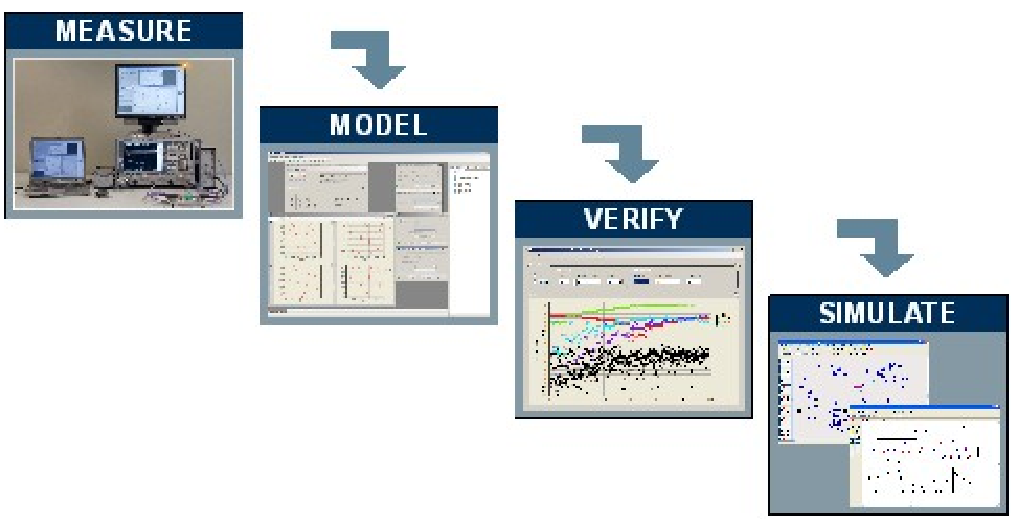
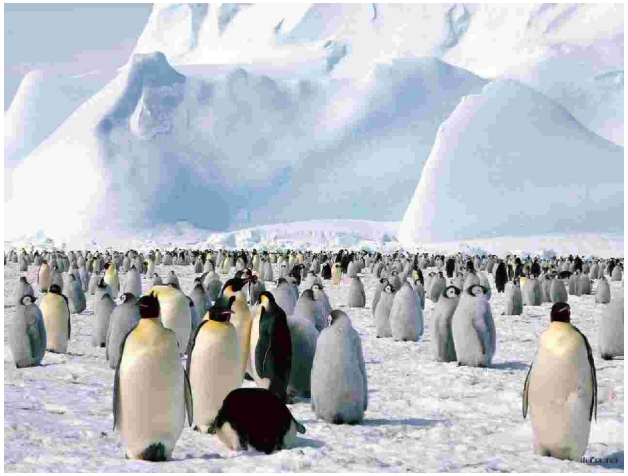
IMS 2010
MicroApps Workshop
Anaheim, 23-28 May

S-Functions

“The S-parameters for nonlinear components”





