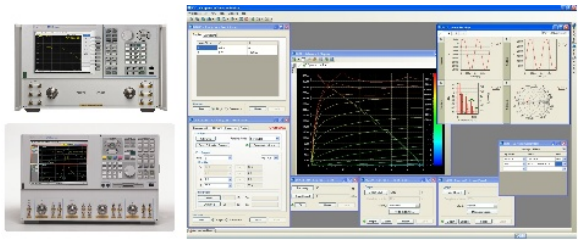
LEADING BEYOND S-PARAMETERS

Product Note : NM100

July 2009

Extension kit for Agilent™ Vector Network Analysers
Characterisation of Nonlinear RF/HF Components in Time and Frequency domain from 600 MHz to 20 GHz



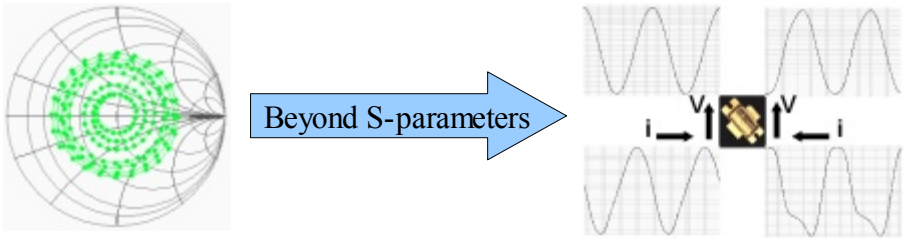
PNAPlus

- **Extension Kit for Agilent™ PNA**
  - **Two-Port N5230A, E836X and N5242A**
  - **Four-Port N5230A and N5242A**
- **Aimed at nonlinear harmonic behaviour**
- **Time Domain Characterisation**
- **Harmonic Characterisation including Phase**
- **Non-50 Ohm Characterisation**
- **Enables Fundamental and Harmonic Tuning**
- **Customisation for power applications**

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.



Full harmonic characterisation of nonlinear RF / HF components

Complete harmonic characterisation of high-frequency components finally becomes possible thanks to the NM100 extension kit from NMDG. The NM100 is a combination of additional hardware and software that runs on top of a selection of PNA vector network analysers from Agilent Technologies™. The combination of the PNA and the NM100 extension kit is referred to as “PNAPlus”.

As known, the network analyser reveals the linear behaviour of components through its S-parameters. But thanks to the PNAPlus, the network analyser now also reveals the nonlinear behaviour of a device. One can actually observe the voltage and current swings occurring at the device, possibly in an non-50 Ohm environment.

The key benefits of the PNAPlus

- **ONE CONNECTION** from small-signal to large-signal HF characterisation
- Reliability testing of semiconductors under HF conditions
- Certified quality of large-signal transistor models and design kits
- Improved large-signal models
- Better and faster amplifier characterisation and design
- **Fast and complete** test capability, even in non-50 Ohm environment
- New insight in diodes, transistors, amplifiers, multipliers and dividers
- Customisation by experts to meet the need of the customer

Using realistic large-signal measurements, the PNAPlus allows to verify and improve transistor models extracted with the same network analyser from small-signal to large-signal conditions. It allows to optimise and validate the biasing and matching conditions of transistors by looking at the actual voltage and current behaviour. It allows to verify the reliability of new semiconductor processing technologies. With this new measurement capability, semiconductor processes will be improved, designs can progress faster and possibly new types of faster tests could result.

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

The key capabilities of the PNAPlus

- **Incident and reflected waves** at input and output port under CW excitation:
  - in frequency domain, fundamental and harmonics in amplitude and phase
  - in time domain, incident and reflected waveforms
- **Voltages and currents** at input and output port under CW excitation:
  - in frequency domain, fundamental and harmonics in amplitude and phase
  - in time domain, voltage and current waveforms
- Realistic non-50 Ohm conditions, at fundamental and harmonics
- Connectorised and **on-wafer** calibration and measurement
- Overrange detection and **autoranging capability**
- **3D dynamic trajectories**, mapping DC and HF conditions
- Derived measurement quantities, e.g. input and output powers, gain, PAE, input and output impedances at fundamental and harmonics
- Integration with Source – and Load-pull: fundamental and harmonic tuning

On top of the standard measurement capabilities of the Agilent™ VNA, the PNAPlus 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. The time waveforms are periodical with a minimal frequency of 600 MHz and with spectral components up to 20 GHz.

