LEADING BEYOND S-PARAMETERS

ZVxPlus

- Characterisation of Nonlinear RF/HF Components in Time and Frequency domain -

An extension kit for Rohde and Schwarz ZVA and ZVT

April 2009 - v2

Outline

- Motivation
- VNA Evolution
- LSNA Measurements and Calibration
- ZVxPlus
  - What?
  - Capabilities
  - Theory of Operation
  - Customisation
  - From small- to large-signal measurements in one connection
- Conclusion

The Market Trend

- RF and HF Components and Circuits = "More for Less"
  - Higher efficiency (power & bandwidth)
  - More complex (circuits & modulation schemes)
  - Smaller, cheaper, shorter time to market

- Nonlinear behaviour of components can no longer be ignored
- Interaction between instruments and devices may lead to wrong conclusions
- Existing characterisation techniques are no longer sufficient

Growing need to characterise
the nonlinear behaviour of components
in time and frequency domain
at DUT reference plane

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Existing Characterisation Techniques

- Existing approaches
  - Power Measurements
  - Spectrum Analysis – Compression - TOI
  - Vector Signal Analysis - EVM
  - AM-AM and AM-PM
  - Source- and Load-pull

- The problem
  - "Limited visibility"
    - Lacking the basic information to gain insight
    - Difficult to perform a step by step diagnostics
  - Instrument – component interaction
    - Impact on (assumed) excitations
    - Impact on results and specifications
  - Different setups
    - Different skill sets
    - Different calibration techniques

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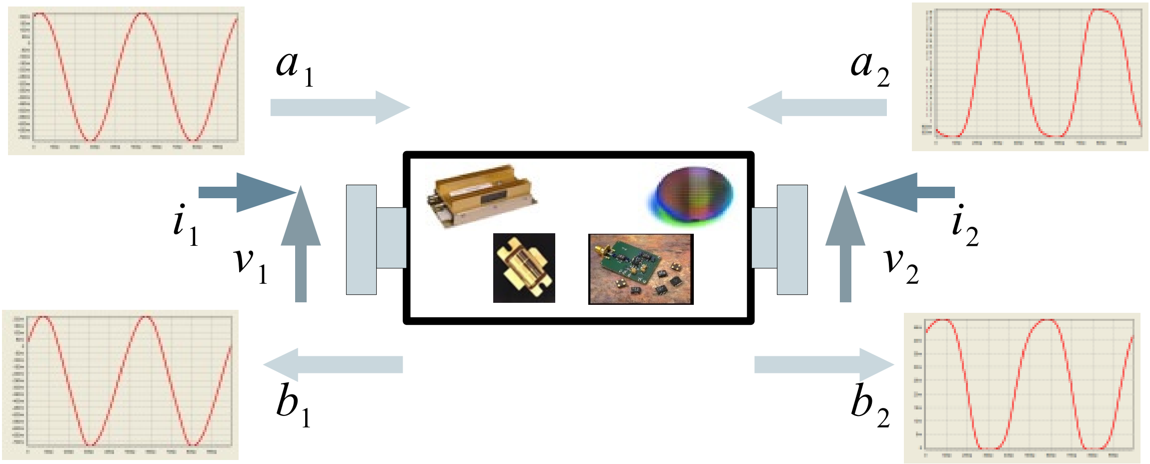
The New Characterisation Technique

- **"Large-Signal Network Analysis"** is
  - Measuring the "complete" behaviour of a device under test
    i.e. the **v and i (or a and b) at all DUT ports** at the same moment
  - Accurately
  - Under almost realistic conditions
    - Excitation and mismatch
  - Using a single connection
    - Including small-signal analysis



Key Benefits

- Deal with the **"More for Less"** market trend
  - for diodes, transistors, amplifiers, multipliers, dividers, ...
- Better – More complete
  - better characterisation = improved and "LSNA-certified" models and design kits
  - better large-signal models = better design
  - better design = reduction of the number of design cycles
  - testing under realistic conditions: excitations & mismatch conditions
- Faster
  - single connection for small- and large-signal characterisation
  - measuring basic information, i.e. PAE, Pin, Pout, ... are simple derived quantities
- At reduced cost
  - applicable from device to system level
  - from R&D to T&M

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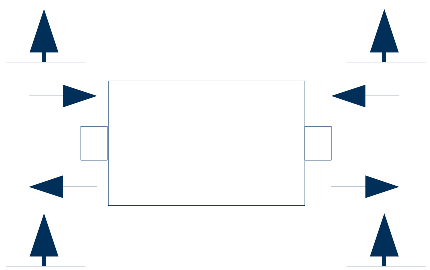
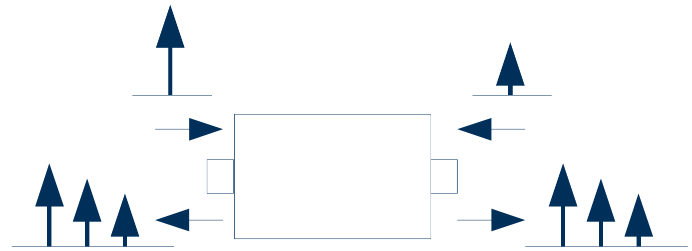
The VNA Evolution

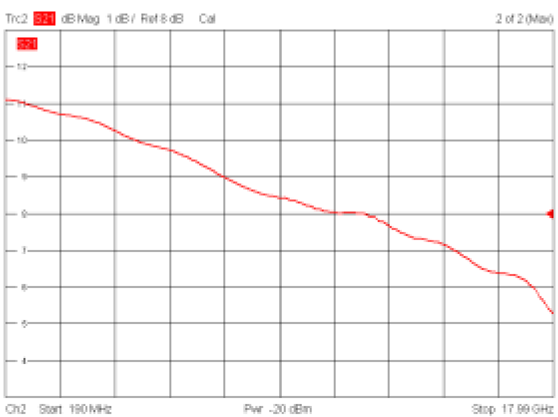


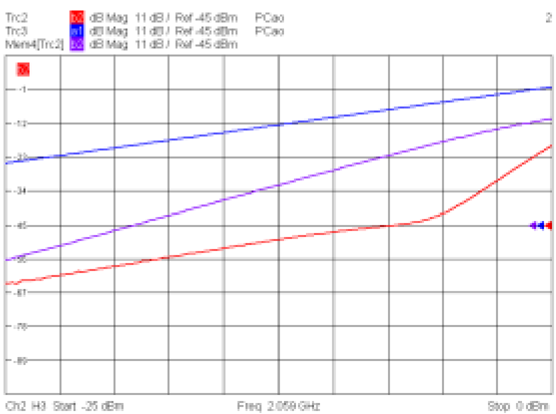
Linear

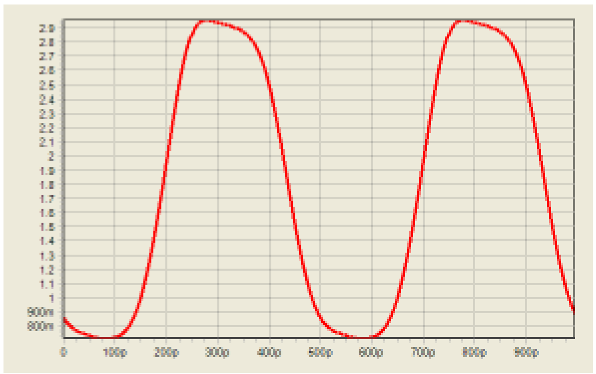


Nonlinear

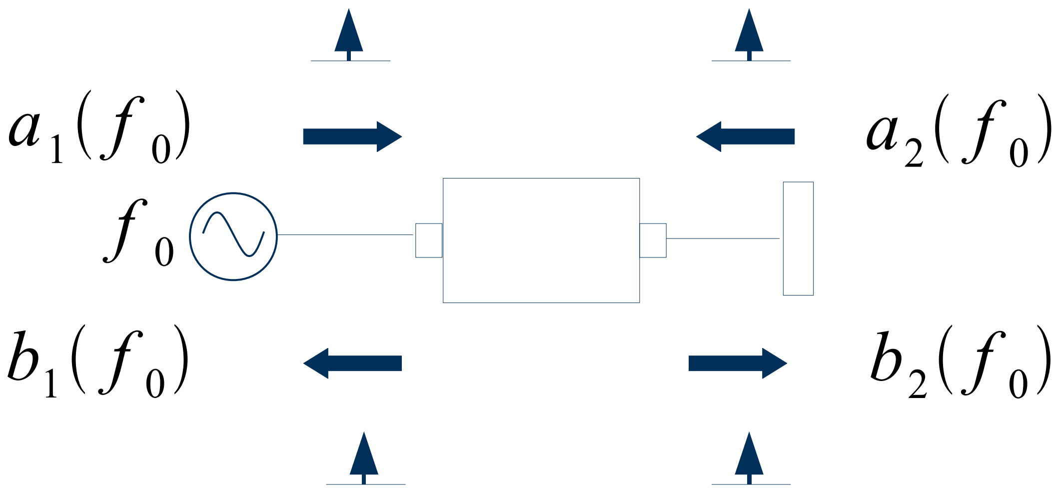
S-parameters → Power of Harmonics and Intermodulation → (ZVxPlus) → Phase of Harmonics







One VNA Measurement

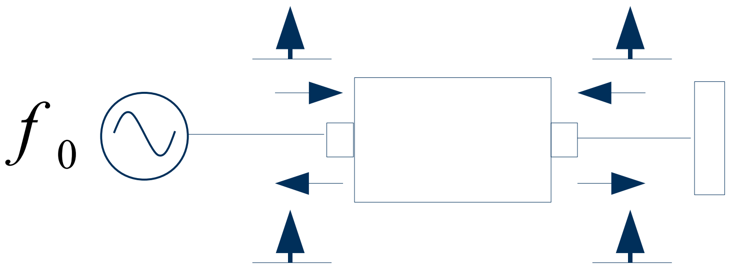


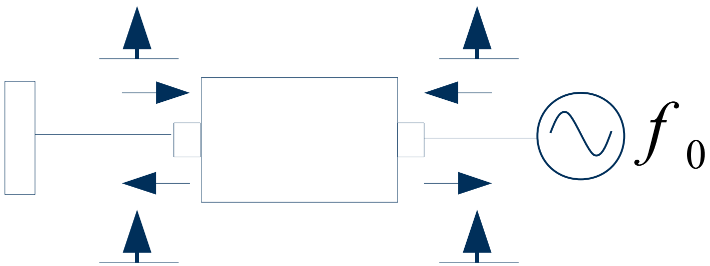
Measuring:

$$\frac{b_1(f_0)}{a_1(f_0)}, \frac{b_2(f_0)}{a_1(f_0)}, \frac{a_2(f_0)}{a_1(f_0)}$$

Basic quantities ≠ S-parameters

S-parameters





Forward Measurement + Reverse Measurement

+

$$b_1 = S_{11} a_1 + S_{12} a_2$$
$$b_2 = S_{21} a_1 + S_{22} a_2$$

= S-parameters

Mathematics
[Linear Model]
[**SUPERPOSITION**]

Behavioural Model

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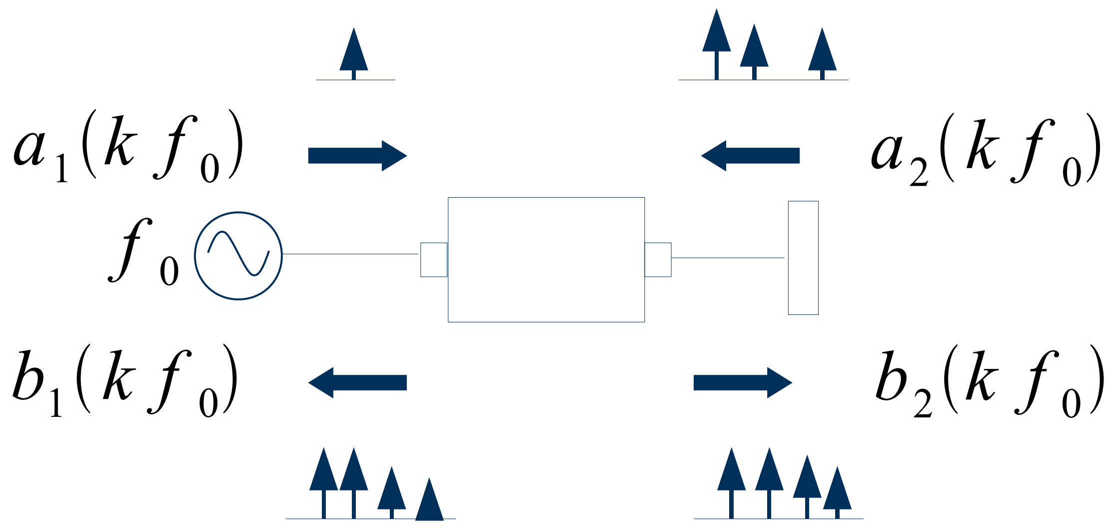
One LSNA Measurement



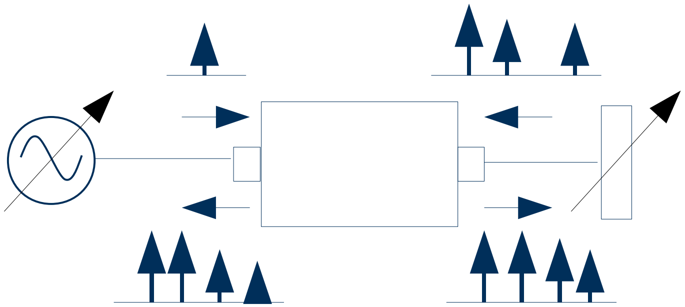
Measuring:

$$a_1(k f_0), b_1(k f_0), a_2(k f_0), b_2(k f_0)$$

OR

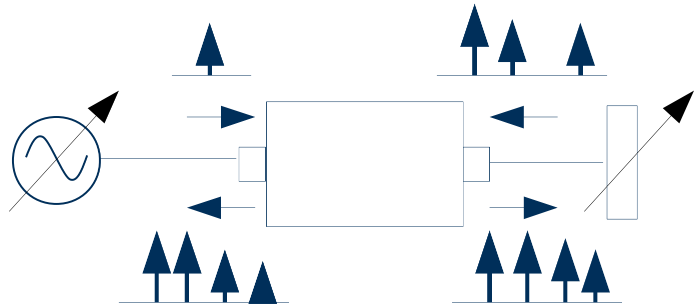
$$v_1(k f_0), i_1(k f_0), v_2(k f_0), i_2(k f_0)$$

???-parameters



Forward Measurement

+



Another Forward Measurement

+ ...