NMDG
LEADING BEYOND S-PARAMETERS

ROHDE&SCHWARZ

Outline

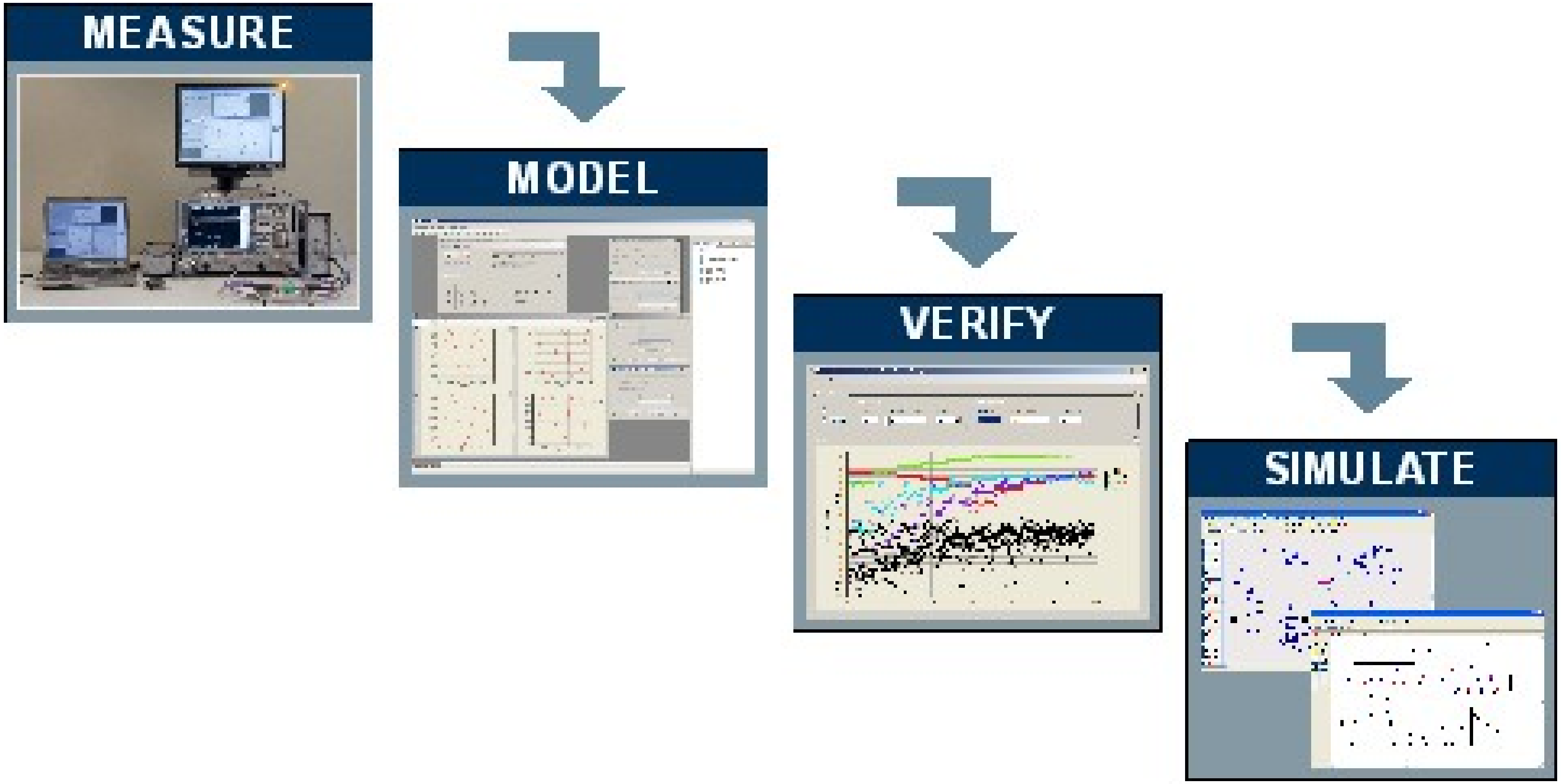
- **Beyond S-parameters ???**
  - ***S-Functions****, the "S-parameters" for nonlinear components*
- **S-Functions in a Nutshell**
- **Measure, Model, Verify, Simulate**
  - *Real and Virtual Components / Circuits*
- **Assumptions of S-Functions**
- **Key Benefits and Capabilities**

Beyond S-parameters???

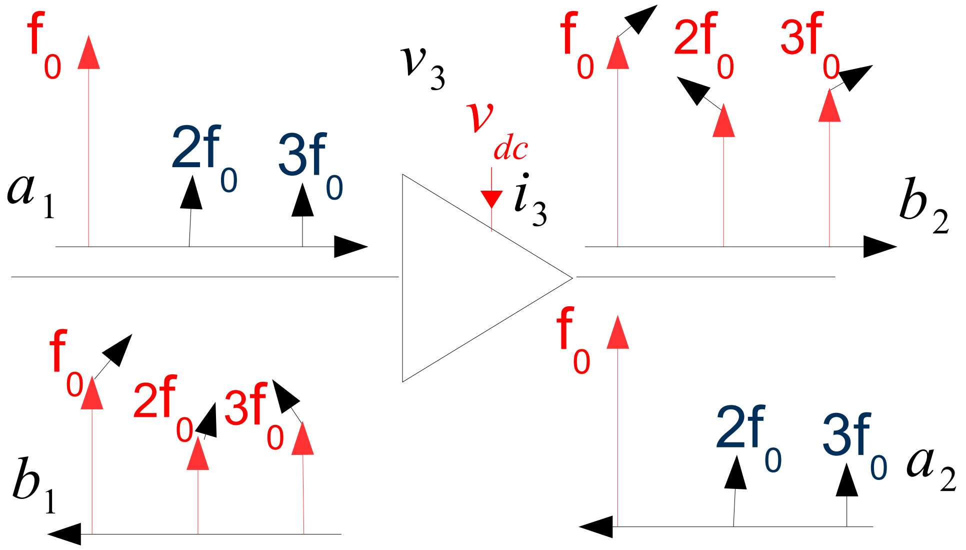
- **S-parameters**, the behavioral model for linear components
  - Components in linear mode of operation **only**
  - Their success is based on its **uniform** approach for **linear** RF and microwave problems both to measure and to simulate
- **What about components in nonlinear mode of operation?**
  - No **uniform** approach for nonlinear RF and microwave problems
  - However, one can deal with a *subset* of nonlinear RF and microwave phenomena in a **uniform way...**