These measurements can be performed under realistic conditions, including non-50 Ohm environment using passive or active tuners.

The product supports a frequency range from 600 MHz up to 20 GHz, limited by the frequency range of the selected network analyser.

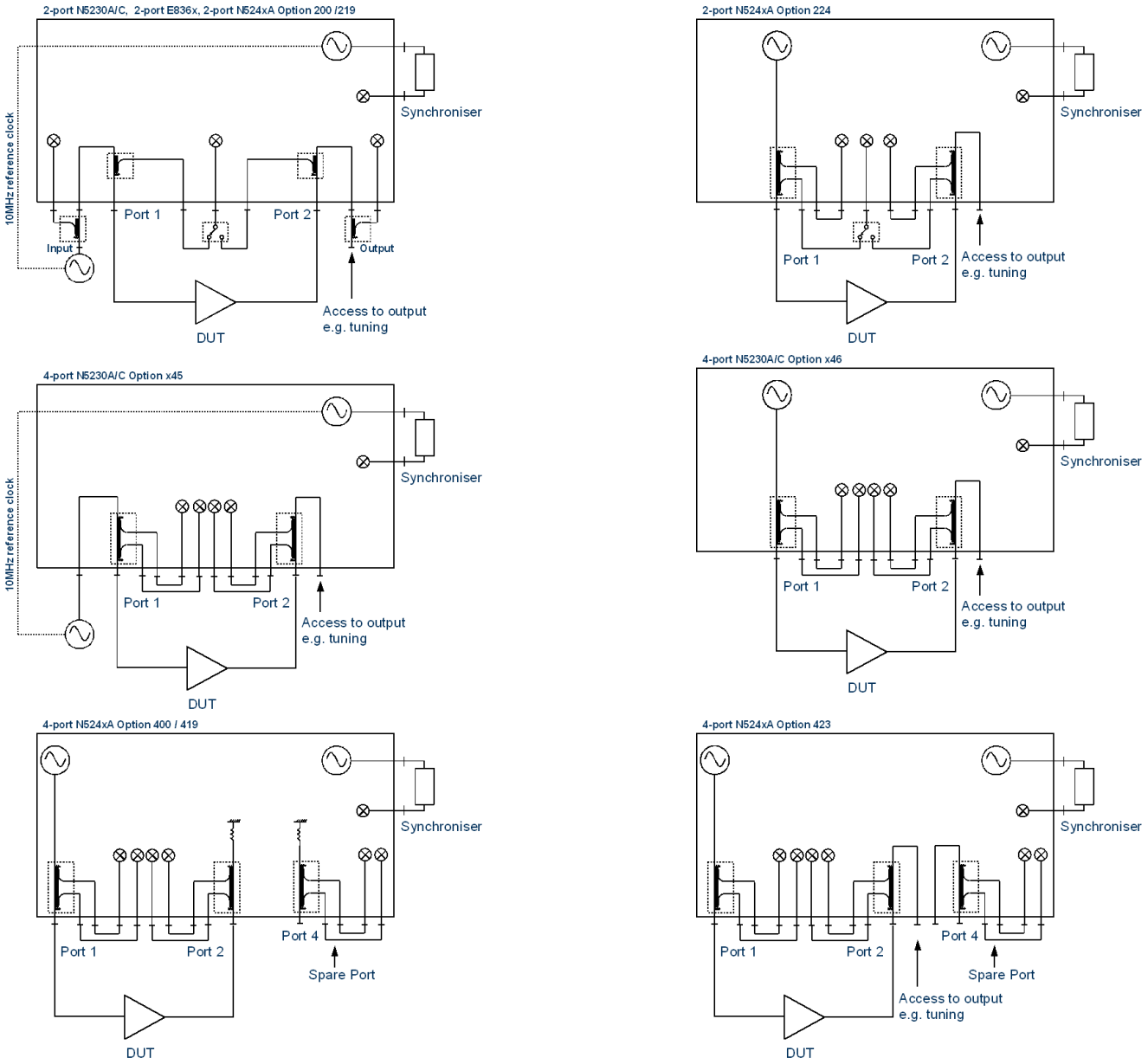
Unless customised, the power is limited by the power limitations of the Agilent™ VNA. Using attenuators with the device under test and/or fixed attenuators in the mixer channels, the power capability can be extended.