+

$$b_1 = F(a_1, a_2)$$
$$b_2 = G(a_1, a_2)$$

=

???-parameters

Mathematics
[Many possible Nonlinear Models]
[**NO SUPERPOSITION**]

Behavioural Model
[**VALIDITY - BOUNDARIES**]

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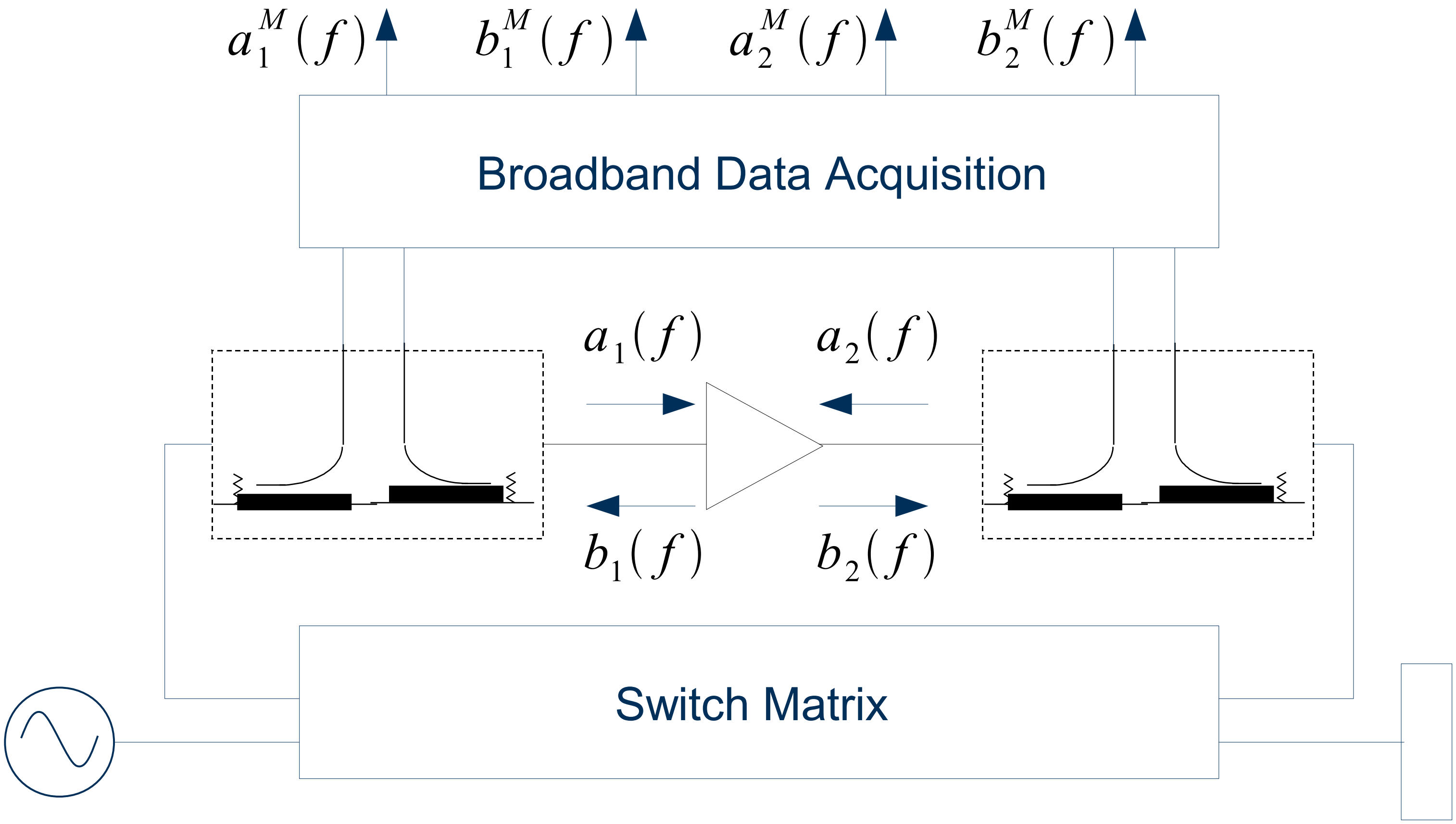
Block diagram of a Large-Signal Network Analyser



$$\begin{bmatrix} a_1 \\ b_1 \\ a_2 \\ b_2 \end{bmatrix}(f) = K(f)\begin{bmatrix} 1 & M_{12} & M_{13} & M_{14} \\ M_{21} & M_{22} & M_{23} & M_{24} \\ M_{31} & M_{32} & M_{33} & M_{34} \\ M_{41} & M_{42} & M_{43} & M_{44} \end{bmatrix}(f)\begin{bmatrix} a_1^M \\ b_1^M \\ a_2^M \\ b_2^M \end{bmatrix}(f)$$

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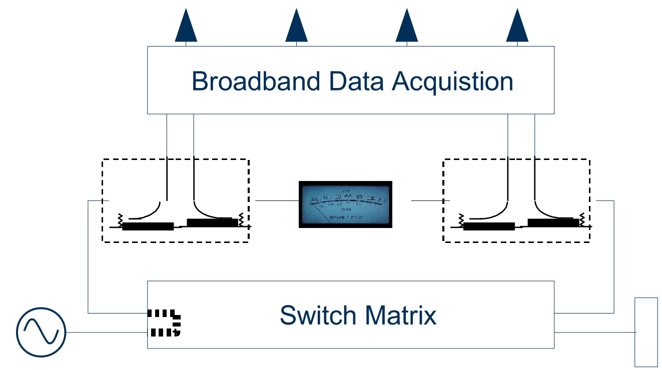
Calibration Techniques

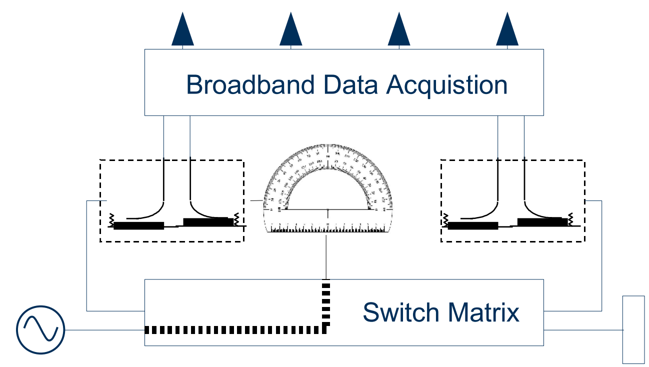
- Step 1: Relative Calibration Technique M_{ij}
  - Same as the regular VNA calibration
  - Traceable to standards

$$\begin{bmatrix} a_1 \\ b_1 \\ a_2 \\ b_2 \end{bmatrix}(f) = K(f) \begin{bmatrix} 1 & M_{12} & M_{13} & M_{14} \\ M_{21} & M_{22} & M_{23} & M_{24} \\ M_{31} & M_{32} & M_{33} & M_{34} \\ M_{41} & M_{42} & M_{43} & M_{44} \end{bmatrix}(f) \begin{bmatrix} a_1^M \\ b_1^M \\ a_2^M \\ b_2^M \end{bmatrix}(f)$$

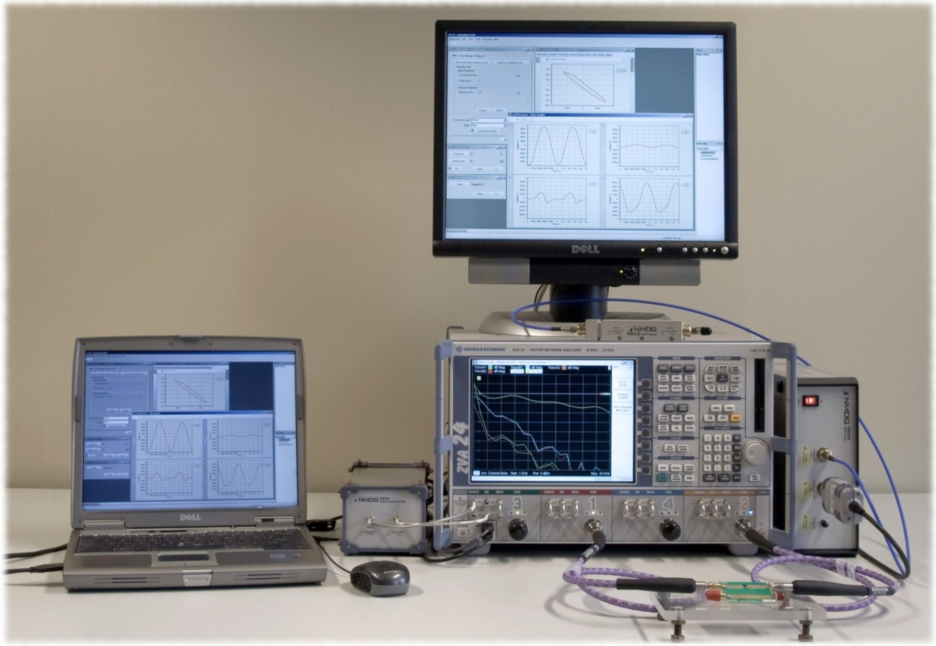
- Step 2: Power calibration $|K|$
  - Power meter and sensor
  - Characterization of power distortion
  - Traceable to standards



- Step 3: Phase calibration $\Phi(K)$
  - Phase reference generator
  - Characterization of phase distortion
  - Traceable to NIST standard



- Remark: On-wafer and fixture calibration require additional steps



ZVxPlus

=

4-port ZVA or ZVT +

- direct gen. & rec. access (B16)
- frequency conversion (K4)
- meas. rec. step att. (opt.) (B3x)

Hardware +

- synchroniser
- harmonic phase ref.

Software

- configuration
- absolute calibration
- measurements

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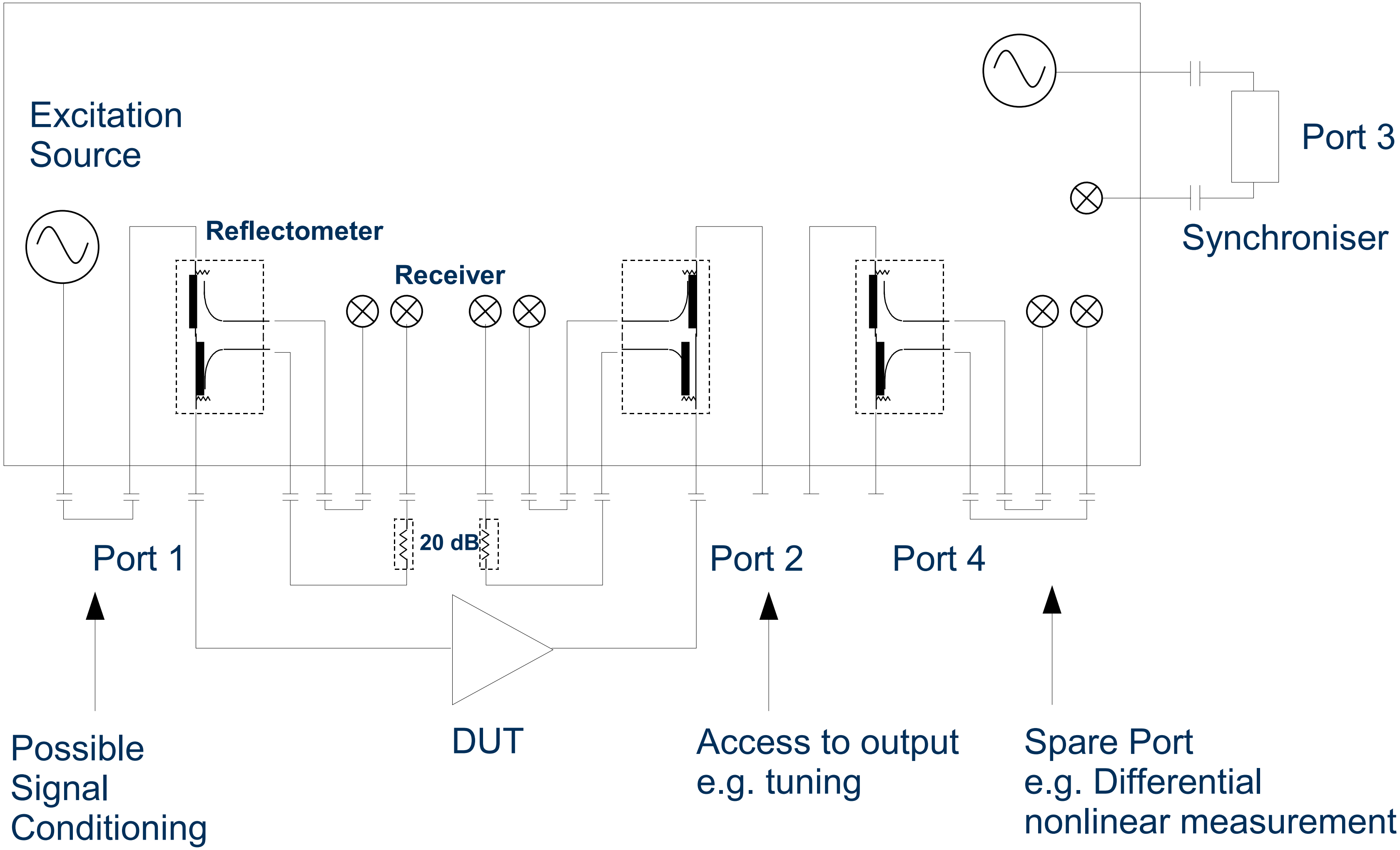
Key Capabilities

