VNA Tools – a software for metrology and industry

The radio frequency and microwave (RF & MW) laboratory at METAS has been developing metrology software for electrical high frequency measurements for many years. This article highlights the use of the software VNA Tools in the accreditation process and accentuates a recently developed interface, which simplifies integration within other software environments.

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Consider the following scenarios: An electrical engineer or technician in a calibration laboratory is faced with the task of determining the measurement uncertainties associated with electrical high frequency measurements in order to satisfy the requirements of the ISO/IEC standard 17025. This is the relevant standard for a calibration laboratory to demonstrate technical competence and obtain accreditation for its measurement services.
A calibration laboratory operates a software environment as part of their quality management system and seeks to implement contemporary uncertainty evaluation.
A component manufacturer has software installed to monitor the production process. He would like to specify the uncertainties in his inspection process.
A VNA manufacturer wants to extend the firmware of his vector network analyzer (VNA) to display real time uncertainties on the screen.

In all these cases the software *VNA Tools* can provide valuable support to master the challenges. But before this is further elaborated we would like to shortly recall history and metrological background related to this software.

S-parameters and vector network analyzers

About 10 years ago we published an article [1] in this magazine announcing the upcoming release of the metrology software *VNA Tools* for the measurement of S-parameters. Back then it was called *VNA Tools* II to distinguish from an even earlier version of the software. By now the original name has been re-adopted and the software has been continuously developed further. New functionalities, improved computational efficiency, increased user friendliness and the interaction with a continuously growing user base of more than 1000 people have turned the software into a versatile, flexible and very mature product.

Reflection and transmission coefficients, also called scattering parameters or S-parameters, are fundamental quantities in RF & MW metrology. They are measured with a VNA. In the past VNAs were large, expensive and complicated instruments used by specially trained RF & MW engineers solely. Nowadays VNAs come in a variety of instrument form factors from USB driven miniature devices to full-size bench top models, covering a wide range of frequencies and different transmission media. The market has vastly expanded with digital technologies pushing to higher frequencies to gain bandwidth and speed. A new generation of VNAs provides in addition the

measurement support required by modern RF devices, such as time domain, multiport, spectrum analysis, mixer/converter tests and pulsed-RF measurements. At the same time, requirements related to quality control become more prominent and users are increasingly confronted with the demand to provide reliable measurement uncertainties. However, evaluating measurement uncertainties associated with S-parameters in accordance with the GUM [2] is a demanding task.

S-parameters are measured in magnitude and phase, or real and imaginary components. Thus, proper uncertainty analysis requires the use of multivariate methods, which take correlation into account. The methodology is described in a supplement [3] to the GUM and requires the use of rather advanced mathematical methods. Furthermore, VNAs need to be calibrated with known standards before the device under test (DUT) can be measured. This leads to fairly elaborate measurement models. Finally, measurements are performed over several hundred frequency points, leading to a relatively large amount of data with uncertainties often showing a strong frequency dependence.
The use of software is therefore almost unavoidable. *VNA Tools* has been designed to support the user in this endeavor. The nowadays preferred way to evaluate S-parameter uncertainties is described in some detail in a EURAMET VNA calibration guideline [4] that was recently revised to reflect the significant progress made in this field over the last few years. All the requirements stated therein are supported by *VNA Tools*. The software has a rich set of useful features, which can not be addressed all in this short article. More in-depth information can be obtained from the website [5] and from [6].

Support for accreditation

VNA Tools supports the calculation of S-parameter uncertainties in accordance with the GUM and EURAMET documents to the full extent. It has built-in measurement models for different calibration algorithms, taking into account all factors that are affecting the measurements. It provides support in the characterization of these influence factors. With the help of the powerful uncertainty propagation engine *METAS UncLib* [7, 8] it propagates uncertainties to the final result by taking correlation into account. The result comes along with an uncertainty budget, which helps to identify the major uncertainty contributors. *VNA Tools* evaluates the measurement uncertainty of VNA measurements in a much more comprehensive and rigorous way than previously well established heuristic methods («Ripple Method»), which had several shortcomings. The calculations performed by *VNA Tools* are fully documented in a publicly available math reference document on the website. The correctness of the calculations has been validated and tested by third-parties in different validation projects.
With this functionality *VNA Tools* ensures an unbroken path of traceability to SI units, if adequately characterized VNA calibration standards are used. It therefore supports the traceability requirements in the normative standard ISO/IEC 17025, used by accreditation bodies in evaluating calibration and testing laboratories. By now, several National Metrology Institutes and calibration laboratories from all over the world base their accredited S-parameter scope on the use of *VNA Tools* and several more are in the process of setting it up.