By customisation of the test set, NM100 supports measurements requiring power beyond the power capability of the test set, provided by the VNA.

PNAPlus, based on Agilent™ PNA series

Presently the NM100 kit is available on top of Agilent™ PNA with the following options:

- 2-port PNA-L N5230A/C with option x25 (configurable 2-port test set) and option 080 (frequency offset)
- 4-port PNA-L N5230A/C with option x45/6 (4-port test set) and option 080 (frequency offset)
- 2-port PNA E836x with option 014 (configurable 2-port test set) and option 080 (frequency offset)
- 2-port PNA-X N5242A with option 200 or 219 (extended power range) and option 080 (frequency offset)
- 2-port PNA-X N524xA with option 224 and option 080 (frequency offset)
- 4-port PNA-X N524xA – Option 400 (4-port test set – dual source) or 419 (extended power range and bias tees) or 423 (additional switches) and option 080 (frequency offset)



Blockdiagrams of PNAPlus for different PNAs

Due to the test set configuration of the Agilent 2-port PNA-L N5230A/C, E836x and N5242A Option 200 / 219, external couplers are required. Additionally, for all mentioned types and the Agilent 2-port N5242A Option 224, one of the four receivers is sacrificed for the synchronizer 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.

The kit consists of:

- NM400 Synchroniser (600MHz - 20 GHz), enabling the reconstruction of time waveforms
- NM200 and NM210 Harmonic Phase Reference (HPR) 600 MHz - 20 GHz, supporting the required phase calibration
- NM101 3.5mm connection kit, including cables and adapters
- ICE 2009A, an easy-to-use software for nonlinear HF component characterisation, supporting system configuration, absolute calibration and measurement

An 2.4mm to 3.5mm adapter kit (NM100-10) is provided for the Agilent™ E8361, E8363, E8364, N5230C 40GHz/50GHz, N5244A and N5245A.

The user needs to provide:

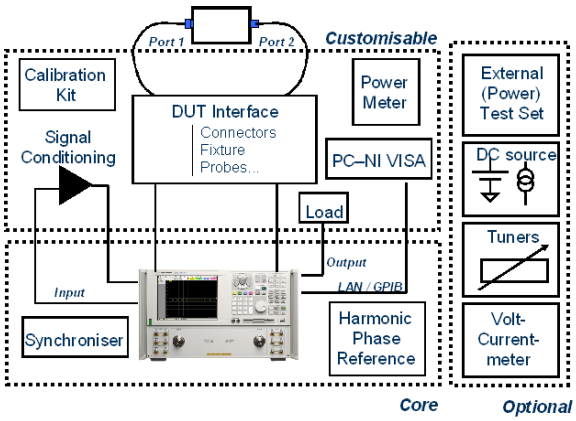
- A power meter (and sensor) in order to perform the required power calibration
- A standard calibration kit, consisting of a short, open and load, used for the relative calibration
- With the 2-port E836x, the 2-port N5230A/C, the 4-port N5230A/C Option 145/245 and the 2-port N524xA Option 200 / 219, 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 2-port N524xA Option 224, the 4-port N5230A/C Option 146/246 and the 4-port N5242A Option 400 / 419 / 423, 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.

In addition, an external high-resolution screen is advised to display the rich nonlinear information.

The PNAPlus comes with NMDG's software package, ICE 2009A (Integrated Component Characterisation Environment). ICE is a software package that supports the complete nonlinear characterisation of components under realistic conditions with almost real-time feedback. This package allows to combine different instruments and equipments, enabling realistic stimuli – response measurements.

ICE runs on a desktop, a laptop or on the selected network analyser. Running on a desktop or laptop, external instruments can be controlled via standard GPIB. Running on the selected network analyser, external instruments are controlled via the LAN, USB or optional GPIB connection of the network analyser. Thanks to the open system approach of ICE, the system can easily be extended from a basic component characterisation system to an advanced characterisation system.