Aimed at the characterisation of the nonlinear harmonic behaviour of active components and circuits (e.g. diodes, transistors, amplifiers, multipliers, dividers)

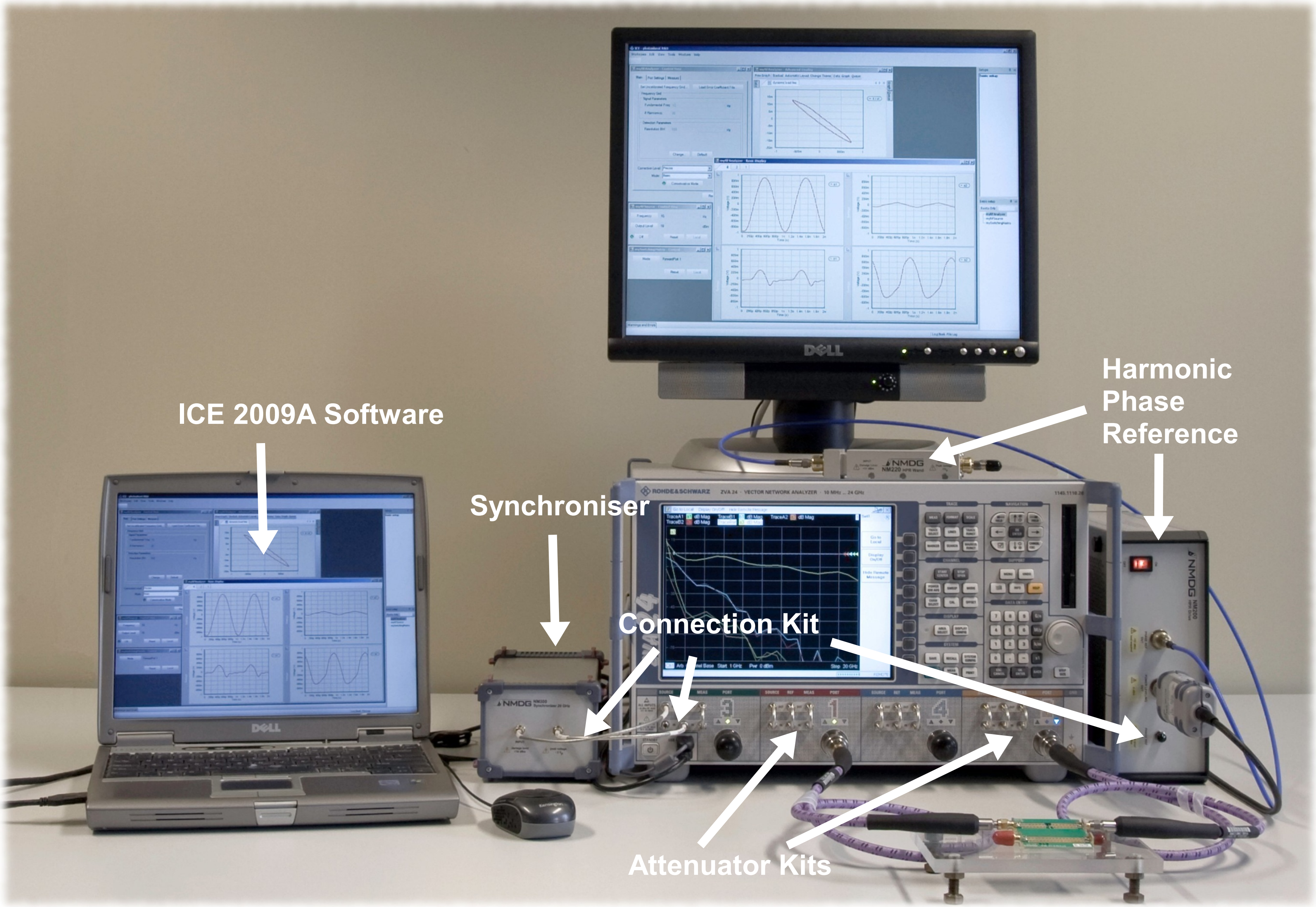
by providing

- Amplitude and phase of fundamental and harmonics
- Incident and reflected waves or voltages and currents
- In frequency and time domain
- Under mismatched conditions (non-50 Ohm)
- Connectorised and on-wafer measurement and calibration
- Overrange detection and autoranging capability
- 3D Dynamic loadline, mapping DC and HF conditions
- Derived quantities: Pin, Pout, Gain, PAE, input & output impedances
- Integration with Source – and Load-pull: fundamental and harmonic tuning
- Customisation for power applications
- Customisation to solve a customer problem

Block diagram of standard ZVxPlus



ZVxPlus Parts



ZVxPlus Details

NM300 600MHz-20GHz Kit includes:

- 1x NM400 Synchronizer 600MHz-20GHz,
  enabling the reconstruction of time waveforms
- 1x NM200 Harmonic Phase Reference Drive Box +
  1x NM210 Harmonic Phase Reference Wand 600MHz-20GHz,
  supporting the required phase calibration
- 1x NM301 3.5mm Connection Kit,
  including cables and adapters
- 1x ICE 2009A Software License
- One year warranty and support

ZVxPlus Options

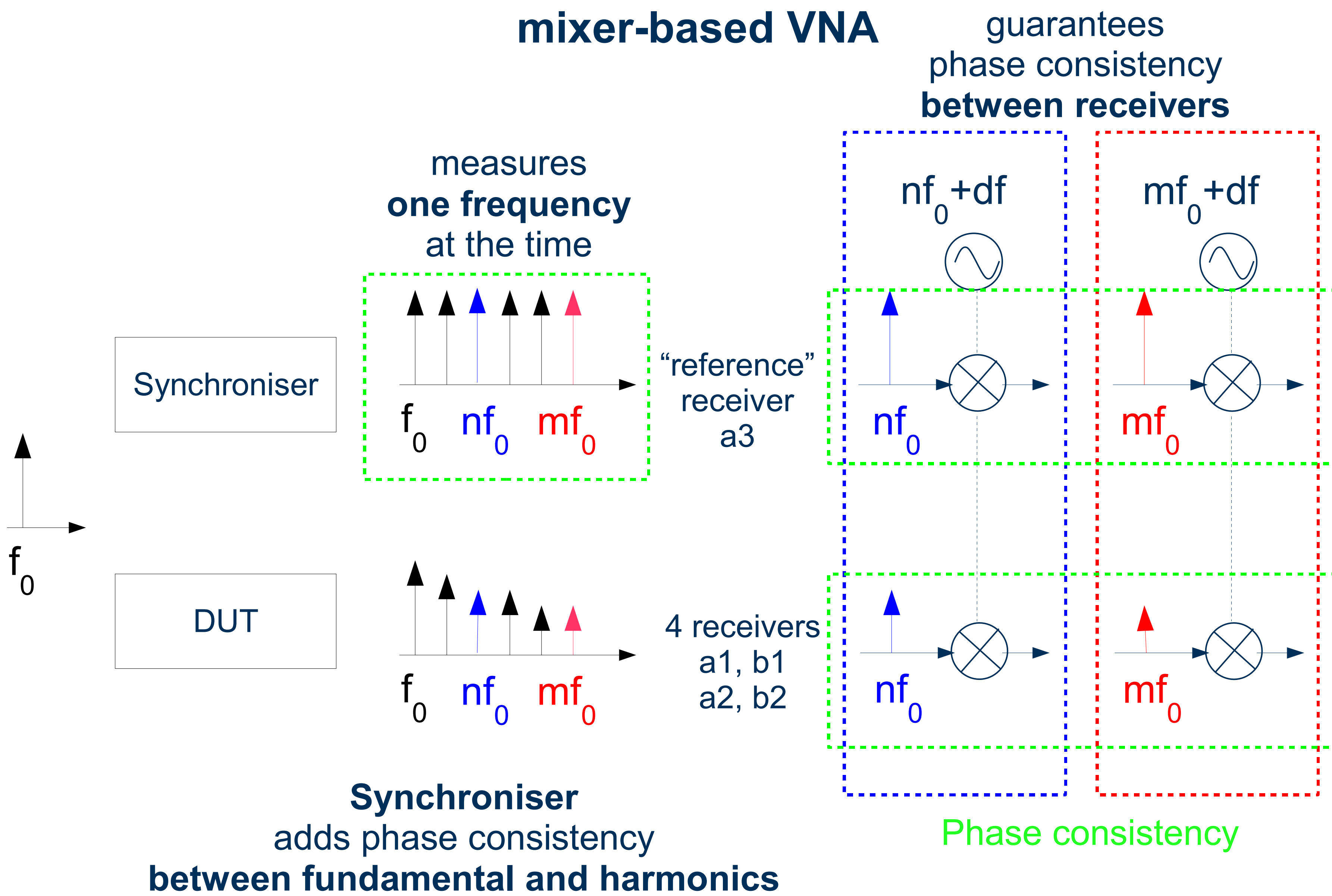
Adapter Kits

- **NM300-10** 2.4mm to 3.5mm adapter option for NM301, required for R&S®ZVA50

Attenuator Kits, required ***per port*** when corresponding internal step attenuator is missing (option B31 and/or B32)

- **NM300-20** 20GHz attenuator option for R&S®ZVT20 / R&S®ZVA24
- **NM300-40A** 20GHz attenuator option for R&S®ZVA40
  or
  NM300-40B 40GHz attenuator option for R&S®ZVA40
- **NM300-50A** 20GHz attenuator option for R&S®ZVA50
  or
  NM300-50B 50GHz attenuator option for R&S®ZVA50

VNA as LSNA: Theory of Operation



References

- U. LOTT, “Measurement of Magnitude and Phase of Harmonics Generated in Nonlinear Microwave Two-Ports”, *IEEE Transaction on Microwave Theory and Techniques*, vol. 37, n°10, October **1989**, pp. 1506-1511
- D. BARATAUD, et al., "Measurements of time domain voltage/current waveforms at R.F. And microwave frequencies, based on the use of a Vector Network Analyzer, for the characterization of nonlinear devices. Application to high efficiency power amplifiers and frequency multipliers optimization", *IEEE Transactions on Instrumentation and Measurement*, vol. 47, n°5, October **1998**, pp.1259-1264

NM300 ZVxPlus: Specifications

based on a 4-port R&S®ZVA24	Value	Remarks:
Frequency range	**600 MHz – 20 GHz**	**limited by phase calibration**
Minimal frequency grid spacing	**600 MHz**	
Power level *	**+10 dBm**	**@ Test port**
Absolute phase uncertainty **		**1 σ @ 20 GHz**
using second internal source	**0.6°**	**independent of IF BW, due to phase variations between the internal sources**
using external source (locked to 10 MHz)	**6°**	**@ 100 Hz IF BW, highly dependent on external source**