VNA Tools has a built-in calculator to determine best measurement capabilities over the entire S-parameter space (CMC calculator). This is based on a virtual VNA and and comes in particularly handy when required to define best uncertainties in the declaration of the accredited measurement scope.

VNA Tools Inside

A recent addition to *VNA Tools* is the Real Time Interface (RTI). The RTI is a well defined and documented software interface, which provides simplified high level access to *VNA Tools* functionalities. It is also guaranteed to be stable and does not change with each new release. It is therefore particularly suitable, if *VNA Tools* support should be integrated in an already existing software environment. The cases mentioned in the introduction are examples of such an integration.

VNA Tools inside, experts behind: Supporting industry, research and academia with a metrology grade software that builds trust in measurement.

As of now two companies have made use of the RTI to develop commercially available software products. Rohde & Schwarz, the German test equipment manufacturer, has started to extend his VNA platforms with a real time uncertainty option [9]. Maury Microwave, an American RF & MW company, has launched a VNA software [10] aiming to provide a simple and easy approach to VNA uncertainties and verification. In both cases *VNA Tools* functions are accessed through the RTI, which led to a simplified and faster development of the commercial software products.

Unlike *VNA Tools*, the RTI is not available for free. The interface is protected by a digital key and access can be licensed from METAS for a fee. For further information the laboratory can be directly contacted through hf@metas.ch.

Outlook

Although being a mature product by now, *VNA Tools* is actively developed further and extended with new functionalities. New versions of the software are released on a biannual basis. Current developments aim at extending the scope of the software significantly with new measurement capabilities supporting wave parameters. S-parameters are based on receiver ratios, whereas wave parameters are based on individual receiver values. The step from receiver ratios to individual values seems small, but it introduces fundamental new requirements in terms of device calibration. This line of attack opens the door to the vast field of active and non-linear VNA measurements. This is a field, which is expected to gain importance in the coming years, and *VNA Tools* is getting ready for it.

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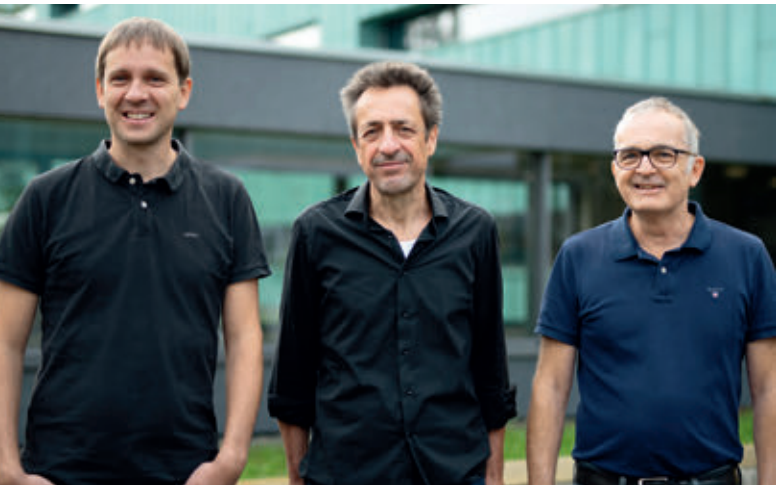

