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## Publishable Summary for 17SIP08 NeWITT New Waveguide Interfaces for Terahertz Technologies

### Overview

Several European industrial sectors require precise and reproducible measurements of high frequency signals which cannot be reproduced without standardised interfaces. Prominent uses are modern multi-sensor applications, including autonomous driving and smart cities, as well as more traditional areas such as security, radio astronomy, medical/healthcare technologies and remote sensing of climate change. Even next generation communication standard 5G uses frequencies up to 90 GHz, subsequent generations will reach even higher frequencies. Thus, current and future applications like Internet of Things (IoT) or Machine to Machine (M2M) communication, which rely on available infrastructures, will operate at frequencies above 100 GHz. The aim of this project was to maximise the uptake, by the end-user community, of a key output from the EMRP project SIB62 HFCircuits – in particular, the new IEEE 1785 series of standards (“Standard for Rectangular Metallic Waveguides and Their Interfaces for Frequencies of 110 GHz and Above – Parts 1, 2 and 3”). Therefore, this project prepared a Good Practice Guide (GPG) and an open source software to promote the adoption and use of the new IEEE 1785 series of standards by the millimetre-wave and terahertz end-user communities. Additionally, feedback on the IEEE 1785 standards was sent to IEEE so that it can be taken into account in the revision of IEEE Std 1785.1-2012, which is scheduled for 2022.

### Need

In Europe, typical applications of systems using frequencies of 100 GHz and above include autonomous vehicles and smart cities, as well as security, radio astronomy, medical/healthcare technologies and climate change monitoring. These applications represent both existing and emerging technologies and markets. It is important for the European industry that products and measurement results follow international standards that are compatible at the international level. This is especially important where signal level restrictions must be met, e.g. a signal at a certain frequency must be below a certain value to not interfere with other signals or to not endanger human health. To achieve all the above, a standardised measurement interface is a key component. Until recently, users have been advised to purchase their equipment from a single manufacturer, thus ensuring compatibility of the waveguide sizes and connections. However, this leads to problems if waveguide components are replaced, interchanged, or resold.

Before 2008 (the year in which the IEEE P1785 Working Group was established), measurement systems for frequencies up to 500 GHz were already commercially available. Since that time, the frequency region in which research and development is carried out has been extended to 1.5 THz and beyond. The end-users of millimetre-wave and terahertz systems require reliable and standardised waveguide sizes and interfaces. The dimensions of the waveguide apertures must be well defined as well as the frequency limits, and the interfaces must be compatible with older designs while also providing the necessary precision for millimetre-wave and terahertz electrical signals. The IEEE 1785 series of standards address all these issues, but many end-users were not aware of this or simply continued to use old methods (with their inherent old problems). To cope with extremely high frequencies (up to 3.3 THz), the interface designs are somewhat more complex than in the past, which also discouraged some end-users from adapting existing systems. These issues were addressed with user information (e.g. GPG), software tools and knowledge dissemination activities (e.g. European workshop).

### Objectives

Precise and reproducible measurements of high frequency signals require standardised interfaces. The aim of this project was to maximise the uptake, by the end-user community, of the new IEEE 1785 series of standards. The primary objective of this project was:

- To promote the adoption and use of the new IEEE 1785 series of standards by the millimetre-wave and terahertz end-user communities to support wider dissemination and uptake by academic and industrial sectors.

## Results

The project produced a GPG on rectangular waveguide connections above 100 GHz. With this GPG, the end-user community can make reliable waveguide measurements with standardised flanges. It was sent to the convenor of the EURAMET Subcommittee Radiofrequency and Microwave (SC RF and MW), which is part of the Technical Committee for Electricity and Magnetism (TC-EM), for publishing it as part of an official EURAMET Guide. Thus, this GPG will be reviewed on a regular basis even after the end of this project. The GPG is published on the PTB OAR (Open Access Repository) and can be accessed [here](#).

The project also created and published a documented open source software for calculating the electrical performance of connected waveguides. It is based on mechanical dimensions and tolerance data and follows the procedures of part 3 of the IEEE 1785 series of standards. To be capable of propagating uncertainties through nonlinear systems, a Monte Carlo approach was applied. The software functions cover the basic physical effects for mated waveguides to calculate repeatability. The software was written in MATLAB and can be accessed [here](#).

Both outcomes (GPG and software) have been disseminated in detail at an international full day workshop with the title "Measurements and Waveguides for Millimetre-wave and Terahertz Frequencies". This workshop took place during the European Microwave Week (EuMW), in Paris, France, on 4<sup>th</sup> October 2019. The workshop reviewed the latest developments of waveguide technology and focussed on new waveguide sizes and interfaces. 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). The documented feedback from the end-users who attended the workshop on rectangular waveguide interfaces for connections above 100 GHz can be accessed [here](#).

Additionally, a report on the work carried out in this project and on errors and problems found in the IEEE 1785 standards was sent to IEEE. It is envisaged that contact with the IEEE standards committee will continue well beyond the end of this project and is likely to lead to these IEEE standards being revised and updated when the time comes for such an activity to be initiated. IEEE standards are routinely reviewed every 10 years to ensure the contents of the standards are still relevant and up to date. The first of the IEEE waveguide standards (IEEE Std 1785.1-2012) is due for such a review in 2022.

## Impact

A one-day workshop, describing the work from this project, has been organised and took place at EuMW, which is Europe's largest microwave event and attracted more than 5,000 attendees in 2019. The funded partners in the consortium (PTB and NPL) chaired the workshop and gave several presentations. The keynote presentation at the workshop was given by the unfunded partner in the consortium (Flann Microwave Ltd). Other presentations have been from organisations in Germany (Spinner), USA (Anritsu and VDI) and Japan (NMIJ). The workshop was very successful, as presenters and attendees engaged in detailed discussion, and new connections and networks have been formed.

Waveguide interfaces based on the new IEEE 1785 series of standards are now available and offered by more manufacturers. The GPG and the software from this project, together with the workshop facilitated the adoption of the standards, leading to other manufacturers adapting their products faster and more efficiently. Thus, soon, incompatibility problems should be limited to a minimum, which in turn should save the Primary Supporter, Flann Microwave Ltd, and other European companies' costs and manpower. These companies and their subcontractors will profit greatly from a consistent standardisation, as their products will be compatible and competitive on an international level and new business opportunities may be created, not only in Europe but also in the USA and Asia.

In 2017, the frequency range of waveguides described in the standard IEC 60154-2 has been increased to 3.3 THz, but the interface itself is based on the IEEE 1785 standards. Thus, there are no compatibility issues between interfaces in accordance with either of both standardisation bodies, and a good acceptance and wide distribution of the IEEE 1785 standards will also be beneficial for users of IEC 60154-2.



**List of publications**

- Kuhlmann, K., Probst, T., Ridler, N., Watts, J., *Good Practice Guide on Making Rectangular Waveguide Connections at Frequencies above 100 GHz*, <https://oar.ptb.de/resources/show/10.7795/530.20190805>, 2019.
- Kuhlmann, K., Probst, T., *Software EMPIR 17SIP08 NeWITT v1 [Source Code]*, <https://doi.org/10.24433/CO.2045615.v1>, 2019.
- Kuhlmann, K., Ridler, N., Watts, J., *Documented feedback from the end-users who attended the workshop on rectangular waveguide interfaces for connections above 100 GHz*, <https://doi.org/10.7795/EMPIR.17SIP08.CA.20200324>, 2020.

Project start date and duration:		01 September 2018, 18 months
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Internal Funded Partners: 1. PTB, Germany 2. NPL, UK	External Funded Partners:	Unfunded Partners: 3. Flann, UK