S-Functions, the "S-parameters" for nonlinear components

- **S-Functions**, the NMDG behavioral model for nonlinear components
  - Deal with a subset of nonlinear RF and microwave phenomena in a **uniform way** as a natural extension of S-parameters
  - S-Functions can be "measured" and used in simulators



S-Functions(*) in a Nutshell



(*): For simplicity, limited to harmonic behavior
(**): Large-Signal Operating Point

Independent variables: a_1, a_2 and v_3
Dependent variables : b_1, b_2 and i_3

Nonlinear behaviour caused by LSOP(**):
$a_1(f_0), a_2(f_0)$ and v_{dc}

Linear perturbation caused by:
$a_1(k f_0), a_2(l f_0)$ with $l, k \neq 0,1$

S-Functions

$$I_{dc} = F(a_1(f_0), a_2(f_0), v_{dc}) + G_k(a_1(f_0), a_2(f_0), v_{dc}) A(k f_0)$$
$$B = H(a_1(f_0), a_2(f_0), v_{dc}) + S_k(a_1(f_0), a_2(f_0), v_{dc}) A(k f_0)$$

and something special: $+G_k^c(a_1(f_0), a_2(f_0), v_{dc}) A^*(k f_0)$
$+S_k^c(a_1(f_0), a_2(f_0), v_{dc}) A^*(k f_0)$

S-Functions for Real and Virtual Components / Circuits

Data Collection

Measurements
on Real Devices
using ICE

Simulations
On Virtual Devices
in Simulation Tool (ADS - MWO)

S-Functions Extraction

S-Functions Tool
in ICE

S-Functions Verifications

S-Functions
and
Verifications

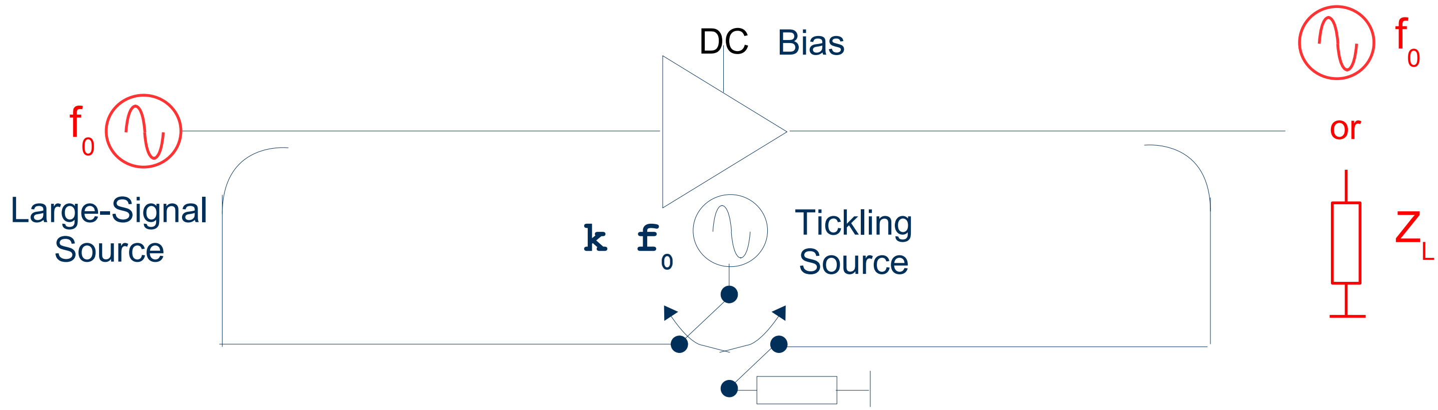
S-Functions Usage

Simulators
(ADS - MWO)

ICE: NMDG <u>I</u>ntegrated Component <u>C</u>haracterization <u>E</u>nvironment Software

Advanced Design System (ADS) is a trademark of Agilent Technologies
Microwave Office (MWO) is a registered trademark of AWR

