# Publishable Summary for 17SIP04 TROVE
# Technology transfer of RF nonlinear verification device to end-user

## Overview

Nonlinear characterisation of RF devices and components benefits the telecommunications sector, through 5G and the Internet of Things (IoT), and the manufacturing sector, through Industry 4.0. At the technology level, the Nonlinear Vector Network Analyser (NVNA) is the key test instrument but it is complex to operate, and traceable calibration is distributed across three different standards. The prototype Nonlinear Verification Devices (NVD), developed in the EMRP project SIB62 HFCircuits, provide a way to verify the calibration.

In this project, sufficient technology has been transferred to the primary supporter, Keysight BE, to allow them to re-optimise the design of a next generation NVD, repurposing it as a diagnostic tool to reduce costly down-time. The benefits of the NVD as a diagnostic tool and verification device have been publicised to achieve traction within the community of end-users. We anticipate that the reduced down-time and improved fault diagnosis will directly benefit NVNA end-users.

## Need

The carbon footprint of mobile phone handsets and telecommunications base-stations is linked to their growing data usage. Telecommunications is probably the largest civil user of RF technology and several solutions are being applied to increase the overall RF system efficiency, but these are more difficult to design and test, requiring complex and expensive test equipment, such as the NVNA, to verify designs and manufacture devices. The NVNA and similar instruments are expensive, complex and require accurate calibration. In the event of a fault, diagnosis and repair may result in significant down-time of the test system, affecting productivity.

Hence there was a need for a simple calibration verification and system diagnostic tool to monitor calibration quality and instrument performance. This required building on the NVD developed in SIB62 HFCircuits, optimising the design to improve its ruggedness and to act as a diagnostic tool.

In order to develop a true nonlinear verification device that could be used in conjunction with the existing multi-port NVNA and Large-Signal Network Analyzer (LSNA) instrument calibration scheme, technology needed to be transferred to Keysight BE. This allowed them to produce prototype test devices to demonstrate the principle of an optimised and robust device to the end-users and to disseminate results more widely than was possible in the earlier project.

## Objectives

The overall goal of the project was to create impact by building on results from SIB62 HFCircuits.

The specific objectives were:

1. To provide design guidance on the NVD prototypes developed in SIB62 HFCircuits to the industrial end user, by means of training with the test models and additional details of the prototype designs. It was expected that device uncertainties and possible use-models would be discussed within the training.
2. To work with the user community so they are aware of the benefits of the NVD and to promote its uptake as a verification and diagnostic tool. Dissemination would be done through user forums and trade publications.

## Results

*To provide design guidance on the NVD prototypes developed in SIB62 HFCircuits to the industrial end user*

The necessary design and simulation knowledge of the NVD device prototypes have been transferred to Keysight BE, providing the tools to adapt the prototype device to form a robust and manufacturable design. Staff from K U Leuven worked at the Keysight BE site in Denmark to transfer this technology. In the process they also gained first-hand knowledge of the multi-facetted requirements of the industrial design process. Discussions to determine the optimum parameter space were interactive and the knowledge and models were transferred from KU Leuven and NPL, to Keysight BE. Prototype NVD design has been made by Keysight BE to verify the approach and there are components available for a further two devices. The application of the NVD was extended to explore its possible use as a fault diagnostic tool in addition to a device to verify the calibration.

*To work with the user community so they are aware of the benefits of the NVD and to promote its uptake as a verification and diagnostic tool*

Keysight BE supported a "MicroApps" presentation at European Microwave Week (EuMW) 2018 on 25th - 27th September 2018 in Madrid, Spain and a presentation was made by Prof. D. Schreurs at the NVNA users' forum, held on 21st January 2019 as part of ARFTG92, Orlando, 2019 during Radio & Wireless Week. The material was also reused at the NVNA short course given by Prof. D. Schreurs at the same meeting.

At present, the prototype device is being further assessed at the Keysight's Research facility in Santa Rosa, USA. A trade journal publication or user guide will be prepared and published, subject to approval by Keysight, following completion of this evaluation.

## Impact

The energy required for the telecommunication sector is increasing rapidly in line with data use and so the proposed 1000-fold capacity increase of 5G has significant economic, societal and environmental implications. The increased energy use can be partly mitigated by more efficient and cheaply manufactured RF systems. This is a particular issue for the mm-Wave components that must now be manufactured and tested at commodity prices. The NVNA is a key instrument to realise low-cost device testing. Better calibration and reduced NVNA down-time have significant cost implications for manufacture and ultimately carbon footprint reduction. The aim is to improve longer handset battery life from the deployment of more power-efficient RF telecommunication systems. Other applications, such as IoT, will also benefit from high-efficiency systems developed using nonlinear measurement and modelling techniques.

The technology transfer to Keysight BE, who manufacture the NVNA and other instruments, has created direct impact through the realisation of the NVD as a diagnostic tool to reduce field-engineer visits and the need to return the instrument to the manufacturer for assessment. The end-users of the NVNA instruments range from academia to industrial fabrication facilities and subsystem manufacturers. The goal is to provide significant cost savings and efficiency benefits to these end users. A wider impact will be achieved via the publication of this work in a trade journal.

The "NVNA Users forum", organised by NIST, is the key forum that brings together industrial and academic leaders in this field. This meeting was held at ARFTG92 (Orlando, 2019), and was attended by key instrument designers, academia and equipment users from around the world. The material was also used as part of an introductory course given by Prof. Schreurs of KU Leuven at the same conference.

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