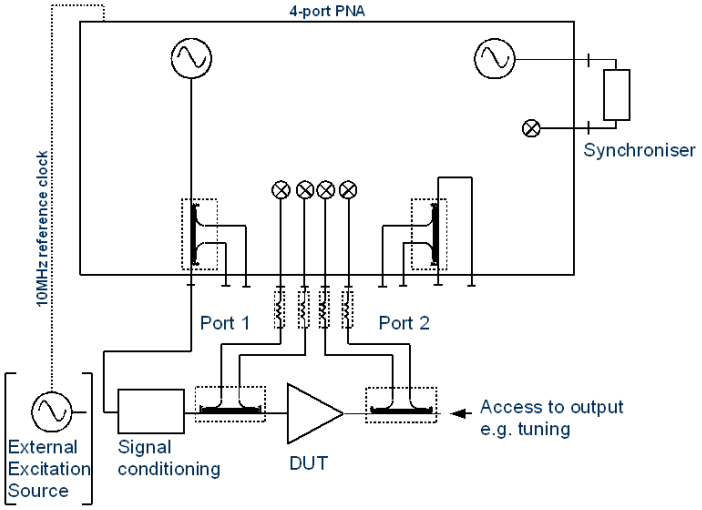
Customisation of the PNAPlus



Configuration and customisation of PNAPlus (E8361A as example)

In contrast to straightforward linear S-parameter measurements, a nonlinear device under test must be characterised under almost realistic conditions. Depending on applications, these conditions are different. Therefore, setups to characterise nonlinearities require often customisation.

Based on a long term experience and relying on the flexible ICE, NMDG offers customisation on top of the PNAPlus to adapt it to customer needs and to link it into the customers process.



Extending power capability with external test set.

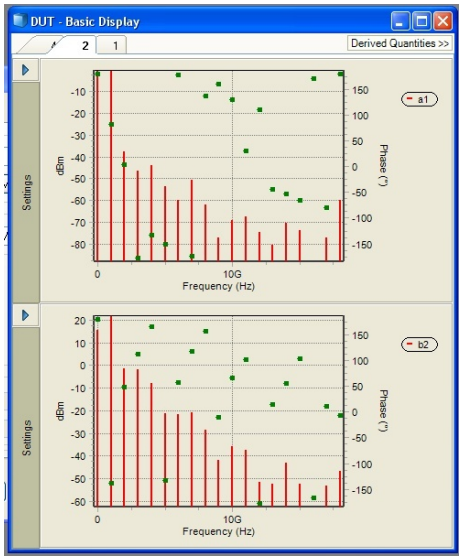
The standard PNAPlus is limited in power capability. Using an external test set with proper coupling and attenuation, the PNAPlus can be extended in power range. Moreover, the internal source power range can be extended using proper signal conditioning. Using passive tuner technology or using fundamental and/or harmonic active tuning techniques, it is possible to study the behaviour of the component in a non-50 Ohm environment.

Data Displays

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, i.e. incident and reflected waves or voltages and currents at the ports of a device under test, can be visualised in different ways.

Spectral data in frequency domain



Amplitude and phase
of incident and transmitted waves
in frequency domain

Similar to a spectrum analyser, the PNAPlus allows to visualise the spectral data of the measured quantities in frequency domain.

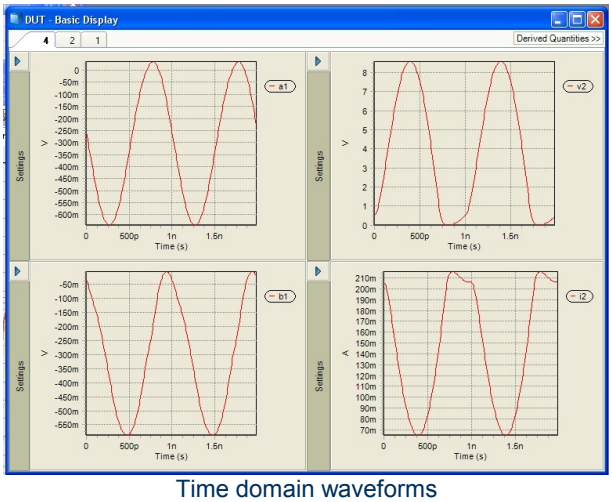
The unique feature is that the spectral data includes calibrated phase information.