"Measure" S-Functions – An application in ICE

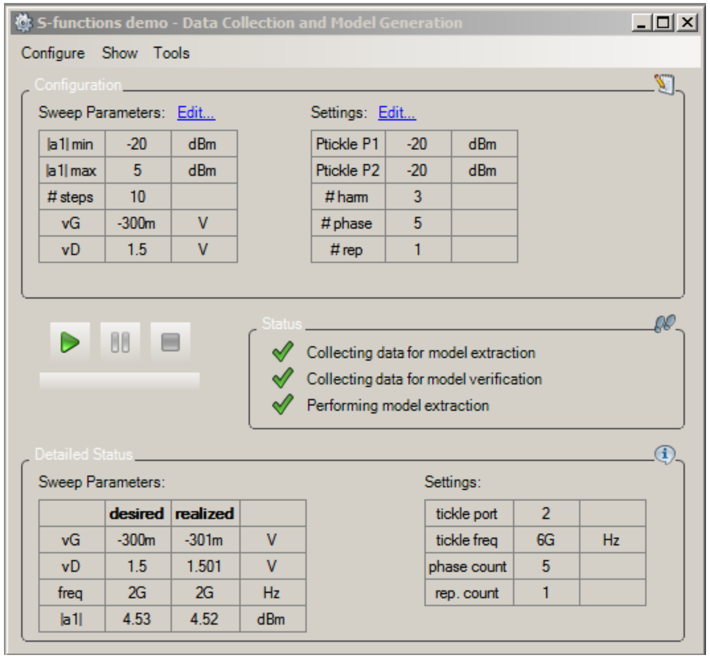


- Repeat the following for all LSOPs of interest
  - Select tickle tones
    - Large enough to be detectable
    - Small enough not to violate linearity assumption