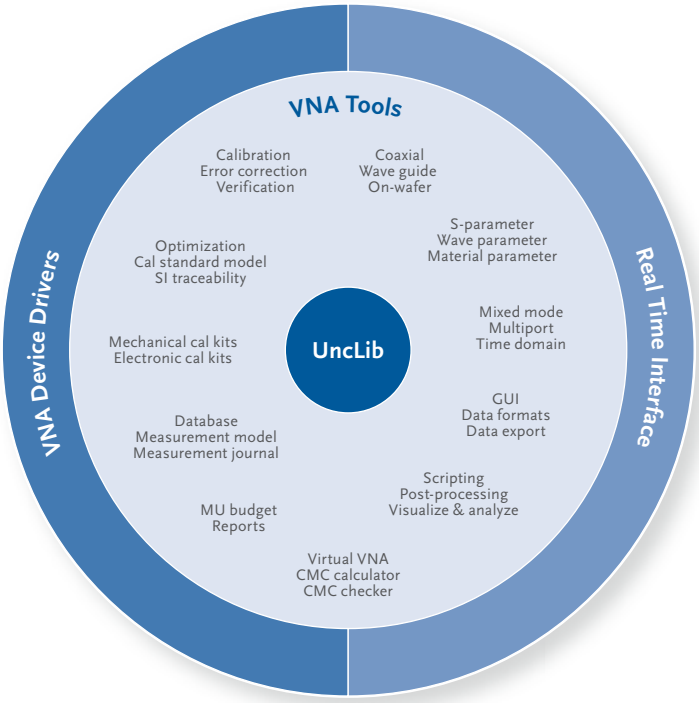

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Entwickelt um die Metrologie und Industrie zu unterstützen

Ein Anruf mit dem Smartphone, Assistenzsysteme im Automobilbereich oder Flugsicherheit haben eines gemeinsam: Elektromagnetische Signale müssen schnell und zuverlässig verarbeitet werden. Dabei ist die Messung von Reflexions- und Transmissionskoeffizienten (auch S-Parameter) eine Schlüsselkompetenz. Sie werden mit vektoriellen Netzwerkanalysatoren (VNA) gemessen. Heutige VNA müssen die Messunterstützung neuer digitaler Technologien beherrschen, (Zeitbereichs-, Multiport-, Spektrum-Analyse, gepulste HF-Messungen) und darüber hinaus zuverlässige Messunsicherheiten liefern. Die Bewertung der Messunsicherheiten von S-Parametern gemäss GUM ist jedoch eine anspruchsvolle Aufgabe. Um die Anwender beim Berechnen von Messunsicherheiten zu unterstützen, hat das METAS bereits vor zehn Jahren die Software VNA Tools entwickelt. Seit 2010 haben neue Funktionalitäten, verbesserte Berechnungseffizienz und erhöhte Benutzerfreundlichkeit diese Software zu einem flexiblen und ausgereiften Produkt gemacht.*

Ursprünglich wurde VNA Tools vor allem für nationale Metrologieinstitute und höchste metrologische Ansprüche entwickelt. Inzwischen haben aber auch Kalibrierlabore entdeckt, dass die Software bei der Akkreditierung nach ISO 17025 wertvolle Dienste leisten kann. Es gibt bereits mehrere Labore, wo die Software zu diesem Zweck eingesetzt wird und weitere sind auf dem Weg dazu. Nebst der kostenlosen Software-Version für einen ständig wachsenden Anwenderkreis, auch aus den Universitäten und der Industrie, hat das METAS vor kurzem VNA Tools mit einem neuen lizenzierbaren Werkzeug erweitert, dem Real Time Interface (RTI). Das RTI ist eine Erweiterung der Software VNA Tools und wurde entwickelt, um unseren Partnern einen umfassenderen Service zu liefern. Das RTI ist eine definierte und dokumentierte Softwareschnittstelle, die einen vereinfachten Zugriff auf die Funktionalität der VNA Tools auf hoher Ebene ermöglicht. Sie ist ausserdem garantiert stabil bei jedem neuen Release des nach wie vor kostenlosen VNA Tools.