Time-domain waveforms

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 PNAPlus provides the same advantage for nonlinear RF and HF applications.

Using the PNAPlus, one can accurately measure and observe the voltage and current behaviour of a component or circuit interacting with its environment. The PNAPlus 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.

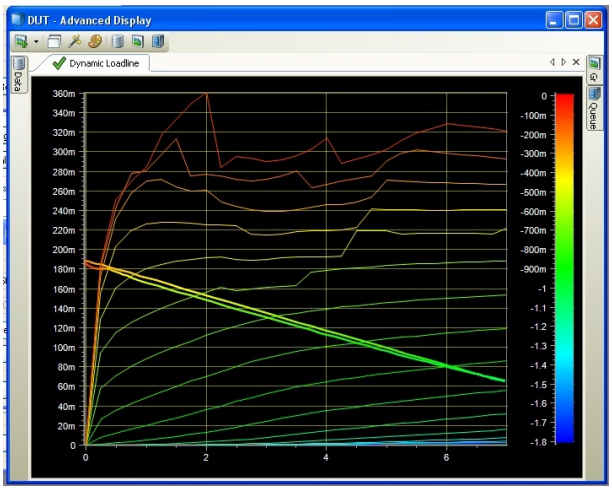


Time domain waveforms
(from top to bottom, left to right: incident wave at input, reflected wave at input, output voltage, output current)

3D dynamic trajectories

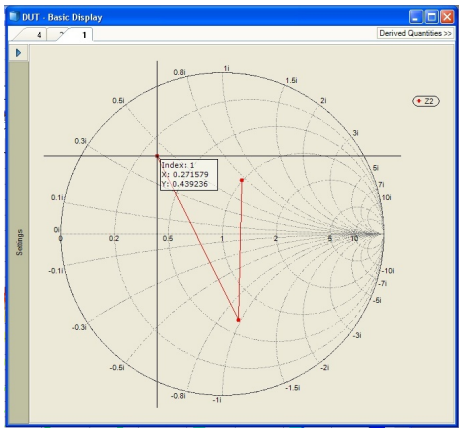
By combining the measured quantities, it is now possible to visualise, almost in real-time, different dynamic trajectories such as the output current waveform versus output voltage waveform, i.e. the dynamic loadline, on top of DC output characteristics of the device under test.

Furthermore, as both quantities at input and output of the device are measured simultaneously, the PNAPlus allows to map, for example, the dynamic excursion of the gate voltage to the static gate voltage, using gradient colours. Different phenomena such as trapping and memory effects or delay between input and output can now be visualised in real-time.



3D dynamic loadline

Input and output impedances on Smith Chart

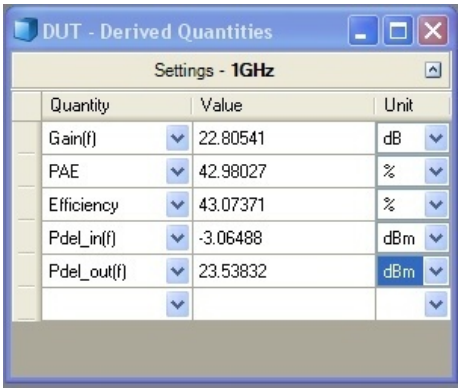


Output impedances with open termination at fundamental, second and third harmonics

Using measured incident and reflected waves, it is possible to calculate and visualise the impedances at DUT input and the output impedances presented at output of the device, at fundamental and harmonics on Smith Chart representations.