- **<u>Measure</u>** incident and reflected waves for different tickle tones

LSOP sweep

"tickle" settings

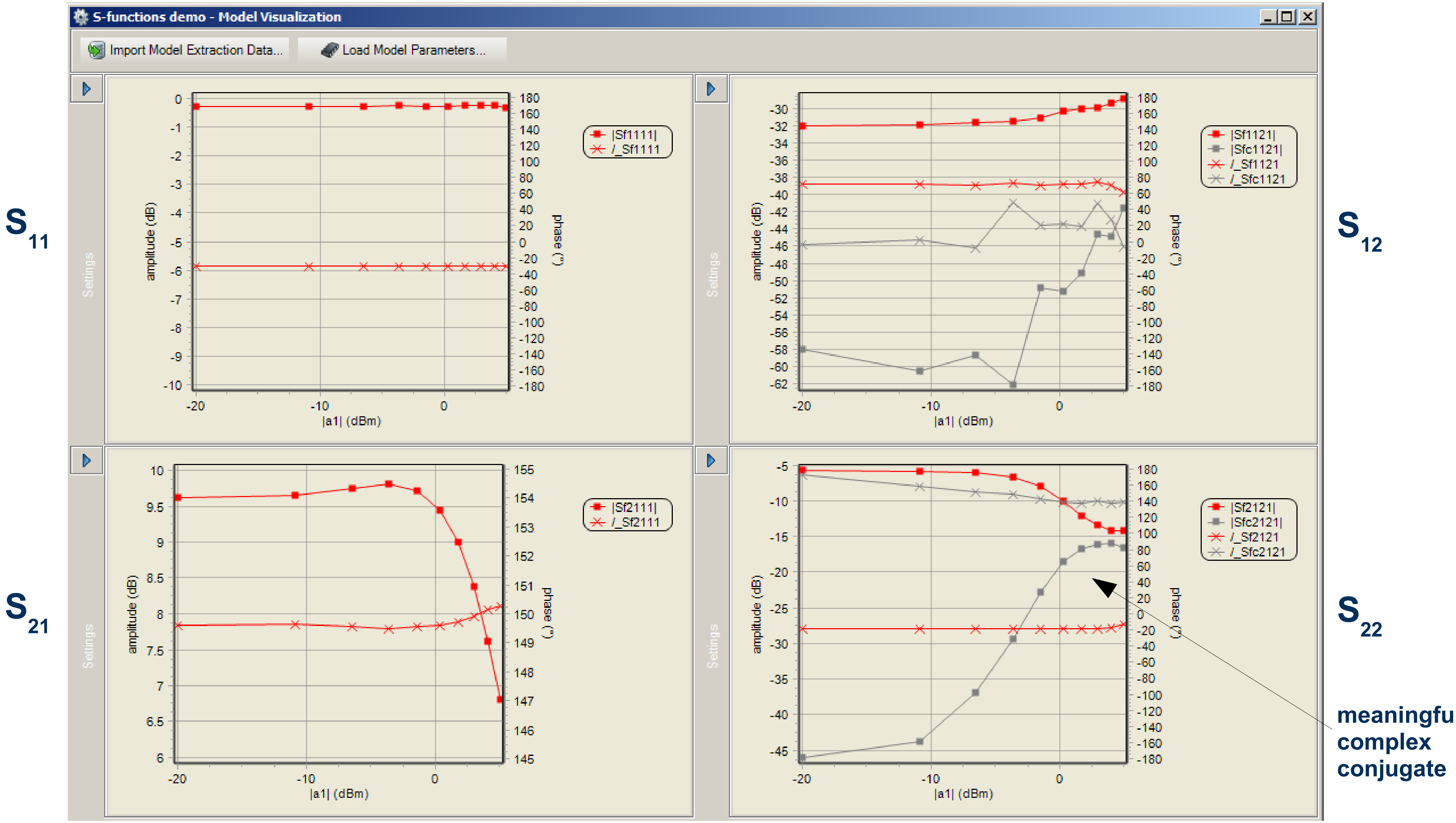


detailed feedback of LSOP for actual measurement

detailed feedback on tickle for actual measurement

“Measure” S-Functions – An application in ICE

- **<u>Model</u>** by solving for F, G, G^C, H, S and S^C



