EMPIR Support for Impact Project:

17SIP08 NeWITT

"New Waveguide Interfaces for Terahertz Technologies"

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Report: "Documented feedback from the end-users who attended the workshop on rectangular waveguide interfaces for connections above 100 GHz"

Nick Ridler (NPL), Karsten Kuhlmann (PTB), James Watts (Flann Microwave Ltd)

NeWITT Project Partners

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Executive Summary:

This workshop took place during European Microwave Week (EuMW), in Paris, France, on 4th October 2019. EuMW is Europe's premier microwave, RF, wireless and radar event. It is held annually at various major cities around Europe. EuMW runs for six days and attracts more than 5,000 attendees. It consists of three co-located conferences, 150 technical sessions and workshops, and a trade show featuring around 350 exhibitors.

The organisers of the workshop were Nick Ridler (NPL, UK) and Karsten Kuhlmann (PTB, Germany). The workshop title was "Measurements and Waveguides for Millimetre-wave and Terahertz Frequencies" and came under the EuMW general topic area of "Millimetre-wave and terahertz measurements and technology". The workshop covered a full day (on Friday) during the EuMW schedule. Each of the 10 talks in the workshop lasted for 45 minutes. The last talk was essentially a round table discussion during which end-users were able to give feedback on the topics discussed during the workshop.

The justification for the workshop was that, in recent years, there has been many new technological developments that require the use of electromagnetic signals at millimetre-wave and terahertz frequencies. Such applications have included communications technologies (5G, IoT, etc), the automotive industry (Connected and Autonomous Vehicles – CAVs), security scanners and imagers, space-borne radiometers, medical diagnostics, etc. This has led to the need for new hardware to realise the systems necessary for these applications. A major building block for this hardware is waveguide, due to its inherent low loss, usability and technology readiness at these frequencies. New waveguide sizes and interfaces have recently been introduced specifically to enable the efficient exploitation of these frequencies – particularly, frequencies above 100 GHz. This, in turn, has led to the need for new measurement techniques to enable reliable and accurate measurements to be available at these frequencies.

The workshop reviewed the latest developments that are taking place for this waveguide technology and focussed on both the new waveguide sizes and interfaces that have been introduced to enable the efficient and reliable use of these frequencies by end-users. This includes activities by both IEEE and IEC standardisation bodies. The workshop also presented the current state of the art of the measurements – both using waveguide and quasi-optical techniques – that are available at millimetre-wave through to terahertz frequencies (i.e. from 30 GHz to at least 1.5 THz).

This Report describes the talks given at the workshop and the related feedback from the end-users.

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Talk No 1 – Keynote Talk

Title: The critical role for millimetre-wave and terahertz measurements

Presenter: James Watts (Flann Microwave Ltd, UK)

Summary: Millimetre-wave and terahertz frequencies have seen limited use for forty years or more in niche applications. Systems working at these frequencies offer real potential benefits to society and are likely to be very important over the next 10 years. Some of these potential uses were described along with the technical challenges they present. The demands in manufacturing millimetre-wave and terahertz components and systems are quite different to working at lower frequencies and these manufacturing and measurement issues were highlighted. Historically, much of the work above 110 GHz has been in qualitative academic research or by small teams, so measurement standardisation has been less important, but the commercial potential of these frequencies now makes it a real priority.

Feedback: The need for continued work to improve standardisation above 110 GHz was discussed, as well as the importance of collaboration to ensure that standards are fully adopted.

Talk No 2

Title: The new IEEE standards for waveguides above 110 GHz: a review

Presenter: Nick Ridler (NPL, UK)

Summary: This presentation provided a review of the three new IEEE standards (IEEE Std 1785.1-2012, IEEE Std 1785.2-2016, IEEE Std 1785.3-2016) that have recently been published that relate to the use of rectangular metallic waveguides at frequencies above 110 GHz (i.e. to at least 3 THz).

Feedback: Each of the standards was examined in detail: Part 1 describes the new waveguide sizes and frequency ranges; Part 2 describes the new flange designs; Part 3 describes the uncertainty specifications for measurements made at these frequencies.

Talk No 3

Title: The European NeWITT project: Best Practice Guide and software tool for waveguide connections at frequencies above 100 GHz

Presenter: Karsten Kuhlmann (PTB, Germany)

Summary: The European NeWITT project ("New Waveguide Interfaces for Terahertz Technologies") promotes the adoption and use of the new IEEE 1785 series of standards by establishing a GPG (Good Practice Guide), describing how to make reliable waveguide connections at frequencies above 100 GHz, and by creating open source software for calculating the electrical performance of connected waveguides.

Feedback: The content of the GPG and the software capabilities was described in detail, supported by both theoretical and measurement data. This will facilitate the adoption of more reliable methods and equipment, and, enable faster and increasingly efficient products.

