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1 Overview

FAME VNA has successfully embedded the present state-of-the-art in Vector Network Analysers (VNA) calibration and uncertainty calculation methods in a user-friendly measurement software. These methods were initially developed during the recently completed EMRP project (SIB62 HFCircuits) and aimed at improving the accuracy of VNA measurement to support the metrological needs of present-generation of high-frequency electrical circuits. The dissemination of these advanced techniques to calibration laboratories was found inadequate, and the Primary Supporter of the project, DARE!!, recognised this. FAME VNA measurement software allows industrial laboratories such as DARE!! to employ a state-of-the-art calibration and uncertainty calculation software for daily calibration services and forms a critical element in the transfer of NMI-level accuracy to industrial end-users.

2 Need

The FAME VNA software has improved measurement quality and accuracy, while reducing the costs of VNA calibrations. To support the Primary Supporter DARE!! in providing high accuracy measurement services to customers was of great importance. At the same time, competitive pricing due to market competition imposed a clear need to reduce calibration costs while increasing the accuracy. This has led to the development of advanced data analysis module, allowing fast and sophisticated in-depth metrological evaluations.

It was a common practice for the calibration of VNA to be a manual task. In particular, processing measurement data and making the complex calculations for uncertainty values was done using excel sheets. A fully automated data calibration and uncertainty calculation module has greatly simplified state-of-the-art VNA measurements. The FAME software resolved these issues by including a data calibration module that supports the latest calibration methods with improved accuracy. Automated data processing forms a key element responsible for reduced the overall calibration time and costs, resulting in increased capacity of the laboratory. This module supports correct and accurate evaluation of a large amount of measurement data and includes advanced error-correction techniques. Automation of all the necessary steps required for accredited VNA calibration services, FAME enables industrial end-users to realize NMI-level accuracy while avoiding the complexity.

3 Objectives

This project aims to provide calibration software and a training course that can be used for VNA calibration and uncertainty calculations. The objectives of the project are as follows:

1. Integrate the JRP SIB62 HFCircuits outputs, i.e. characterisation of VNA setups, characterisation of calibration uncertainties reflection coefficients and the new guideline protocols into a software program in order to improve the calibration process of the relevant industries by increasing reliability, improving uncertainty and reducing overall calibration time.
2. Test and validate this software in a commercial environment and transfer the required knowledge (in particular related to the new calculation and data processing techniques) as necessary for using the software in a commercial environment
3. Organise seminar event to disseminate knowledge of this software to other calibration laboratories in Europe, with the aim to ensure further market uptake.

4 Results

The results corresponding to each of the objectives of the project are as following:

4.1 Objective 1: Integrate the JRP SIB62 HFCircuits outputs into a software program in order to improve the VNA calibration process of relevant industries by increasing reliability, improving uncertainty and reducing overall calibration time

For accredited (i.e. ISO17025) calibration laboratories, reliability and accuracy in the measurement services are of great importance. The results of such calibration services often form a critical element in the production chain of the customers. However, to further improve the accuracy of VNA calibration services, more elaborate and complex methods, i.e. as developed in SIB62 HF Circuits, are needed, and this has hampered the dissemination of NMI-level accuracy to secondary calibration laboratories.

Therefore, the outcome of this projects objective 1 will enable the dissemination of state-of-the-art calibration uncertainties and facilitate a reliable traceability route from the National Metrology Institute (NMI) via accredited calibration laboratories to the end-customers, such as companies from the Radio Frequency (RF) and Microwave Industry.

This project aims to integrate the outputs of JRP SIB62 HFCircuits to serve the needs of accredited laboratories by implementing these in a measurement software. This software integrates the methods developed in the related JRP SIB62 HFCircuits, will operate according to accepted procedures as indicated in the VNA Guide, will reduce errors (in particular errors related to manual work) and reduce overall measurement time by increased automation.

Strong collaboration between the Primary Supporter DARE!! and VSL resulted in the development of software that meets all the requirements of an accredited calibration laboratory, increasing the chances for broader market up-take. The software aims to improve the VNA calibration process of relevant industries by increasing reliability, improving uncertainty and reducing overall calibration time. A software product that meets all the requirements of a commercial calibration laboratory increases the chances for broader market up-take.