Confidence in S-Functions

Measure → Extract S-Functions → Confidence through Verification → Simulate

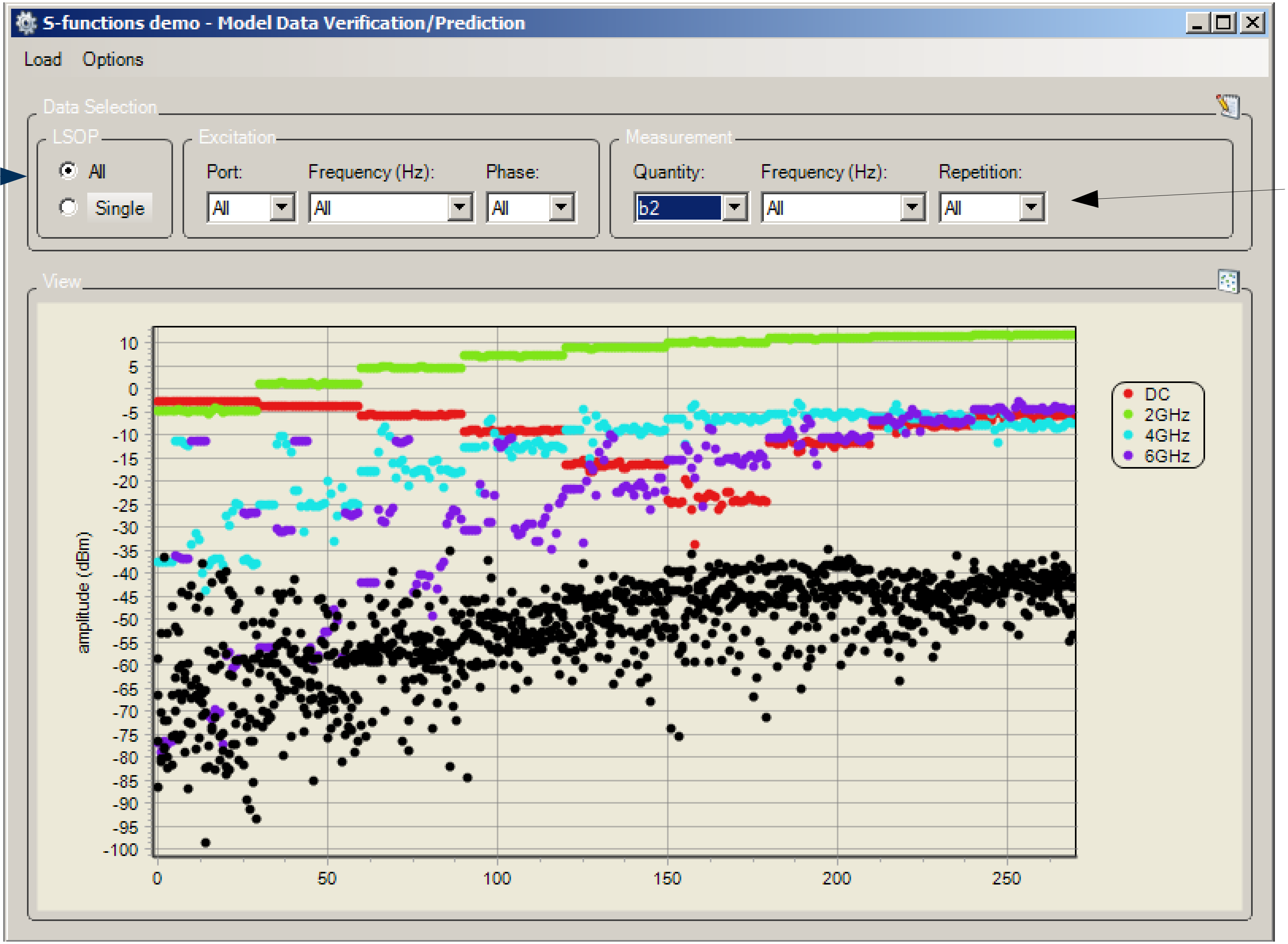
- **Constantness of LSOP**
  - F, G, H, S, G^c and S^c are assumed to be extracted at given LSOP
    - e.g. variation in DC drain voltage due to changing current violates this assumption