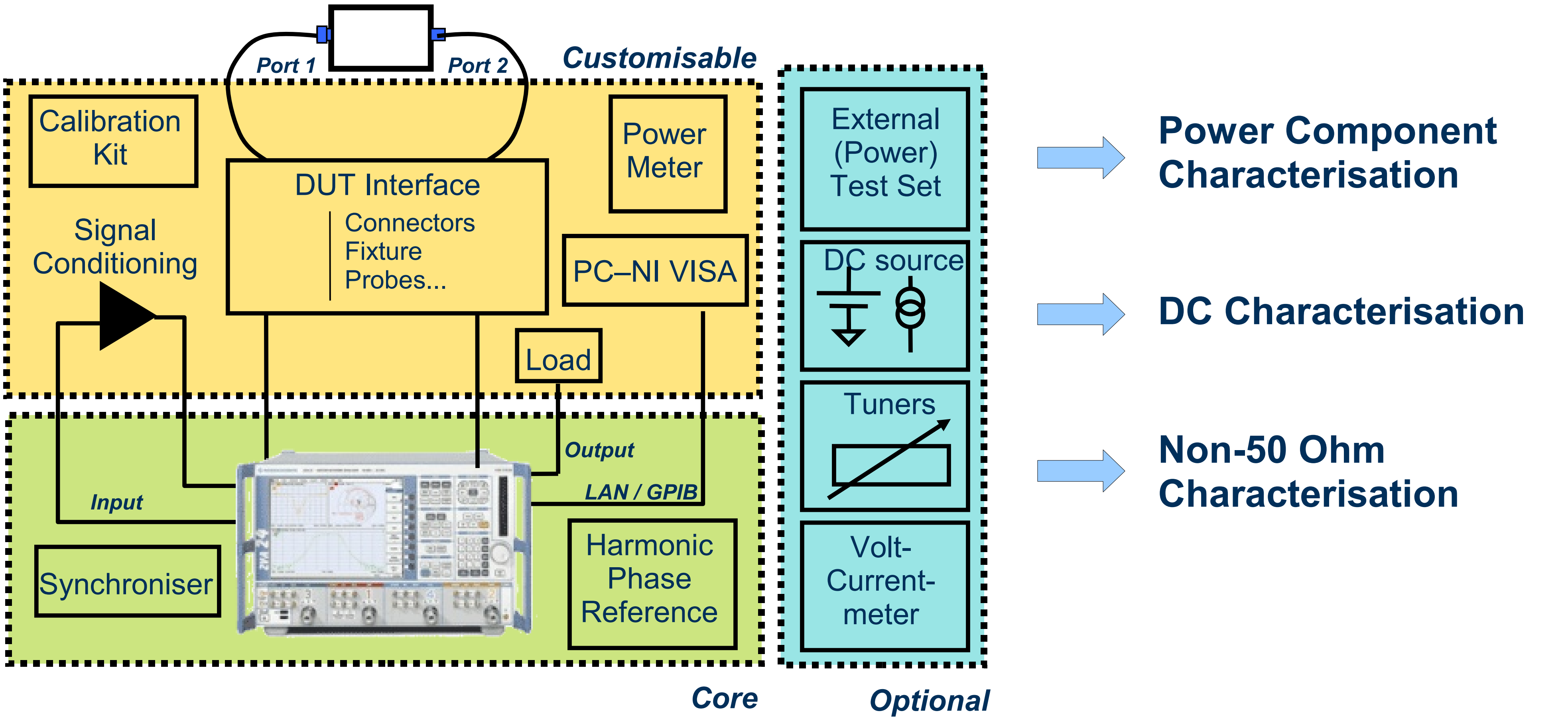
* *Power extension possible using optional step attenuators or external attenuators achieving maximum allowable power of +27 dBm with standard test set*

** *Using one R&S®ZVA internal source to drive Synchroniser @ 600MHz*

Notes: when additive noise is dominant, the phase standard deviation can be linked to the dBm standard deviation using the following:

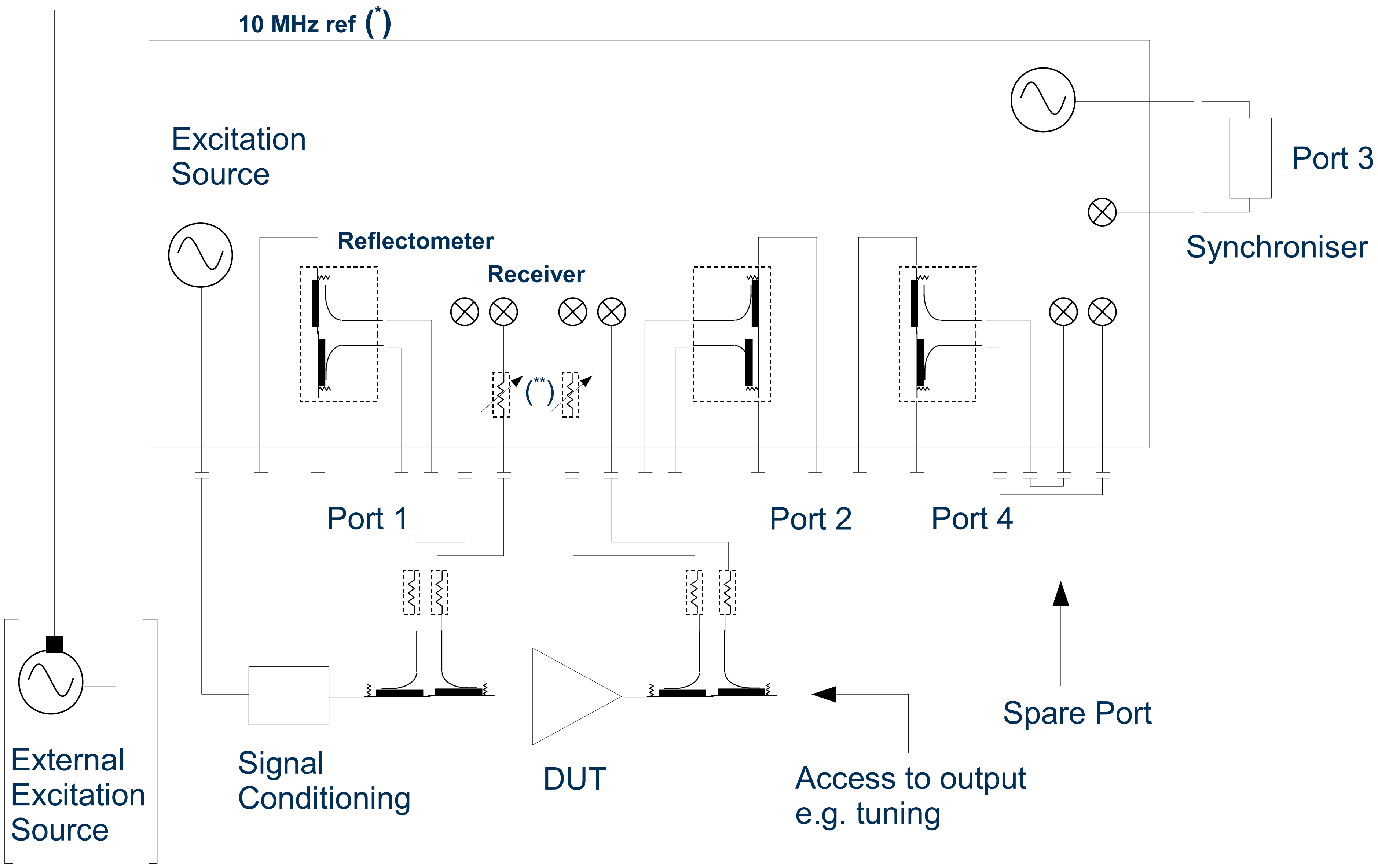
$$\sigma_{Phase(x)_{deg}} = \frac{180}{\pi}\frac{\ln(10)}{20}\sigma_{dBm(x)} \approx 6.6\,\sigma_{dBm(x)}$$

Customisation and Options



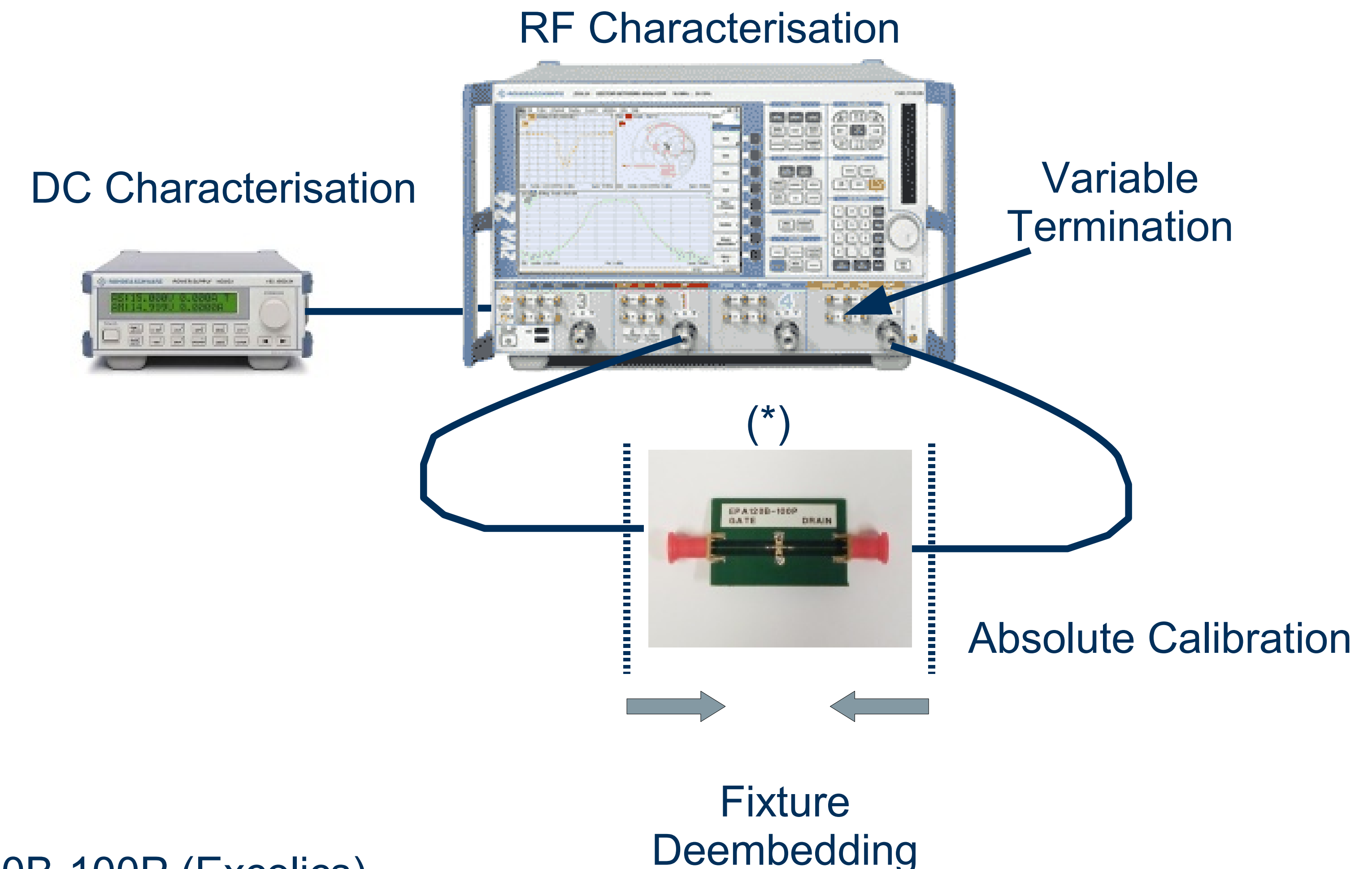
Core: ZVx and ZVxPlus
Customisable: required and supplied by customer or at additional cost
Optional: depending on characterisation needs, supplied by customer or at additional cost