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Talk No 4

Title: Impact of dimensional imperfections on waveguide measurements in the millimetre-wave and terahertz range

Presenter: Xiaobang Shang (NPL, UK)

Summary: Waveguide components are extensively utilised at millimetre-wave and terahertz frequencies due to their low loss characteristics. A Vector Network Analyser (VNA) is usually employed to characterise S-parameter responses of these devices, subject to a waveguide calibration. Among all the candidate calibration techniques, TRL (Thru-Reflect-Line) is considered as very attractive for precise metrology applications. The guided-wavelength reduces with the rising frequencies, making the typical ¼-wave Line standard too thin to fabricate/use at these high frequencies. ¾-wave Line standards have been proposed to address this problem and have been utilised at NPL as primary national standards. However, these ¾-wave Line standards and the waveguide sections used as the measuring instrument test ports have dimensional imperfections which have significant impact on electrical performance.

Feedback: This presentation addressed aspects of quantifying the impact of these dimensional imperfections on waveguide measurements in some selected waveguide bands at these frequencies.

Talk No 5

Title: Design considerations for an improved interface for millimeter waveguides

Presenter: Hans-Ulrich Nickel (Spinner GmbH, Germany)

Summary: Over the years, different waveguide interfaces for millimetre-waves have been favoured. The basic four pin M3299/67 design has been in widespread use for decades whereas other designs, such as the Philips claw-flange, have been almost forgotten. The M3299/67 design was recently refined and standardised in IEEE 1785.2 and IEC 60154-2. Since all interface concepts have certain advantages and disadvantages, and a fully satisfying and appropriate solution for the frequency range of up to several hundred GHz is not known yet, a fresh look on this topic was given in this talk.

Feedback: Starting with the existing designs, a set of important features was given, which are currently not fulfilled in total by any of the existing standards and which could be used to derive requirements for the specification of a new waveguide interface. The new interface should be suitable for millimetre- and submillimetre-waves and compatible with current production techniques.

Talk No 6

Title: Terahertz Waveguide Vector Network Analyser Measurement - IEC standardization and Traceability Research in Japan

Presenter: Masahiro Horibe (NMIJ, Japan)

Summary: High precision and good repeatability in THz Vector Network Analyser (VNA) measurement has been established by optimisation of measurement set up and precision claw-type

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waveguide flange which has been standardised, in IEC 60154-2 type-F, by IEC TC46/SC46F. The claw-type flange produces high repeatability, i.e. less than -40 dB at 1 THz for S11 of a line standard. Other contributors of measurement precision, i.e. connection torque, air floating stage for frequency extension modules and cable type connected to LO (Local Oscillator) signal port, etc, are optimised.

Feedback: As a result of this work, small measurement uncertainty has been established for VNA measurements up to 1.1 THz.

Talk No 7

Title: Network Analyser Instrumentation and Advanced Measurements at Millimetre-wave and Terahertz Frequencies

Presenter: Jon Martens (Anritsu, USA)

Summary: While most Vector Network Analyser (VNA) measurements at the higher millimetre-wave frequencies are straightforward extensions of their lower frequency counterparts, certain sensitivities and uncertainty contributors in the instrumentation may be of heightened importance. In linear S-parameter measurements, the available dynamic range can be more sensitive to local oscillator and source signal purity – these dependencies were examined. More advanced VNA measurements at these frequencies, including those requiring true differential drive, nonlinear analysis and noise figure are somewhat more challenging.

Feedback: The elevated impact of coherence limits, system linearity and noise contributors (including image issues) in these measurements were also discussed.

Talk No 8

Title: Recent Developments in Waveguide Extender Heads and Interfaces to Enable Vector Network Analysis to 1.5 THz

Presenter: Jeffrey Hesler (VDI, USA)

Summary: There have been significant challenges in extending Vector Network Analysers (VNAs) to 1.5 THz, including the achievement of high transceiver sensitivity and repeatable mechanical waveguide interfaces. Recent developments in the multiplier chains and receivers have enabled significant improvements in test port power and dynamic range. For example, in the WM-380 band (500-750 GHz) the test port power has been improved to -16 dBm typical, and the dynamic range is now approaching 120 dB (in 10 Hz IF bandwidth).

Feedback: Waveguide based VNA measurements of THz components and interfaces at WM-164 (1.1 - 1.5 THz) were presented and discussed.

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Talk No 9

Title: Quasi-optical measurements in the millimetre-wave and terahertz range

Presenter: Thomas Kleine-Ostmann (PTB, Germany)

Summary: Measurement set-ups for quasi-optical measurements in the millimetre-wave and terahertz range were presented. This included discussions on the RF sources, the antennas, the mirrors, and the lenses as well as ways to calibrate the set-ups.

Feedback: Different calibration methods were shown and compared, as well as results from typical applications like e.g. material measurements, including typical measurement uncertainties.

Talk No 10

Title: Panel Discussion Session

Presenters: All workshop speakers

Summary: The workshop concluded with a discussion session that reviewed the key issues that have been identified in each of the talks given in the workshop.

Feedback: Particular emphasis was expressed concerning future needs (for hardware, software, etc) to enable reliable measurements to be made at these frequencies. This included the information given in the IEEE standards relating to waveguide interfaces for these frequencies and the related 'NeWITT' European project.

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