- **Interpolation capability of F, G, H, S, G^c and S^c**
  - LSOP interleaving verification measurements

- **Linearity assumption of tickle tones**
  - Model verification for different amplitude and phases of tickle tones

S-Functions Verification – Interpolation Capability

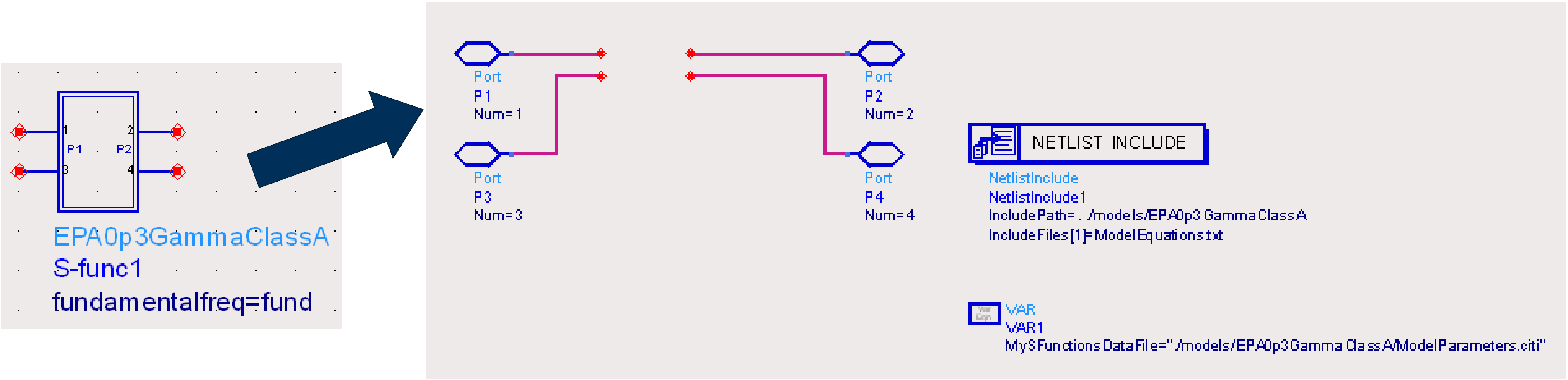
zoom in on tickling

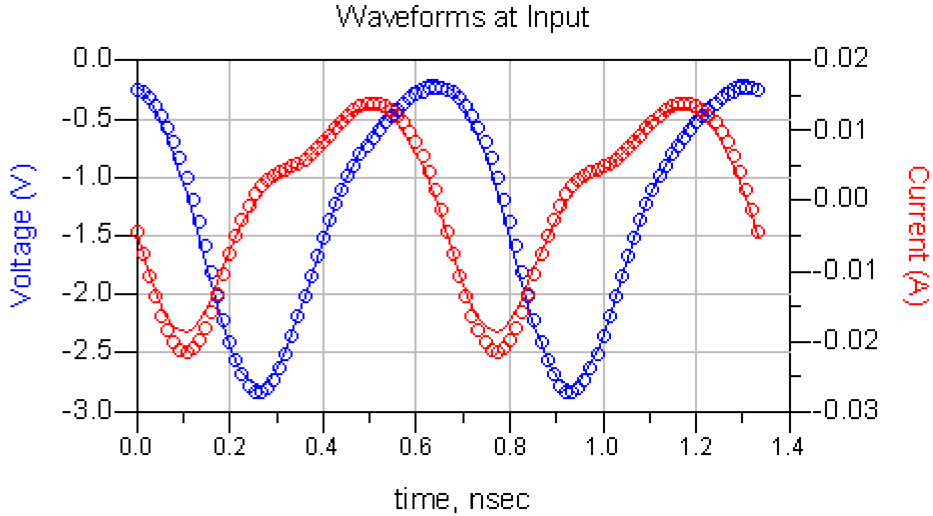


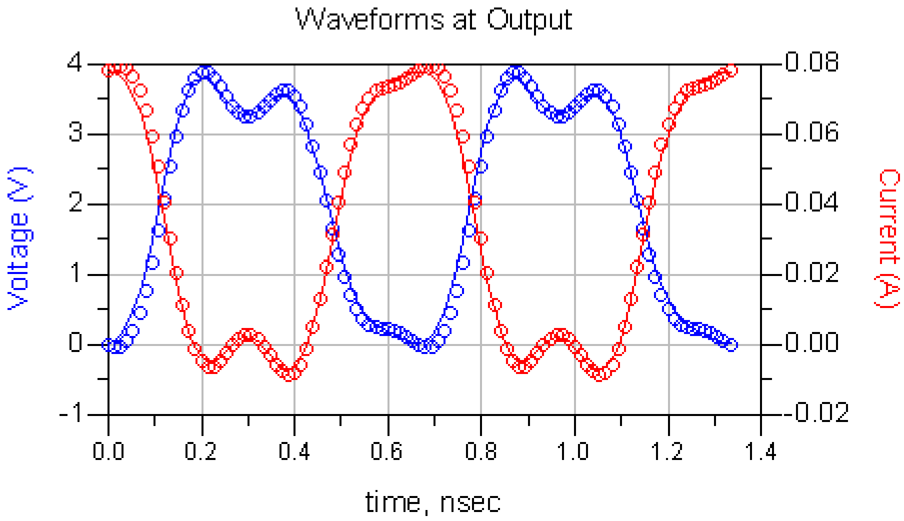
zoom in on result