Blockdiagram of customised ZVxPlus for Power Applications



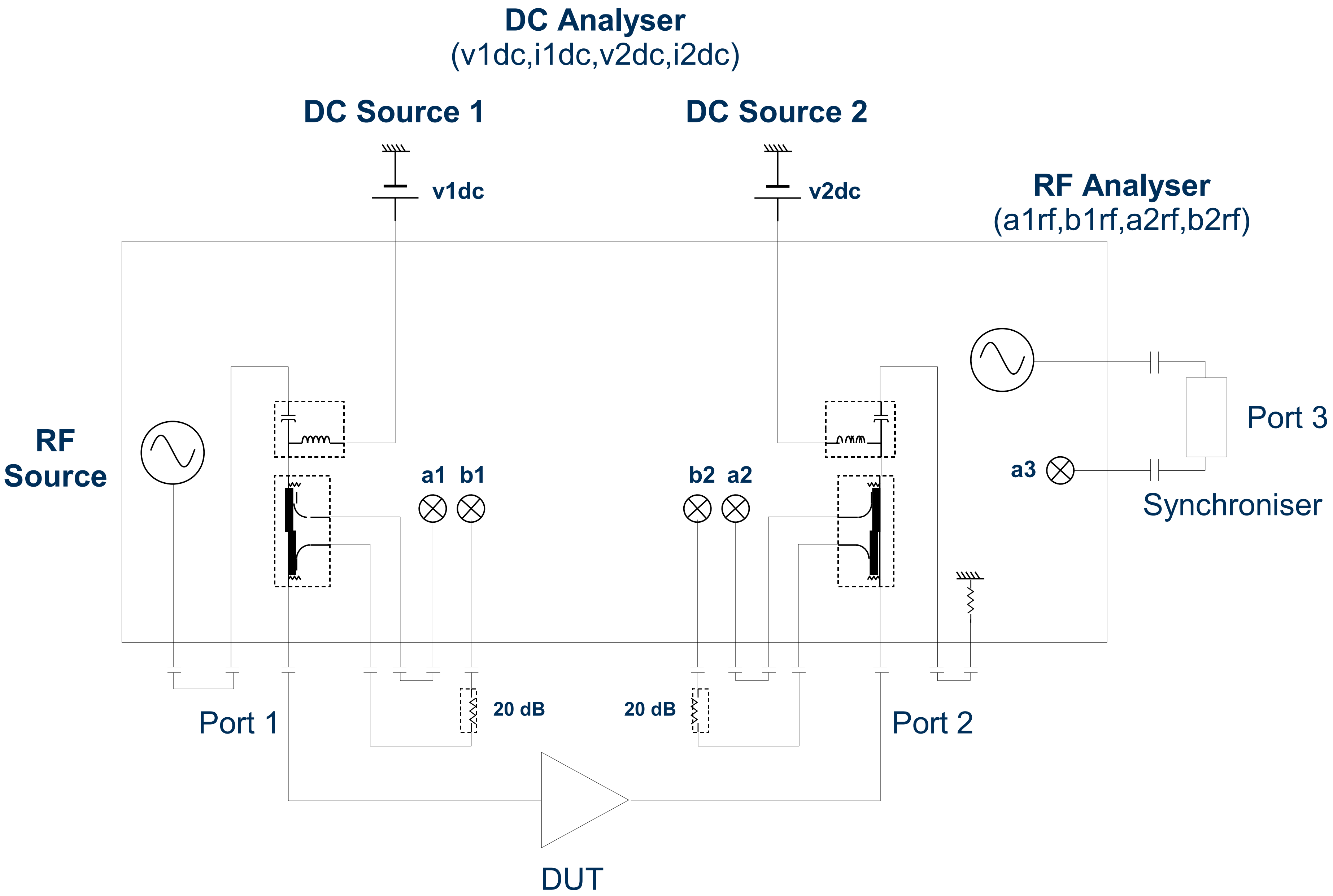
(*): impact on phase noise (**): optional step attenuator option

From Small-Signal To Large-Signal with ***one connection***



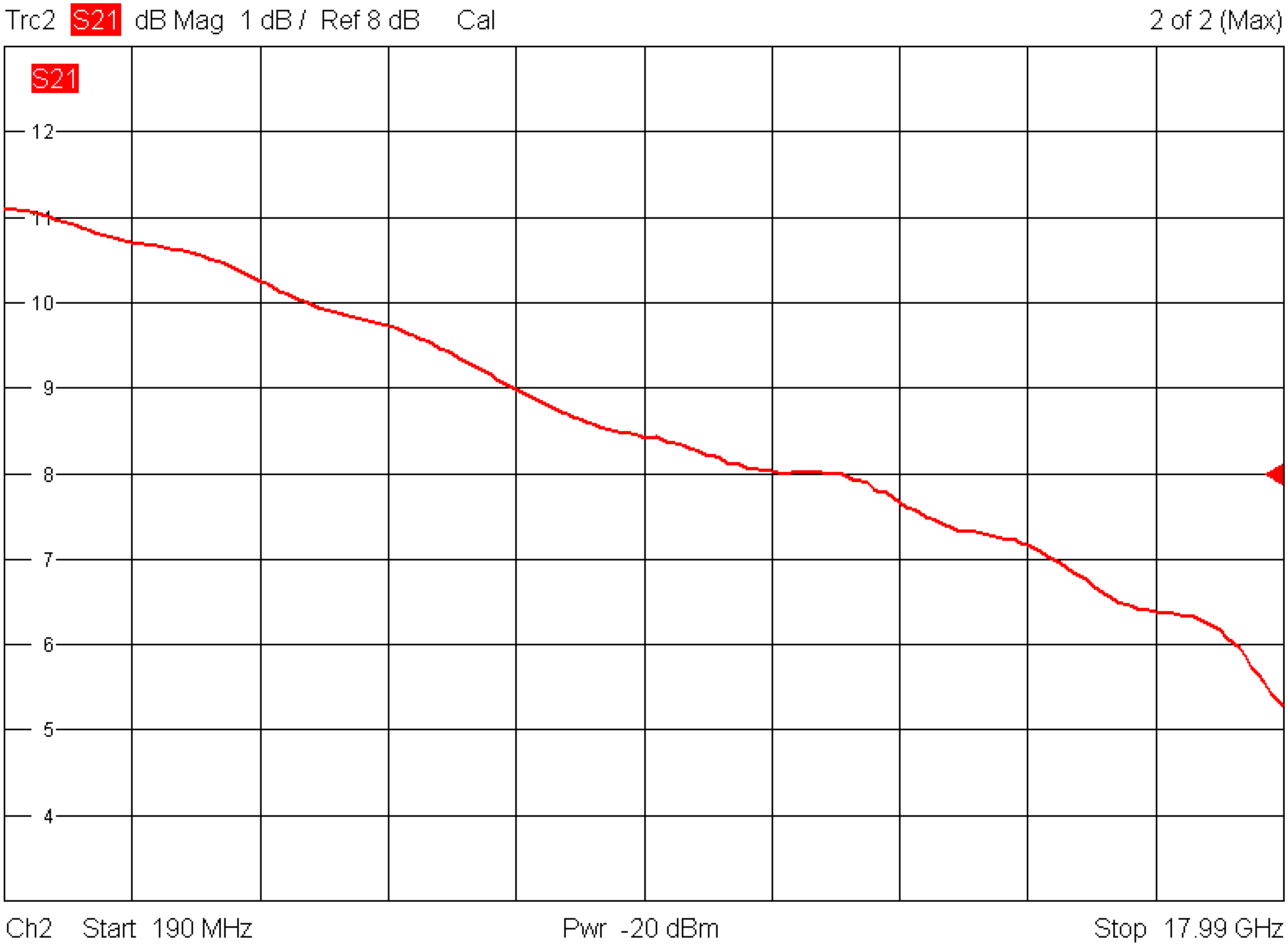
(*) EPA120B-100P (Excelics)
•high efficiency heterojunction power FET
•power output: + 29.0dBm typ.
•power gain: 11.5dB typ. @ 12 GHz

Classical Measurement Setup



ZVx(*): S-parameters

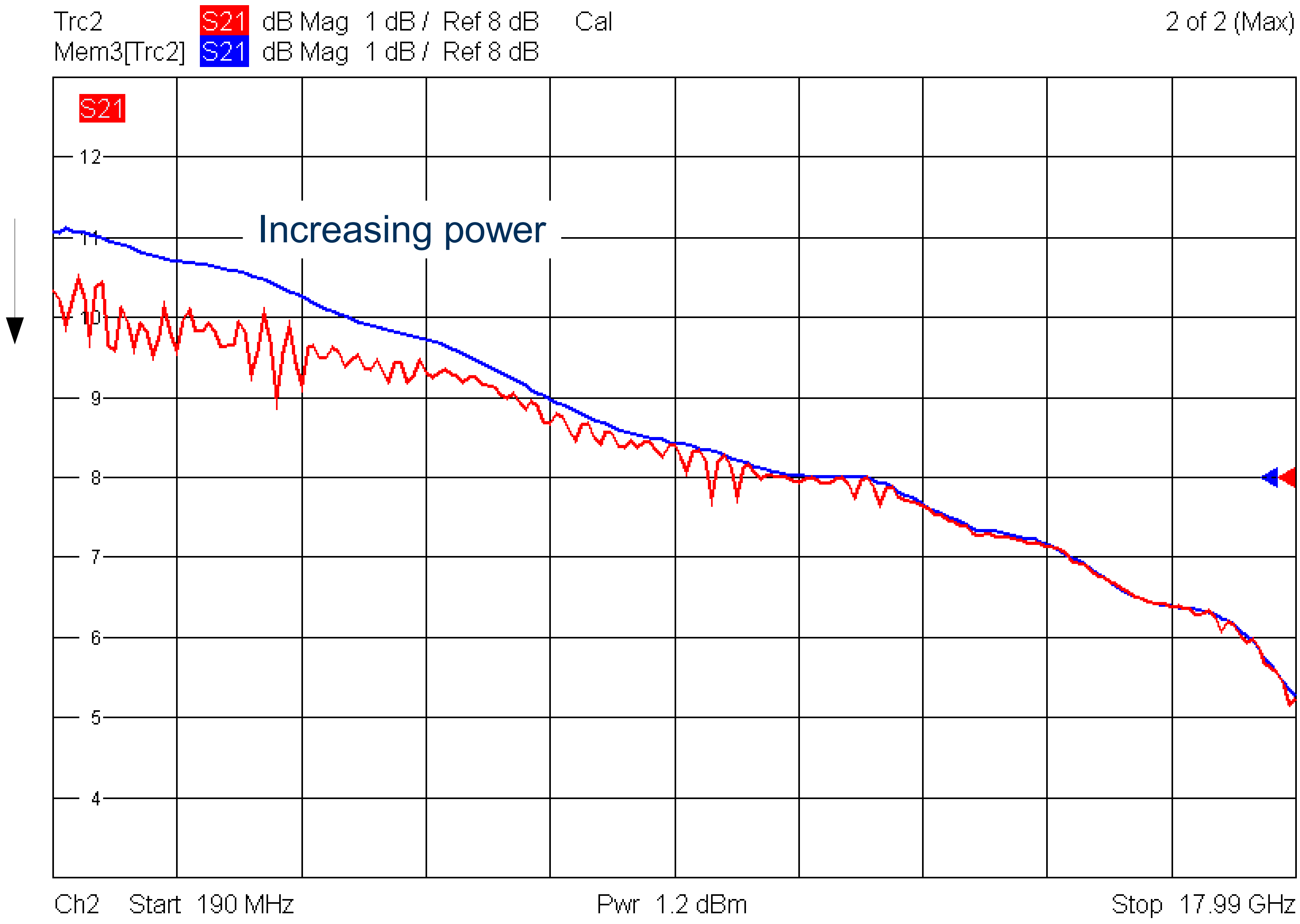
$v_{gs} = -0.5\,\text{Volt}\; v_{ds} = 2.0\,\text{Volt}\; P_{in} = -20\,\text{dBm}$



(*) ZVA or ZVT

"Noisy" S-parameters ???

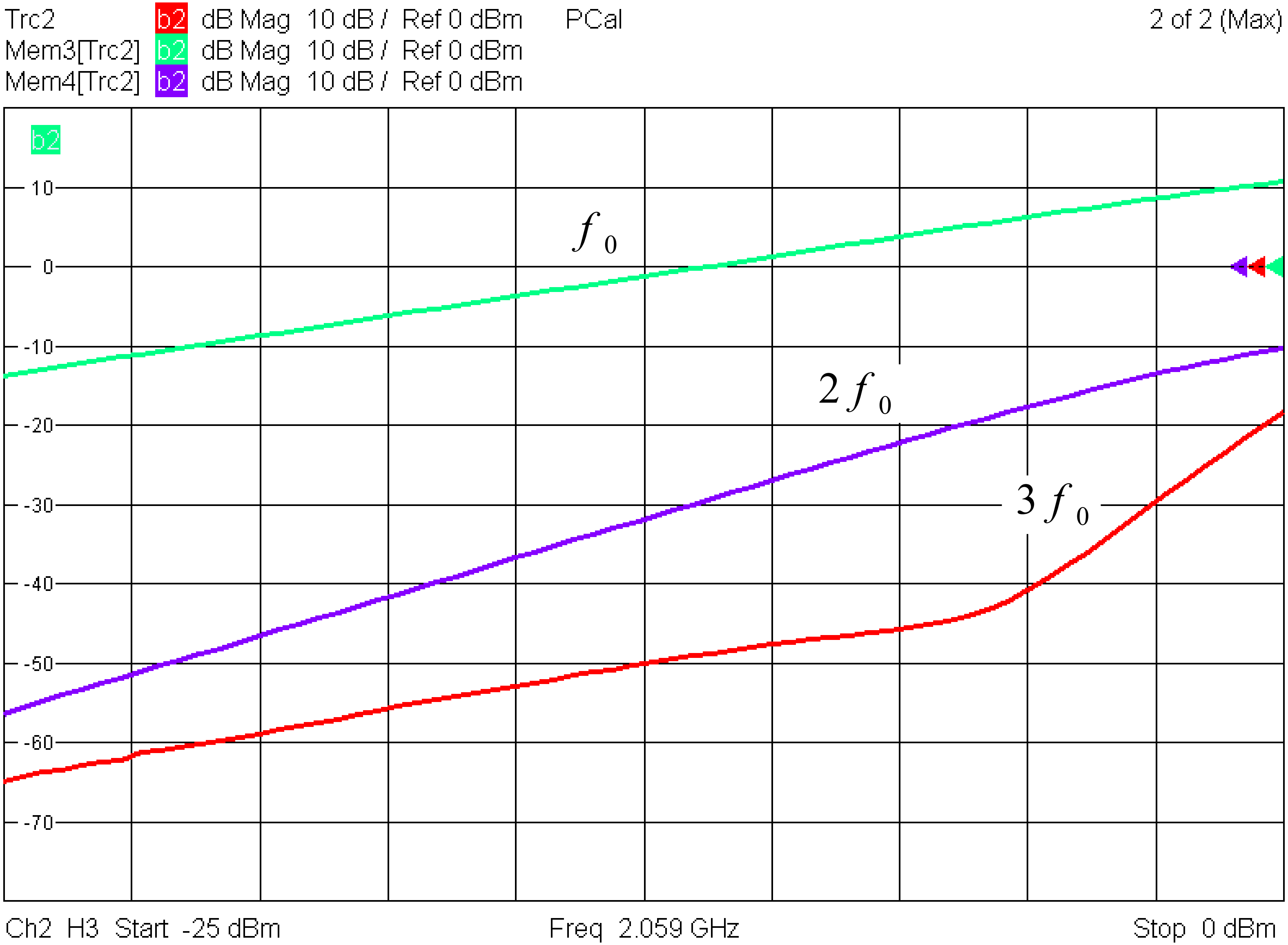
$v_{gs} = -0.5\ \text{Volt}\ v_{ds} = 2.0\ \text{Volt}\ P_{in} = 0\ \text{dBm}$



