title in Czech: Měření výkonové úrovně v LTE systémech),” 43rd meeting of the Czech Electrotechnical Society, subgroup Microwave technique, Prague, 18th Nov. 2015, pp. 1-4, ISBN 978-80-02-02627-3
15. Visweswaran, A.; de Martino, C.; Sirignano, E.; Spirito, M., "An IQ-steering technique for amplitude and phase control of mm-wave signals," 86th ARFTG Microwave Measurement Conference, vol., no., pp.1-4, 3-4 Dec. 2015.
16. M. Hudlička, C. Lundström, D. A. Humphreys and I. Fatadin, "BER estimation from EVM for QPSK and 16-QAM coherent optical systems," 2016 IEEE 6th International Conference on Photonics (ICP), Kuching, 14 - 16 Mar 2016, pp. 1-3.

17. S. S. Dash, F. Pythoud, B. Baeuerle, A. Josten, P. Leuchtmann, D. Hillerkuss, and J. Leuthold, "Approaching the Shannon Limit Through Constellation Modulation," in Optical Fiber Communication Conference, OSA Technical Digest (online) (Optical Society of America, 2016), paper Th2A.46, March 2016.
18. T. H. Loh, C. Li, H. Wang and F. Qin, "A software-defined-radio platform for multiple-input-multiple-output over-the-air measurement," 2016 10th European Conference on Antennas and Propagation (EuCAP), Davos, pp. 1-4. 10-15 April 2016.
19. B. Fuchs, L. Le Coq and M.D. Migliore, "Fast Antenna Array Diagnosis from a Small Number of Far-Field Measurements," IEEE Transactions on Antennas and Propagation, vol. 64, no. 6, pp. 2227-2235, June 2016.

Newsletters, articles and downloadable reports from http://www.emrp-ind51-morse.org unless stated otherwise. These publications may require stakeholder registration.

1. P. Miller, Z. Tian, "Near-Field to Far-Field Transform Strategies," REPORT, Oct 2013.
2. P. Miller, B. Fuchs, "Antenna pattern measurement:- undersampling strategies," REPORT, Nov. 2013.
3. D. A. Humphreys, "Overview of EMRP IND16 "Ultrafast" and IND51 "MORSE" Joint Research Projects," IC1004 TD(14)09013, 5-7 Feb. 2014. Available to COST IC1004 members and IND51 Stakeholders.
4. Newsletter May 2014, Articles on LTE power measurements, Characterization of antennas and Characterization of ultrafast photodiodes.
5. S. S. Dash, "Preliminary study to define concept for power metrology in LTE systems," REPORT, 5th September 2014.
6. T. H. Loh and W. Qi, "MIMO OTA Measurement – an overview," REPORT, Oct. 2014.
7. Newsletter April 2015, Articles on Characterization of MIMO antenna, available reports,
8. Newsletter November 2015, Articles on Metrology for High-Speed Optical QPSK and 16-QAM Coherent Transmission at Chalmers University, Sweden. Near Field Setup for Millimetre-Wave System Embedded Antennas. Antenna reference for signal processing assessment
9. S. S. Dash, "Best practice guide: guidelines for the evaluation of uncertainties when measuring LTE signals with diode based sensors," 11 Nov 2015.
10. D. A. Humphreys, "Working with the Telecommunications sector," Presentation, MSU Impact meeting, Teddington, UK, 11 Nov. 2015,
11. S. S. Dash, "Best Practice Guide: Sensitivity of LTE R0 measurement with respect to multipath propagation," 27 Nov. 2015
12. S. S. Dash and F. Pythoud, "A reference setup to calibrate LTE Code selective field probes," METinfo, Vol. 23 No. 1, pp. 20 - 24, 2016. available at http://www.metas.ch/dam/data/metas/Dokumentation/METASPublikationen/metinfo/METinfo2016/A%20reference%20setup%20to%20calibrate.pdf
13. P. Miller, "Best Practise Guide: - Improving the Acquisition Time in Spherical Near-Field Measurements," May 2016.
14. T. H. Loh, D. Cheadle, "Best Practice Guide: Efficient measurement of Smart Antennas," June 2016.
15. D. A. Humphreys, "Best Practice Guide: Measurement of dual photodiode common-mode rejection ratio," June 2016
16. M. Bieler, "Best Practice Guide: Guidelines for the full-waveform characterisation of photodiodes using an electro-optic test bench," June 2016
17. L. Le Coq, B. Fuchs, "Best Practice Guide: Guidelines for the alignment of a scanner inside a compact range for field measurements of Quiet Zone field," 3 June 2016,

18. D. A. Humphreys, M. Bieler, P. Struszewski, "Characterization of differential photodiodes," Poster, JRP - MORSE Final one-day workshop NPL, Teddington, 9 June 2016:
19. D. A. Humphreys, C. Lundström , Henrik Eliasson and Irshaad Fatadin, "Digital Real-Time Oscilloscope calibration for high-speed optical communications," Poster, JRP - MORSE Final one-day workshop NPL, Teddington, 9 June 2016
20. J.-M. Lerat, "Signal processing techniques for antenna measurement improvement," Presentation, JRP - MORSE Final one-day workshop NPL, Teddington, 9th June 2016
21. T. H. Loh, C. Li and D. Humphreys, "Development of MIMO OTA metrology at NPL," Presentation, JRP - MORSE Final one-day workshop NPL, Teddington, 9th June 2016
22. J.-M. Lerat, M. Charles, "Signal processing techniques for compensation of CATR effect on antenna measurement," Presentation, JRP - MORSE Final one-day workshop NPL, Teddington, 9th June 2016
23. M. Hudlička, C. Lundström, D. A. Humphreys, I. Fatadin, "Characterization of high-speed optical transmitters using error vector magnitude," Presentation, JRP - MORSE Final one-day workshop NPL, Teddington, 9th June 2016:
24. M. Bieler and P. Struszewski,"Characterization of fast photodiodes using a laser based vector network analyzer," Presentation, JRP - MORSE Final one-day workshop NPL, Teddington, 9th June 2016
25. M. Spirito, "Measurement of system embedded antennas," Presentation, JRP - MORSE Final one-day workshop NPL, Teddington, 9th June 2016
26. Y. Deng, H. Füser and M. Bieler, "Near-field antenna measurements using electro-optic probes," Poster, JRP - MORSE Final one-day workshop NPL, Teddington, 9th June 2016

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