Extension kit for Vector Network Analysers Characterisation of Nonlinear RF/HF Components in Time and Frequency domain

Introduction
The linear behaviour of RF/HF components like filters, interconnects and transistors under small-signal operation is completely characterised by S-parameters, measured using a vector network analyser (VNA). Over time, VNAs evolved from single-ended two-port instruments to multi-port instruments to handle differential linear devices.

Triggered by the growing need for better insight in the nonlinear behaviour of components, VNA manufacturers are adding some “nonlinear” features to some of their models. These competitive features include AM-to-AM, AM-to-PM, harmonic power measurements and mixer characterisation. Unfortunately, these features characterise the nonlinear behaviour only partially.

Complete harmonic characterisation of high-frequency components finally becomes possible thanks to the NM101 extension kit from NMDG. The NM101 is a combination of additional hardware and software that runs on top of the two-port N5230A, E836X and N5242A (option 200 / 219 / 224) vector network analyser from Agilent Technologies. The combination of the PNA and the NM101 extension kit is referred to as “VNAPlus”.

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Amongst others, it is very suitable to characterise diodes, transistors, power amplifiers, multipliers, dividers and fast switching devices.

On top of the standard measurement capabilities of the Agilent PNA, the VNAPlus provides calibrated measurement capability of the time waveforms of the incident and reflected waves or voltages and currents at the ports of a component under test. These measurements are performed under realistic conditions, including a non-50 Ohm environment using passive or active tuners from Maury Microwave. By customisation of the test set, NM101 supports measurements, requiring power beyond the power capability of the test set, provided by the PNA.

The NM101 software and hardware can be customised to run on top of certain other vector network analysers.

**VNAPlus, based on Agilent two-port N5230A, E836X**

Presently the NM101 is only available on the following Agilent two-port PNA’s:

- PNA-L N5230A with option 125 or 225 or 425 or 525 (configurable 2-port test set) and option 080 (frequency offset)
- PNA E836X with option 014 (configurable 2-port test set) and option 080 (frequency offset)
- PNA-X N5242A with option 200 or 219 (extended power range) and option 080 (frequency offset)
- PNA-X N5242A with option 224 and option 080 (frequency offset)

Presently the NM101 is only available for the Agilent two-port PNA N5230A, E836X and N5242A with the proper options (see above). The product supports a frequency range from 600 MHz up to 20 GHz. Due to the test set configuration of the Agilent PNA N5230A, E836X and N5242A Option 200 / 219, external couplers are required. Additionally, for all mentioned types one of the four receivers is sacrificed for the synchroniser to enable time domain measurements. Therefore, an external switch needs to be added to share one receiver between two couplers, to measure incident and reflected waves at both ports. The selection of couplers, switch, switch drive and the required cabling is configured in consultation with the customer.

By using external couplers and directly accessing the receivers of the Agilent PNA through attenuators, it is possible to create setups for higher power applications. NM101 supports such configurations seamlessly.
The NM101 is an extension kit that turns the vector network analyser into a calibrated two-port receiver to measure the voltages and the currents at the ports of a device under test under a nonlinear mode of operation. The kit consists of:

- LSNA v2.0.0 software¹, supporting system configuration, absolute calibration and measurement
- Synchroniser (20 GHz), enabling the reconstruction of time waveforms
- Harmonic Phase Reference (HPR) 600 MHz - 20 GHz, supporting the required phase calibration

The required external couplers, switch, switch drive and cables are configured in consultation with the customer and priced separately.

The user needs to provide:

- A power meter (and sensor) in order to perform the required power calibration
- A standard calibration kit, consisting of a short, open and load, used during the relative calibration. Presently electronic calibration (Ecal) is not supported.
- With the N5230A, E836X and N5242A Option 200 / 219 the user also needs to provide at least one external RF source as stimulus of the device under test. This source only needs to cover the desired frequency range of the fundamental and not the frequency range covered by the generated harmonics.
- With the N5242A – Option 224 the second internal source of the PNA can be used as excitation of the device under test as long as it provides the required power.

An external high-resolution screen is needed to display the rich nonlinear information.

Amongst others, the software that comes with the NM101 allows to superimpose the dynamic load line under large-signal conditions on the static DC-IV curves of the device under test, assuming the proper DC instrumentation is present.