ZVx: Harmonic Characterisation in Power

$v_{gs} = -0.5\,\mathrm{Volt}\; v_{ds} = 2.0\,\mathrm{Volt}\; P_{in}$: from -25 to $0\,\mathrm{dBm}$ at $f_0 = 2.059\,\mathrm{GHz}$

b_2



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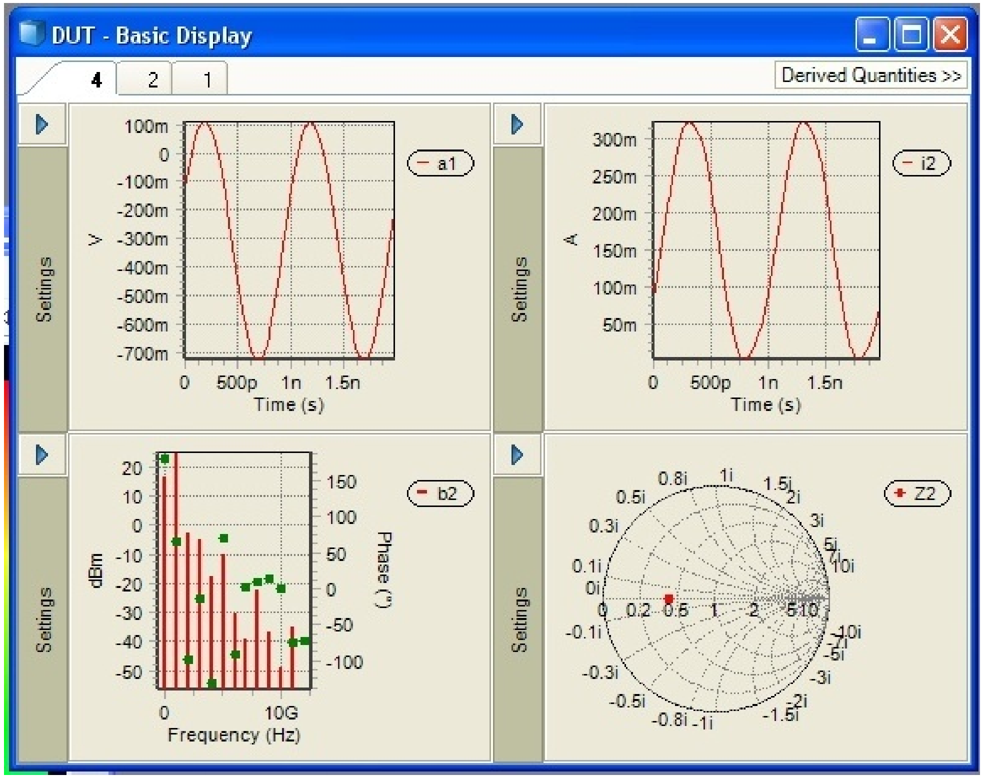
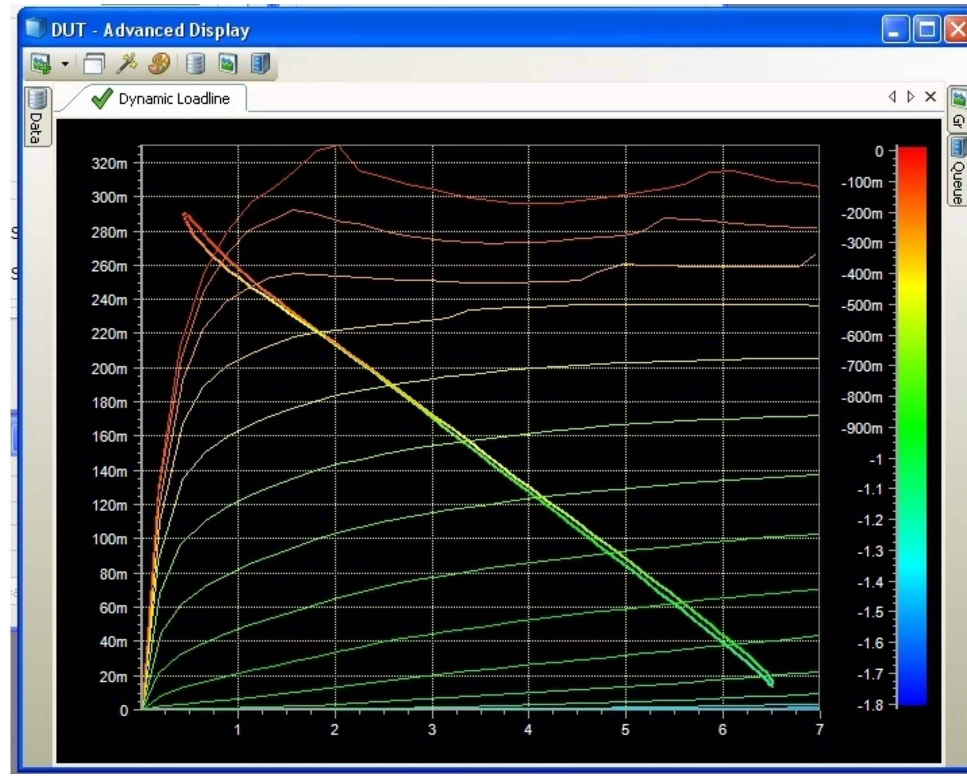
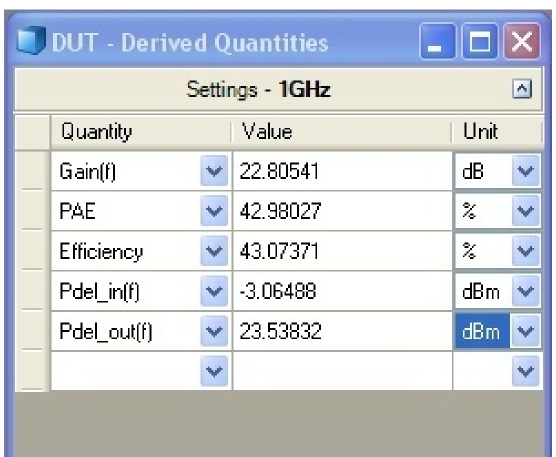
ZVxPlus: Displays



Basic Display

Advanced Display





DUT - Derived Quantities

Settings - 1GHz

Quantity	Value	Unit
Gain(f)	22.80541	dB
PAE	42.98027	%
Efficiency	43.07371	%
Pdel_in(f)	-3.06488	dBm
Pdel_out(f)	23.53832	dBm

Derived Quantities

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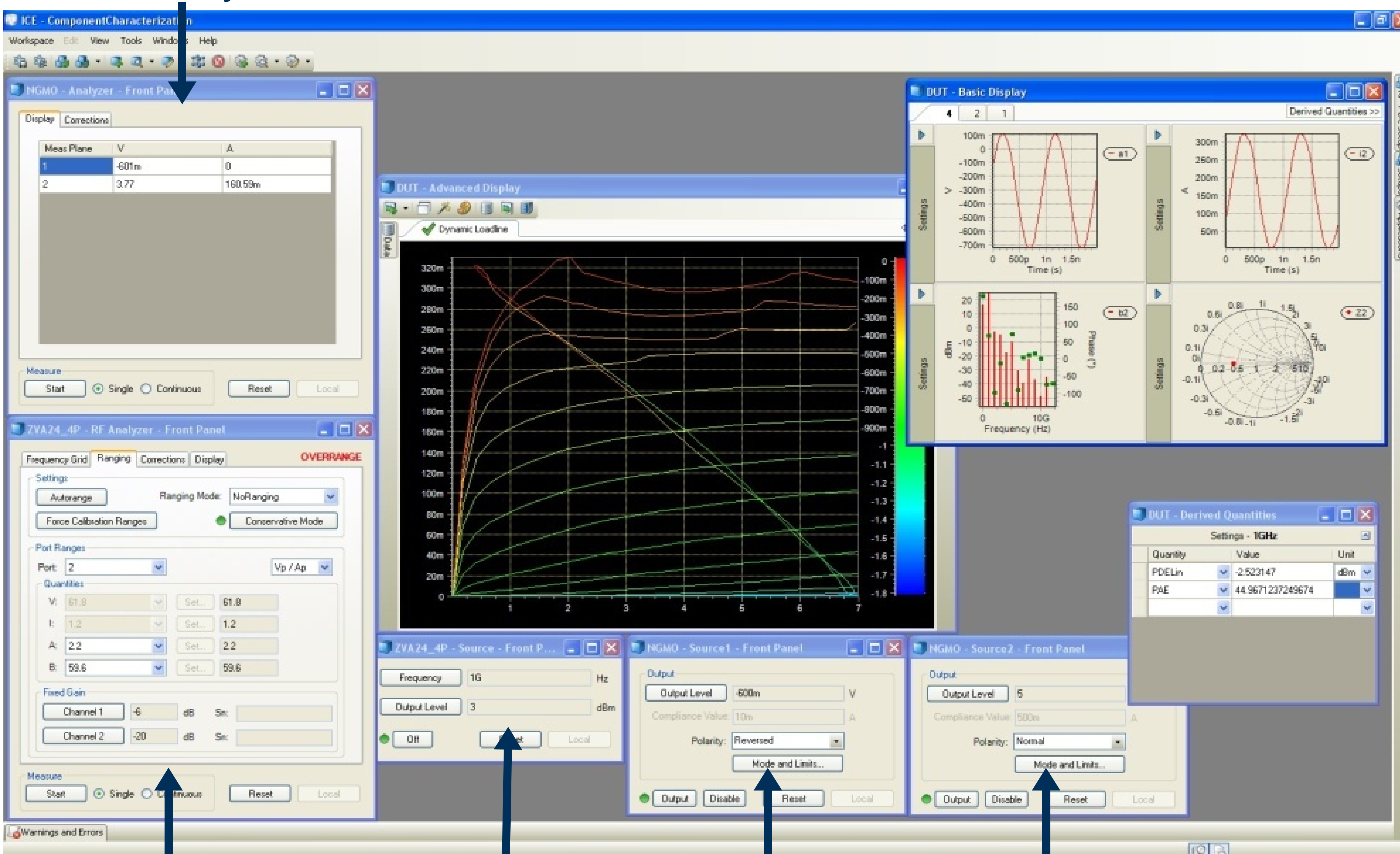
ZVxPlus: Flexible Component Characterisation Software

DC Analyser



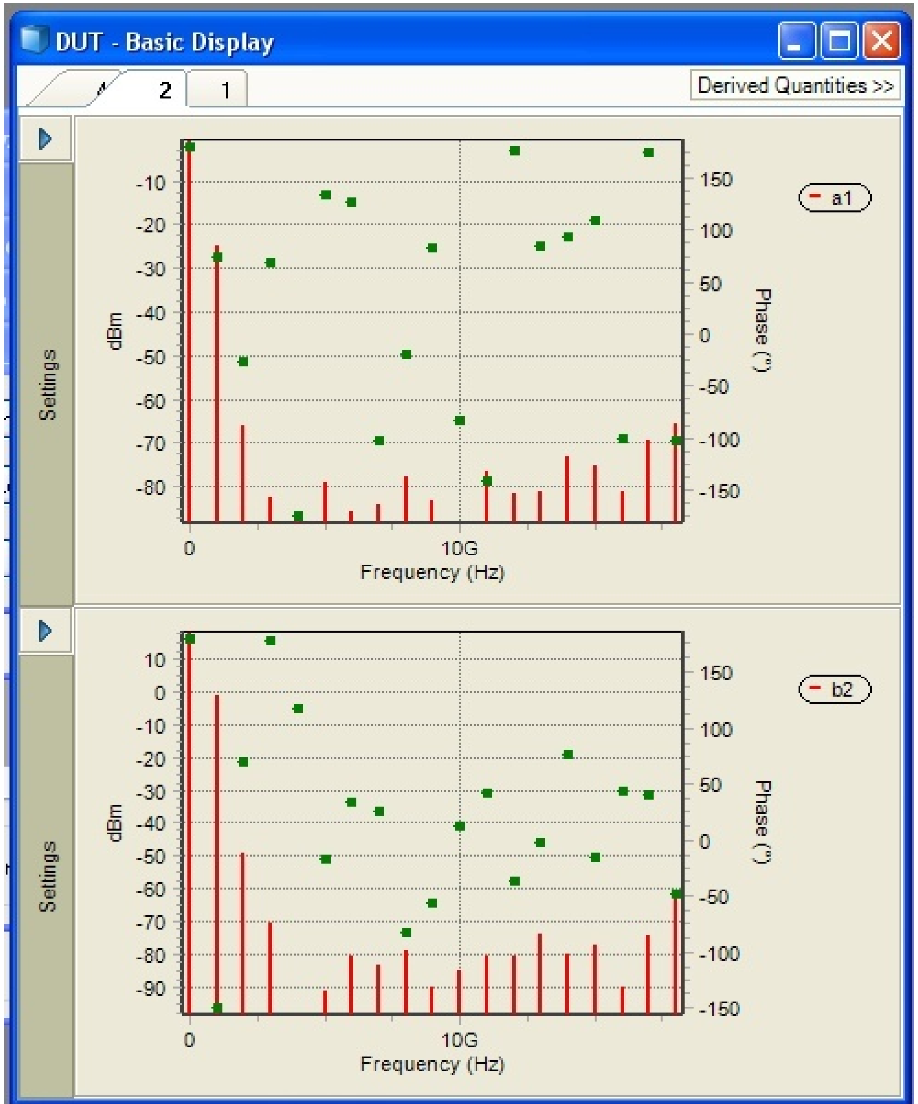
RF Analyser RF Source DC Source 1 DC Source 2