The design of the software is completed in Matlab App designer software. It has a modular structure:

- The data analysis module allows users to easily visualize and analyze S-parameter measurement data. This module supports the following data file formats (citi, touchstone, sdatcv and mat). In addition, the module supports visualization and analysis of 1- and 2-port S-parameter measurement data files. It is possible to visualize the data in tabular form and graph form. Whereas, the data can be analyzed in polar format or cartesian format, supported by linear or logarithmic scales. The data analysis module design is optimised based on user feedback from the Primary Supporter.
- The VNA control module allow users to automatically retrieve measurement data from the VNA and store it on the computer for error-correction and calibration purposes. This module furthermore supports a range of VNAs, which can be selected by means of a drop-down menu. The VNA control module is capable of retrieving and editing all necessary measurement parameter settings independently without manual user interactions with the VNA.
- The Measurement module supports all four S-parameter measurements and includes an advance feature supporting direct receiver measurements as well. There are two measurement modes supported by the module, a single measurement mode and a series measurement mode.
- The Data calibration module supports error-correction based on the following three methods: SOL calibration method, SOLT calibration method and SOLR calibration method.
- The Uncertainty module is designed to allow users to define values of each source of uncertainty corresponding to their VNA measurement system. The following sources of uncertainty are supported:
    - Reference (calibration) standard uncertainty
    - VNA noise floor and trace noise uncertainties
    - VNA non-linearity uncertainty
    - VNA drift uncertainty
    - Isolation (crosstalk) uncertainty
    - Test-port cable flexure uncertainty
    - Connector repeatability uncertainty
- The Measurement report module is designed to allow users to calculate total measurement uncertainty of measurement data. The module supports the calculation of measurement uncertainty for polar and/or cartesian parameters.

The VNA software meets all requirements for traceable calibration and uncertainty calculation needed for accredited measurement services. The functional requirements set for each module fully comply with the required objective 1 specifications.

4.2 Objective 2: Test and validate this software in a commercial environment and transfer the required knowledge (in particular related to the new calculation and data processing

techniques) necessary for using the software in a commercial environment

The continuous advancement of VNA measurement capability (i.e. frequency range, number of measurement ports) and the need for better accuracy, has called the need for improved reliability in VNA measurement. Reliability means that the data presented to the customer contains no mistakes. Mistakes can occur in every part of the overall measurement chain, in conducting the actual measurements and also in processing the measurement data towards a corrected value, including measurement uncertainty. Thus, error reduction and accuracy improvement techniques, which can be made possible with the project's outcomes, are of great importance to maintaining a high level of service. In addition, these outputs will reduce the cost-price of the measurements, which increases the competitiveness and affordability of traceability by the calibration market in general.

As VNAs are getting more and more complex, both elements above will become more relevant in the future. Most VNAs that are currently used have two ports (connections) measurement capability. This number of ports is increasing in order to be able to measure more complex Radio Frequency (RF) devices and systems. Multi-port VNA's are getting more common and calibrating these VNAs is very difficult and time-consuming using current calibration, and calculation methods as this additional number of ports result in an enormous amount of additional data. With these large datasets, errors are easily made and extremely difficult to identify. Furthermore, calculation times will become exponentially longer when using data processing tools such as Excel.

The initial test of the developed VNA software was performed at module-level. First, the data-analysis module was tested using artificially generated data-files. This method is particularly useful for testing the complete functionality of the entire module. Then the calibration and uncertainty modules were tested with pre-collected measurement data. This method allowed an accurate comparison with other VNA software tools. Finally, the reporting module was tested by generating actual measurement reports, which were subsequently checked on correctness.

The beta version of the software was tested in Primary Supporter laboratory. Here, the software was used in conjunction with a Rohde&Schwarz ZVR VNA available at primary supporter laboratory and a full 2-port SOLT calibration was performed to confirm the correct implementation of necessary modules. In collaboration with the Primary Supporter, a list containing several items were identified for further improvement of the VNA measurement software. The final version of the VNA measurement software was developed by implementing changes following this list, identifying items as necessary for further improvement of the VNA calibrations.

The correct operation of the software has been validated through comparison of software results with those generated by the well-known VNA metrology software VNA-Tools from METAS. The results of the calibration and uncertainty calculation were comparable with those of VNA Tools software and were found satisfactory.