Using passive tuner technology from Maury Microwave or using fundamental and/or harmonic active tuning techniques, it is possible to study the behaviour of the component in a non-50 Ohm environment.

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¹ LSNA v2.0.0 is based on Maury Microwave licenses
For power applications the NM101 allows the use of four external couplers in combination with programmable step attenuators, connecting to the input of the receiver channels of the Agilent PNA.

All the software can run on the embedded PC of the PNA or on a separate laptop or computer. External instruments are controlled via the GPIB of the network analyser. Thanks to the open system approach, the system can easily be extended from a basic component characterisation system to an advanced characterisation system.

With an easy-to-use graphical user interface, the user configures and calibrates the system to perform accurate harmonic measurements. Measurement data can be saved in different data formats. The data can be visualised in different ways, including time-domain waveforms similar to an oscilloscope and spectral data similar to a spectrum analyser. The unique feature is that the spectral data includes calibrated phase information.

For the advanced user, a powerful scripting language (Mathematica™) is available, which can be used in parallel with the GUI. Finally an ANSI C application programming interface (API) is provided to control the instrument from several development tools, including VEE™, LabVIEW™ or MATLAB™.

Some Applications

**Understanding the nonlinear behaviour of RF / HF components**

An oscilloscope is an indispensable tool on the lab bench to probe signals and to diagnose the proper behaviour of circuits. For analogue circuits and components operating at an ever increasing signal frequency and information density, voltage information only is not enough. The advantages of using vector network analysers instead of oscilloscopes have clearly been proven for linear RF and HF applications. The VNAPlus provides the same advantage for nonlinear RF and HF applications.

Using the VNAPlus, one can accurately measure and observe the voltage and current behaviour of a component or circuit interacting with its environment. The VNAPlus is a powerful diagnostics tool. These measurements are also directly comparable to the voltage and current probes that one commonly uses in simulators to understand what is going on.

Visualising the breakdown and possible restoration of transistors under realistic RF conditions is one of the many examples where the advantages of the VNAPlus become clear.

**Model verification and tuning**

With VNAPlus, a transistor model can be verified at the level of the mathematical formalism. State-of-the-art verification consists of confronting source-pull and load-pull measurements to simulations. Unfortunately, derived quantities like available power, TOI and SOI are used and these can agree, even when the model is not predicting the voltage and current behaviour properly. The VNAPlus confronts measured voltage–current behaviour to simulated voltage–current behaviour. These are the essential quantities.
In order to enhance the agreement, it is possible to tune the model parameters. This tuning becomes much easier by confronting the basic quantities instead of using derived quantities.

**Optimal amplifier design**

It is possible to perform measurements in a non-50 Ohm environment by combining the VNAPlus with tuning technology. Due to the access to the input and output port, fundamental and harmonic active tuning is possible (see block diagram). Once the system is calibrated, one can modify the setup at these ports without invalidating the calibration.

The software, provided as part of the NM101, does support accurate measurements in combination with the tuners from Maury Microwave. Additionally, the Maury Automated Tuner System (ATS) seamlessly interoperates with the VNAPlus.

Thanks to the VNAPlus it is now possible to match transistors at both fundamental and harmonics to optimise their performance based on instantaneous feedback provided by the voltage and current waveform measurements. The observed waveforms can immediately be compared with the optimal waveforms, described in the textbooks for different modes of operation of amplifiers.

**Measurement-based behavioural modelling**

Accurately measuring the voltage and current behaviour at the input and output of a component or a circuit, provides the basic information to establish the voltage–current relationship under different excitations.

On top of the VNAPlus, NMDG provides a tool to extract a measurement-based behavioural model for a component at the fundamental frequency in a non-50 Ohm environment. This typically requires passive tuners from Maury Microwave.
Source- and Load-Pull Prediction with a Measurement-Based Behavioural Model, verified with measurements

More information

Agilent Technologies PNA  
www.agilent.com

Maury Microwave Tuners and ATS  
www.maurymw.com

VNAPlus, NM101 and other products and services, focusing on nonlinear RF and HF characterisation, behavioural modelling and test:

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October 2007- Product description and specification are subject to change without notice.