ZVxPlus: Frequency Domain Characterisation - Phase

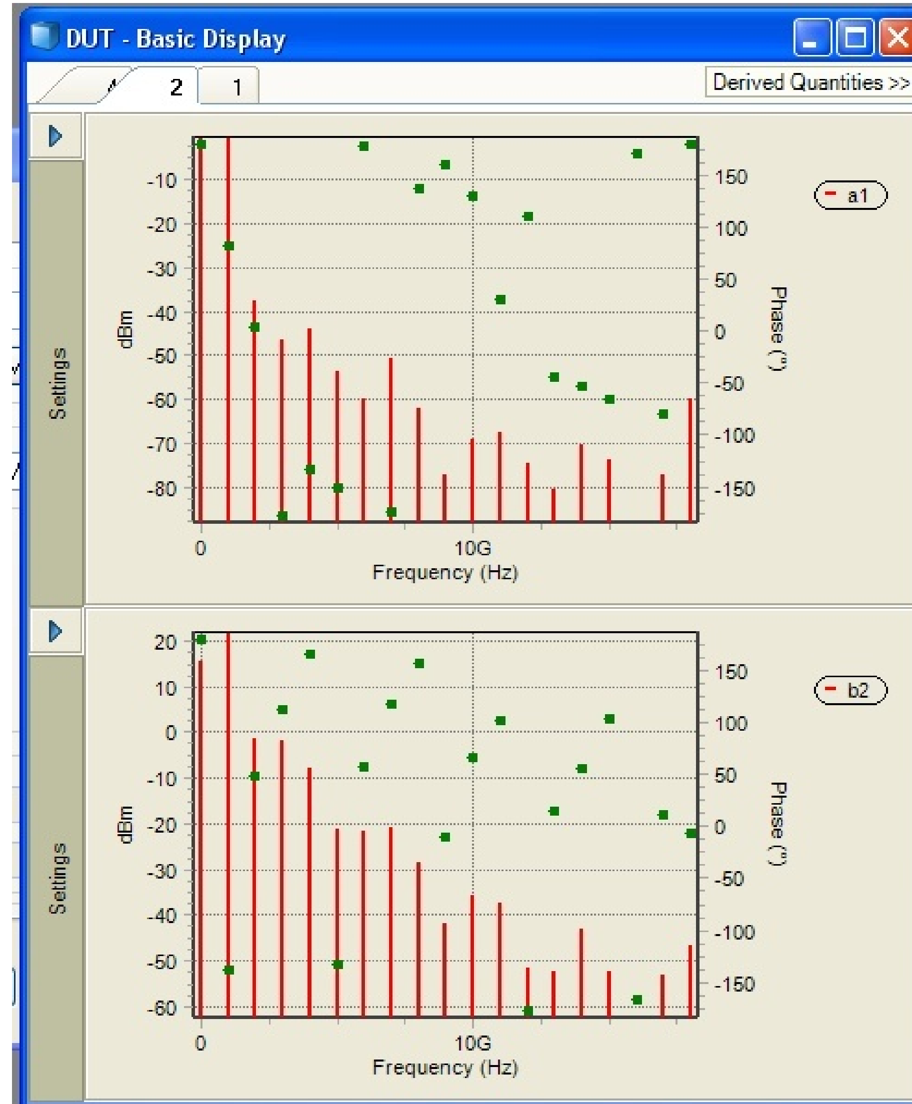
V_{gs}=-0.6V, V_{ds}=5V f_0=1GHz

amplitude phase

Pin=-25dBm

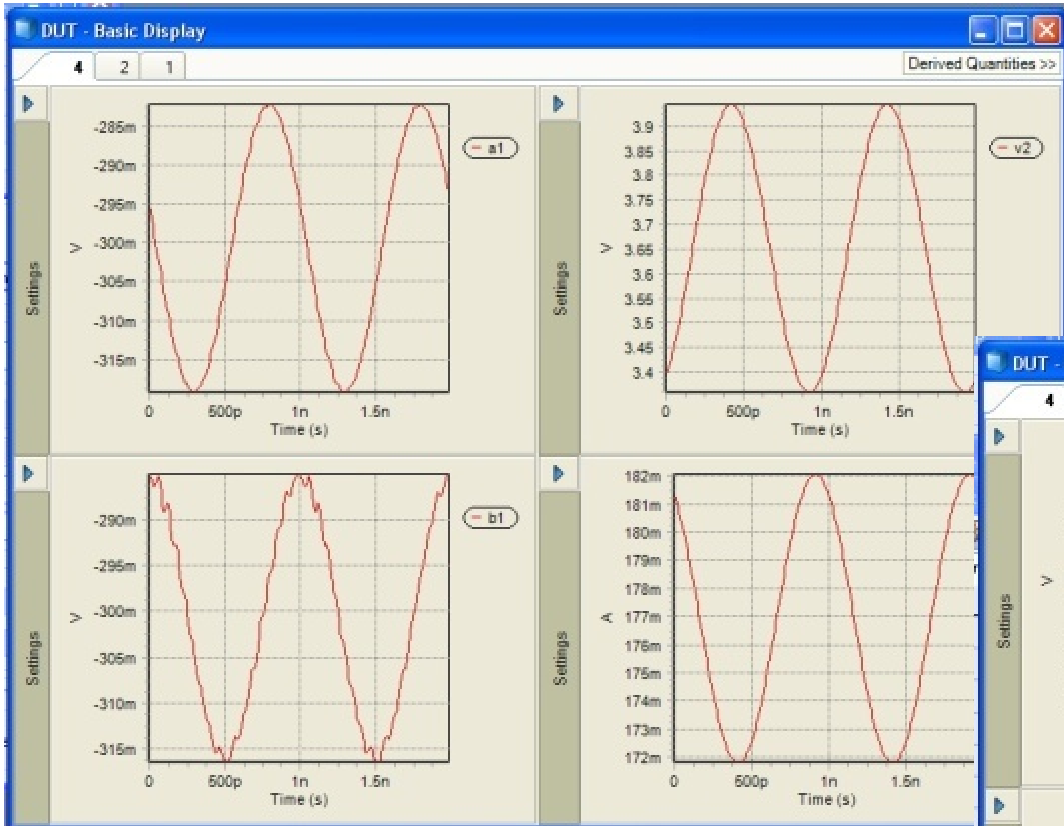


Pin=0dBm



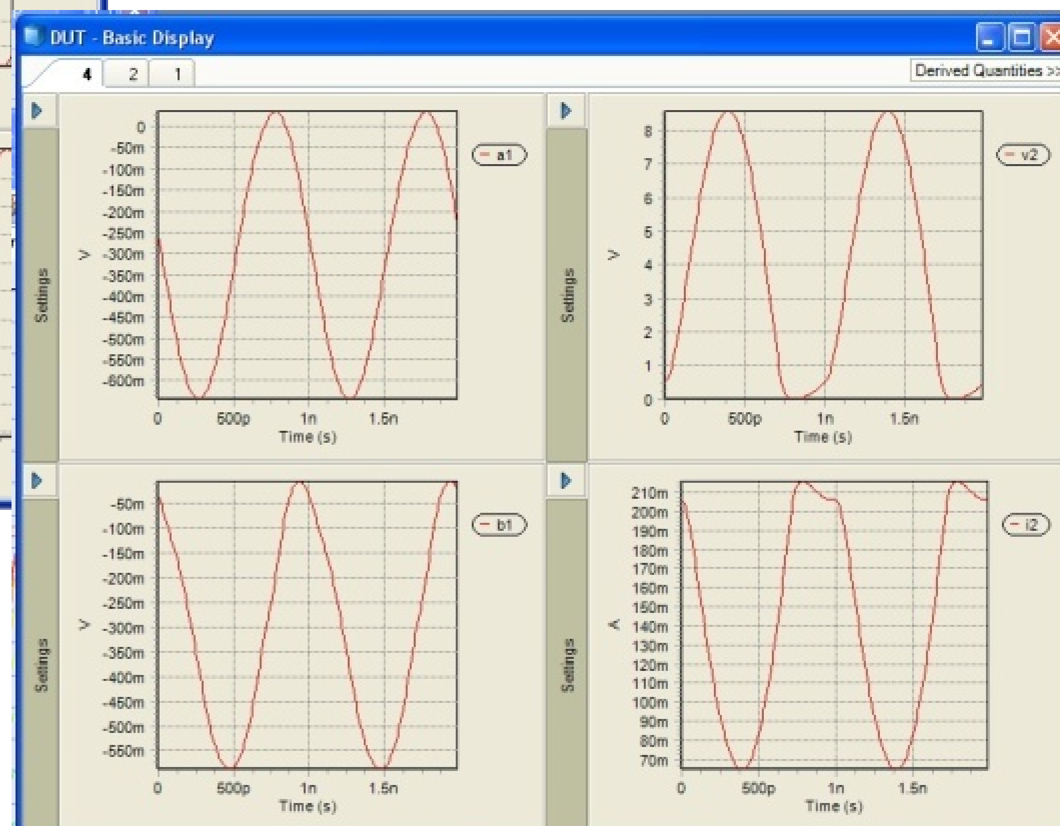
ZVxPlus: Time Domain Characterisation

V_{gs}=-0.6V, V_{ds}=5V f_0=1GHz

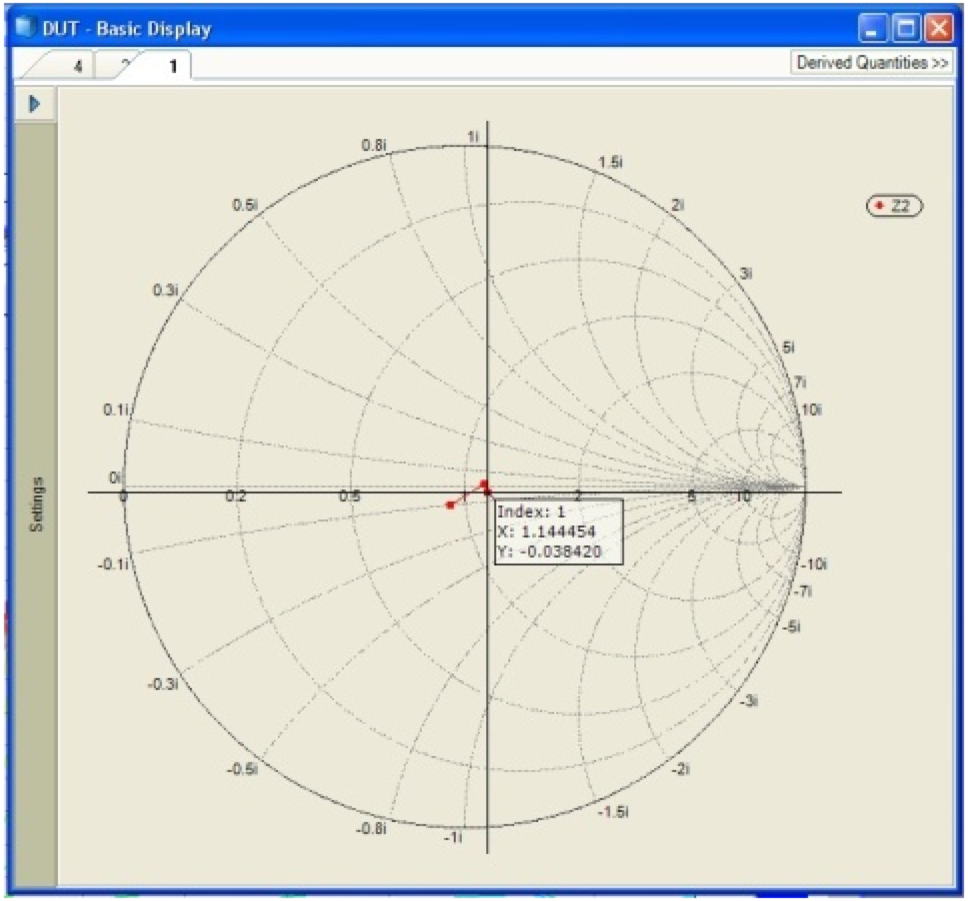


Pin=-25dBm

Pin=0dBm

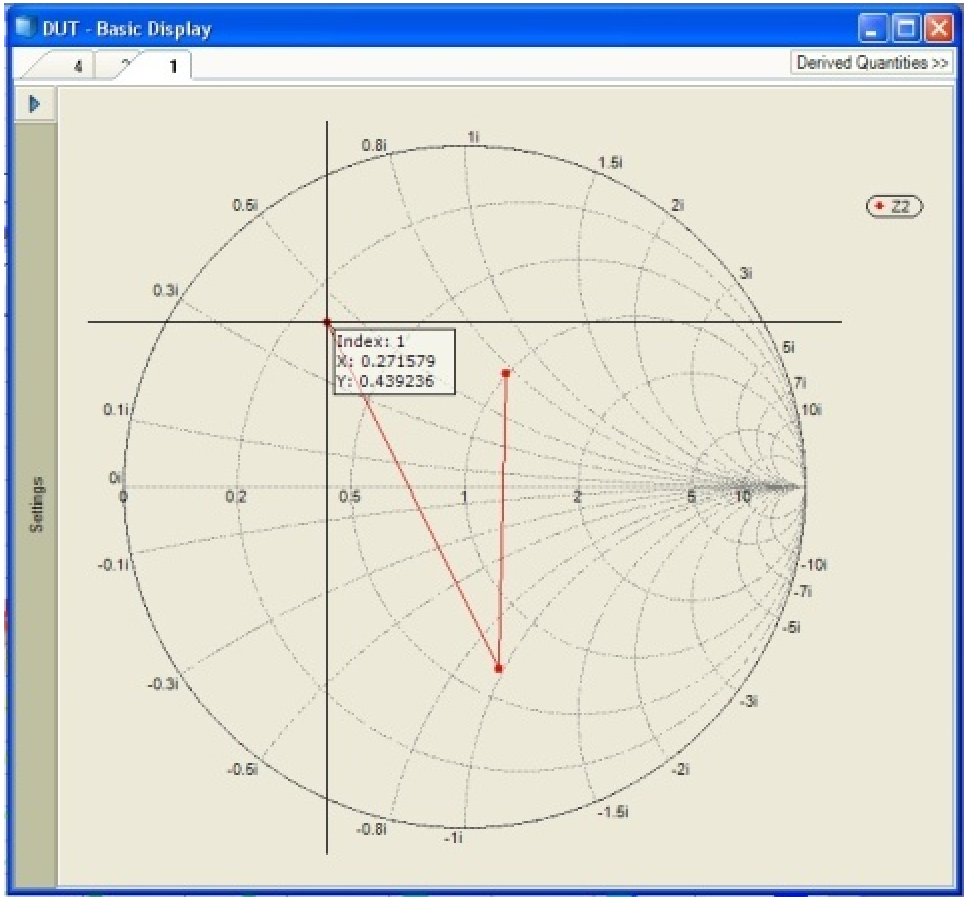


ZVxPlus: Terminating Impedances

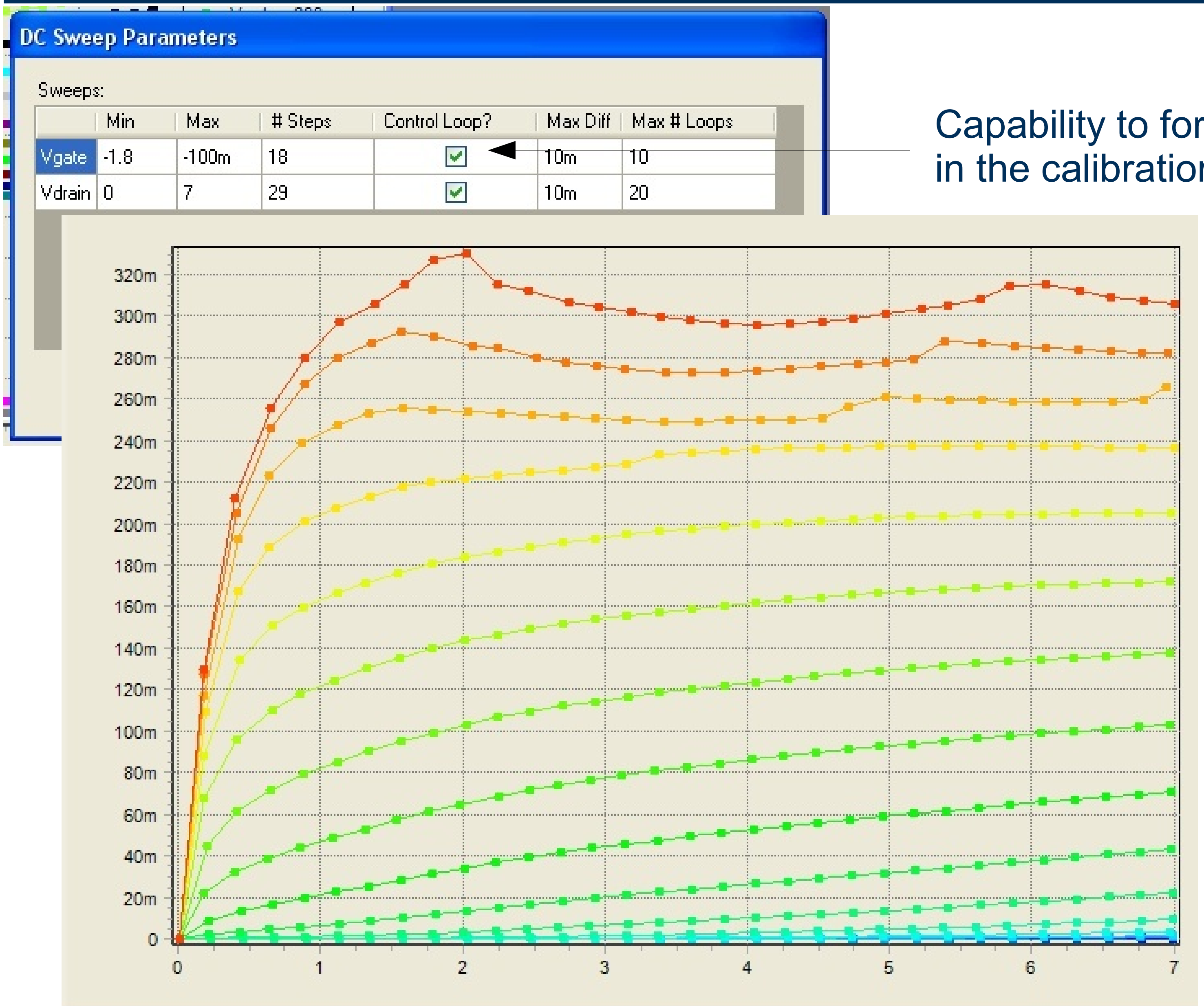


Output Impedance with 50 Ohm termination at fundamental and 2 harmonics

Output Impedance with Open termination at fundamental and 2 harmonics

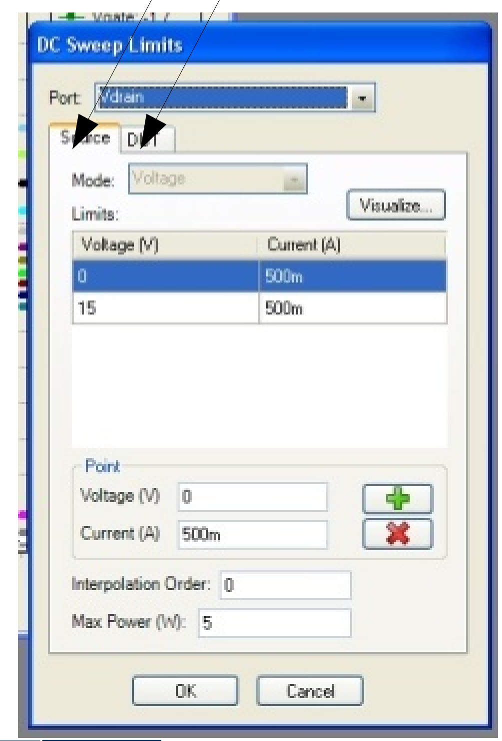


ZVxPlus: DC IV Application



Capability to force the control variables in the calibration plane

Defining limits at DC source and in calibration plane