Derived quantities

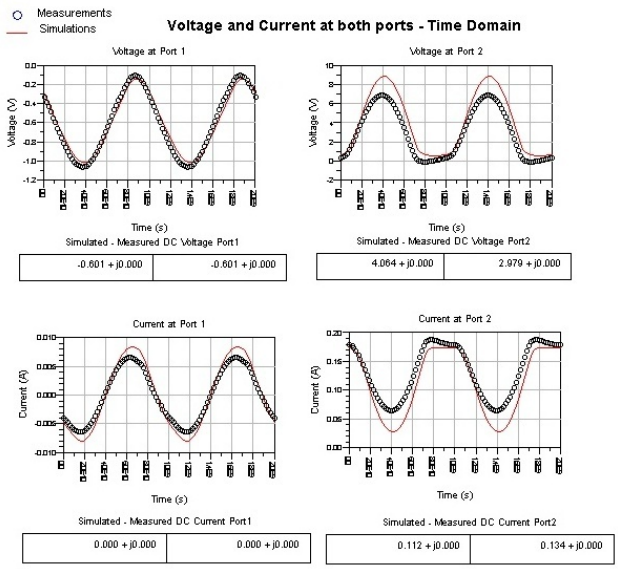
Thanks to the measurement of the basic quantities, one can easily calculate derived quantities such as gain, delivered input and output powers, efficiency and power added efficiency.



Derived quantities

Some Applications

Model verification and tuning



Comparison of measured and simulated voltage and current waveforms

State-of-the-art model 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.

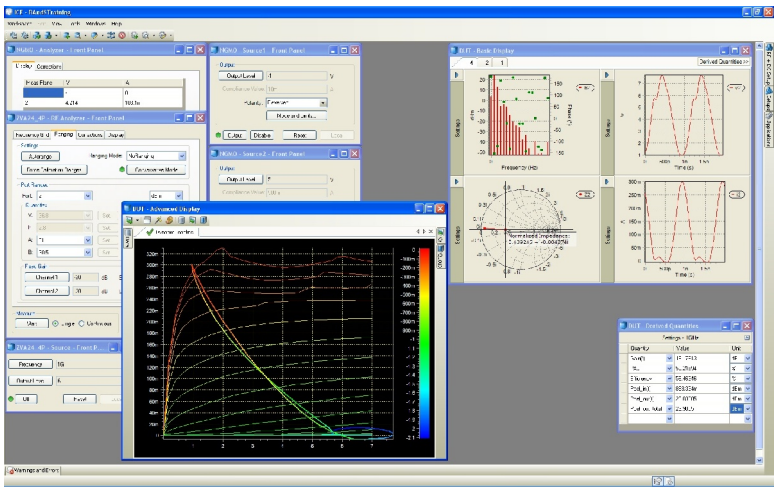
With PNAPlus, a transistor model can now be verified at the level of the mathematical formalism. The PNAPlus confronts measured voltage–current behaviour to simulated voltage–current behaviour. These are the essential quantities.

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.

"On the fly" amplifier design

It is possible to perform measurements in a non-50 Ohm environment by combining the PNAPlus 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.

Thanks to the PNAPlus 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.



Amplifier set in class AB operation optimising fundamental and 2nd harmonic terminations. Direct visualisation of transmitted wave, output impedances, output voltage and current waveforms, derived quantities and dynamic loadline.

The observed waveforms can immediately be compared with the optimal waveforms, described in the textbooks for different modes of operation of amplifiers.

Order information

Designation	Type	Order number
PNAPlus 600MHz-20GHz Kit	NMDG NM100	NM100
2.4mm Adapter Option for NM101 on Agilent™ E8361, E8363, E8364, N5230C 40GHz/50GHz, N5244A and N5245A	NMDG NM100-10	NM100-10
Harmonic Phase Reference Drive Unit	NMDG NM200	NM200
Harmonic Phase Reference 600MHz-20GHz Wand	NMDG NM210	NM210
3.5mm Connection Kit	NMDG NM101	NM101
2.4mm Adapter Kit for NM301 on Agilent™ E8361, E8363, E8364, N5230C 40GHz/50GHz, N5244A and N5245A	NMDG NM101A	NM101A
Synchroniser 600MHz-20GHz	NMDG NM400	NM400

More information

Agilent Technologies™ PNA www.agilent.com

PNAPlus, NM100 and other products and services, focusing on nonlinear RF and HF characterisation, behavioural modelling and test:

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July 2009 - Product description and specification are subject to change without notice.