** Guide to the Expression of Uncertainty in Measurement*

Conçu pour soutenir la métrologie et l'industrie

Un appel avec un smartphone, les systèmes d'assistance dans le domaine de l'automobile ou la sécurité aérienne ont un point commun: les signaux électromagnétiques doivent être traités de manière rapide et fiable. À cet effet, la mesure des coefficients de réflexion et de transmission (également appelés paramètres S) est une compétence clé. On mesure ces coefficients au moyen d'analyseurs de réseau vectoriels (VNA). Les VNA actuels doivent maîtriser le soutien de mesures des nouvelles technologies numériques (analyse du domaine temporel, analyse Multiport, analyse de spectre, mesures hautes fréquences pulsées) et livrer par ailleurs des incertitudes de mesure fiables. Toutefois, l'évaluation de l'incertitude de mesure des paramètres S selon le GUM est une tâche complexe. Il y a déjà dix ans, METAS a développé le logiciel VNA Tools afin de soutenir les utilisateurs lors du calcul des incertitudes de mesure. Depuis 2010, ce logiciel est devenu un produit flexible et sophistiqué grâce à de nouvelles fonctionnalités, à une efficacité de calcul améliorée et à une facilité d'utilisation accrue du logiciel.*

À l'origine, VNA Tools avait avant tout été développé pour les instituts nationaux de métrologie et pour des exigences métrologiques élevées. Entre-temps, des laboratoires d'étalonnage ont également découvert que ce logiciel peut fournir de précieuses prestations pour l'accréditation selon la norme ISO 17025. Plusieurs laboratoires utilisent déjà VNA Tools dans ce but et d'autres laboratoires sont sur cette voie. Outre la version de logiciel gratuite destinée à un cercle d'utilisateurs toujours plus vaste, également issus du milieu académique et de l'industrie, METAS a récemment étendu le périmètre de VNA Tools avec l'ajout de fonctionnalités sous licence: le logiciel Real Time Interface (RTI). Le RTI est une extension du logiciel VNA Tools. Il a été développé dans le but de fournir un service de logiciels plus étendu à nos partenaires. Le RTI est une interface de logiciel définie et documentée, permettant un accès simplifié aux fonctionnalités du logiciel VNA Tools de haut niveau. En outre, sa stabilité est garantie pour chaque nouvelle version du logiciel, toujours gratuit.

** Guide pour l'expression de l'incertitude de mesure (GUM)*

Progettato per supportare la metrologia e l'industria

Una chiamata con uno smartphone, i sistemi di assistenza nel settore automobilistico o la sicurezza del traffico aereo hanno una cosa in comune: i segnali elettromagnetici devono essere elaborati in modo rapido e affidabile. La misurazione dei coefficienti di riflessione e di trasmissione (anche dei parametri S) è una competenza chiave. Essi vengono misurati con analizzatori di rete vettoriali (VNA). I VNA odierni devono essere in grado di controllare il supporto di misurazione delle nuove tecnologie digitali (analisi del dominio temporale, analisi multiporta, analisi spettrale, misurazioni RF pulsate) e fornire anche incertezze di misura affidabili. Tuttavia, la valutazione delle incertezze di misura dei parametri S secondo GUM è un compito impegnativo. Per supportare gli utenti nel calcolo delle incertezze di misura, già dieci anni fa il METAS ha sviluppato il software VNA Tools. Dal 2010 nuove funzionalità, migliore efficienza di calcolo e maggiore facilità d'uso hanno reso il software un prodotto flessibile e maturo.*

Originariamente, il software VNA Tools è stato sviluppato principalmente per gli istituti nazionali di metrologia e per le massime esigenze metrologiche. Nel frattempo, però, anche i laboratori di taratura hanno scoperto che il software può fornire servizi preziosi per l'accreditamento ISO 17025. Ci sono già diversi laboratori in cui il software viene utilizzato a questo scopo e altri sono in procinto di farlo.

Oltre alla versione gratuita del software per una cerchia di utenti in costante crescita, anche accademici e industriali, il campo di applicazione di VNA Tools con l'aggiunta di funzioni su licenza. La Real Time Interface (interfaccia in tempo reale) (RTI). L'RTI è un'estensione del software VNA Tools ed è stata progettata per fornire un servizio più completo ai nostri partner. L'RTI è un'interfaccia del software definita e documentata che consente un accesso semplificato alla funzionalità del software VNA Tools ad alto livello. È inoltre garantito che sia stabile ad ogni nuova versione del software VNA Tools tuttora gratuito.

** Guide to the Expression of Uncertainty in Measurement (Guida di riferimento per l'espressione dell'incertezza di misura)*