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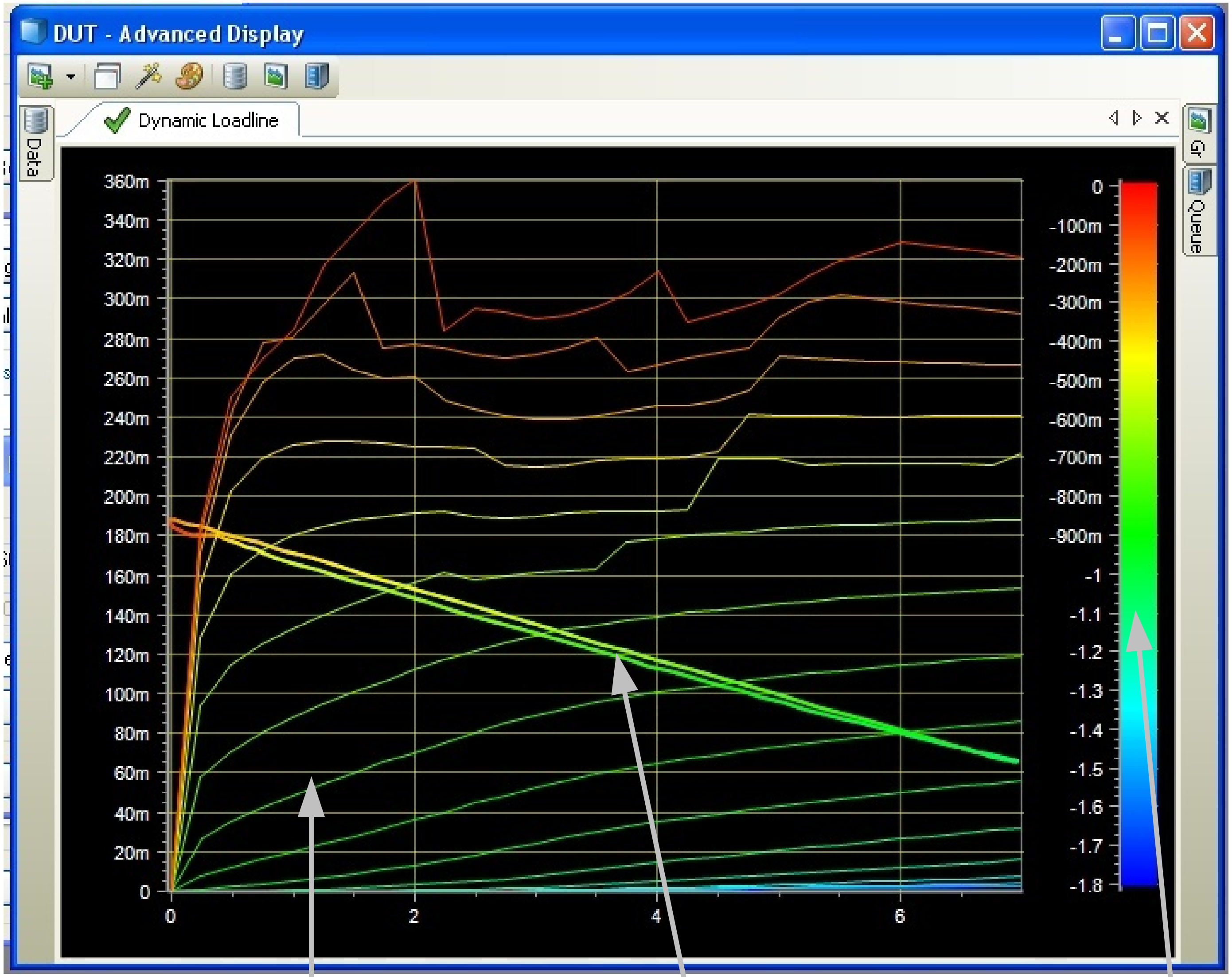
ZVxPlus: 3D Dynamic Loadline

V_{gs}=-0.6V, V_{ds}=4V f_0=1GHz Pin = 0 dBm



Compare the static V_{gate} with the dynamic V_{gate} through color Z-axis

Conclusion

- With an incremental investment on a suitable R&S ZVA or ZVT, it is possible to characterise devices with one single connection
  - small-signal behaviour: S-parameters
  - large-signal harmonic behaviour under realistic conditions: complete input and output waveforms
- The accurate and complete large-signal harmonic measurements enable new insights in component behaviour, resulting in
  - better semiconductor technologies
  - better models and design kits
  - better designs
  - faster ways of testing, possibly in non-50 Ohm environments

For more information info@nmdg.be

www.nmdg.be