An online workshop was organized for the dissemination of knowledge concerning the software's sophisticated mathematical techniques and the interpretation of results. The software contains complex methods, and correct analysis of the results using the software requires training through, i.e. a workshop. Training material was developed for this workshop. The workshop was attended by the Primary Supporter and a calibration laboratory.

With the feedback from the primary supporter on the beta version of the software, definitive improvements are implemented in the final version, which is also thoroughly tested and validated by comparison with VNA metrology software VNA-Tools (METAS) and fully comply with the required objective 2 specifications.

4.3 Objective 3: Disseminate knowledge of this software to other calibration laboratories in Europe, with the aim of ensuring further market uptake.

The calibration industry faces the challenge to improve their quality and accuracy while reducing costs. At the same time, competitive price, due to for an example (international) competition, imposes a clear need to reduce calibration costs in order to become and/or remain competitive. Continuous innovation and smarter working are key elements in taking on this challenge. To support a large market uptake, objective 3 aims to facilitate promotion of the software to other calibration laboratories in Europe.

The project communicated to a wide group of stakeholders and end-users through a dedicated project website (http://www.vsl.nl/fame), providing information concerning the project, seminars and workshops. This website will be maintained after the project end to serve as a platform for communicating the latest news concerning the software to all end-users.

Furthermore, VSL organized an online webinar to disseminate knowledge of this software stakeholders. ***The webinar was attended by VNA measurement experts from several leading NMIs (METAS, PTB and NPL) and VNA manufacturers (Anritsu).***

5 Impact

Strong collaboration between VSL and the primary supporter, led to the development of a software that significantly improved the VNA calibration process by increasing reliability, improving uncertainty and reducing overall calibration time. For example: at VSL, a specific calibration that took four hours for completion, now with the new software is completed within two hours. As the uncertainty calculation process is fully automated, the operator now has more time for qualitative metrological evaluation and with this also increase the reliability of the service. This collaboration resulted in a software product that meets all the requirements of a commercial calibration laboratory and enhancing the chances for broader market up-take. For example: a measurement report module is specially designed to enable laboratory technicians to generate calibration data in a format as required for the calibration certificate directly with the software and avoid further time-consuming data processing.

To further enhance the impact of the project, VSL developed a dedicated product website, brochure and organised online webinar event and keen interest in RF measurement community was generated. The webinar was attended by 15 VNA measurement experts from several leading NMIs, RF instrument manufacturers and secondary calibration laboratories.

The project has achieved the following impact:

Support for product development and R&D by more accurate calibrated VNA-instruments
Product design and specifications are significantly improved when measurement accuracy is enhanced. The trade between customers and suppliers of products used in the high-frequency electronics communities will be advanced on a technical and financial level. The technical improvements will come about due to improved measurement traceability processes made available, that will, in turn, enable manufacturers to specify products more precisely. More accurate product specifications will impact areas such as systems' design and tests that will provide financial benefits for the supplier and the customer (by reduced product prices). Examples include products used in consumer electronics (such as computers and mobile telephones), breast cancer detection (using radio frequency (RF) and microwaves) and security systems (using passive millimetre- and submillimetre-wave imaging). VNA instruments with multiple ports will enable calibration using the same software, which can facilitate more accurate measurements to the industry while reducing measurement time.

Replication potential
The VNA measurement software is compatible with most high-end VNAs as sold by leading VNA manufacturers. Furthermore, usage of existing calibration kits is supported by including manufacturers' calibration kit reference database in VNA software. Users are also able to add dedicated calibration kit reference files for their calibration kits. This function is especially useful for end-users requiring high calibration accuracy by using data-based reference files. These reference files can come from NMI calibrations and are traceable to SI units, hence provide a direct route to traceability. Care is taken to ensure compatibility of VNA software with existing VNAs, calibration kits and equipment in order to facilitate up-take from a larger group of stakeholders and end-users.

The Primary Supporter, DARE!!, is the first laboratory implementing this software and served as the ideal candidate to test the VNA software in the actual calibration environment. Furthermore, VSL actively approached other calibration laboratories in Europe to utilise the replication potential of the software.

6 List of publications

n/a

7 Contact details

For more information, see http://www.vsl.nl/fame or contact Jacob Jan de Boer (jjdeboer@vsl.nl).