verify interpolation of b_2 using independent set of measurements

Coupling in CAE Tools

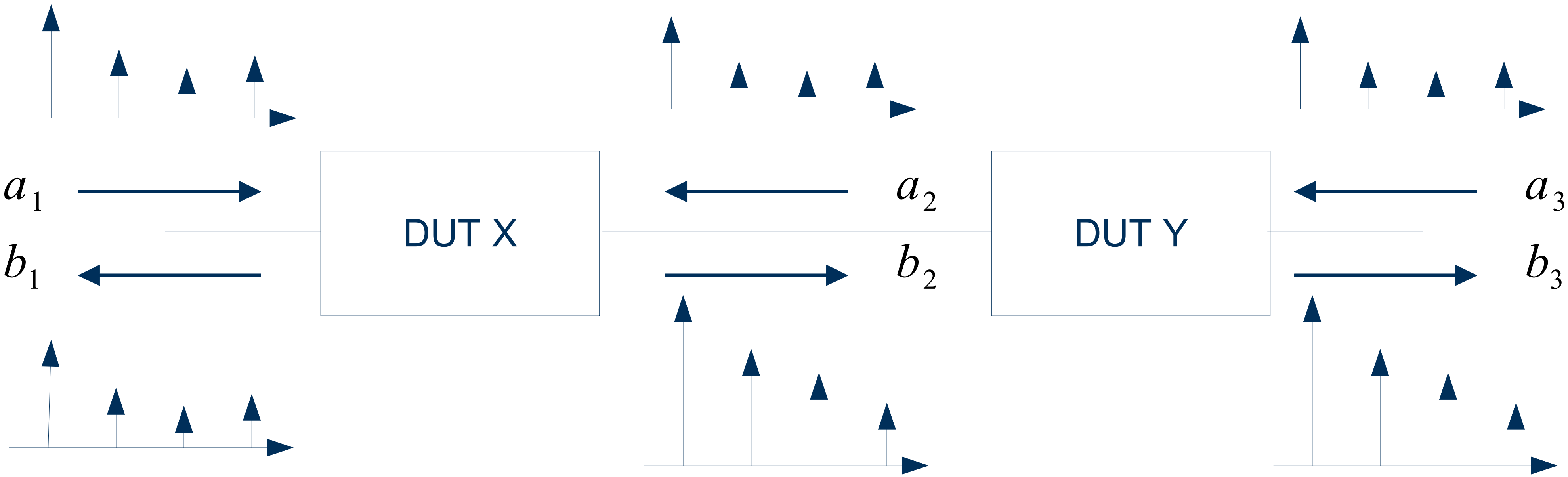






circles – measurements
solid lines - simulations

Applicability of S-Functions



Components

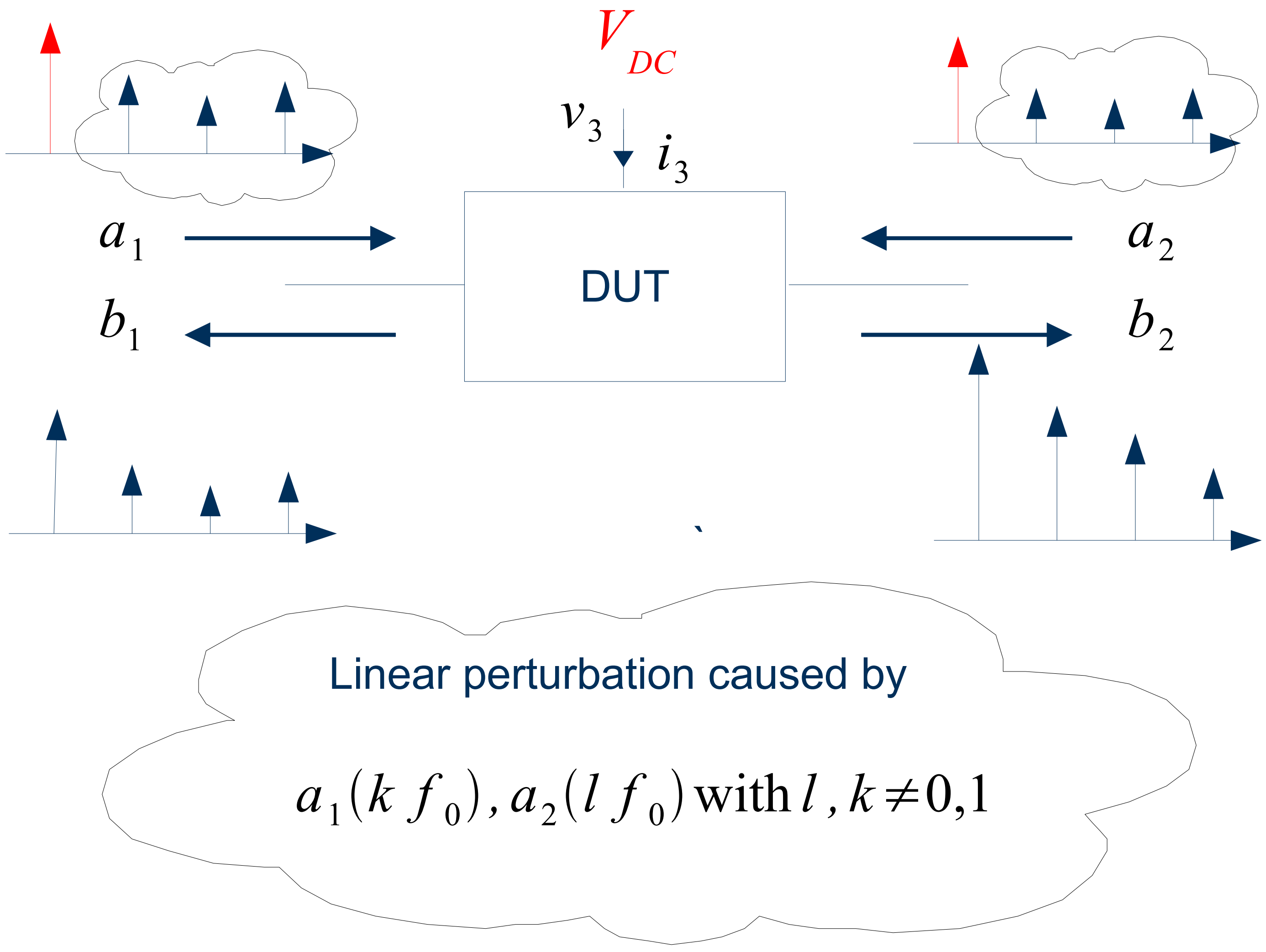
- Transistors
- Amplifiers
- Dividers
- Multipliers

Prediction

- Harmonic distortion
- AM – AM and AM - PM
- Source-pull
- Load-pull
- Modulation behavior (*)
- Intermodulation

(*): The component is assumed to be pseudo-static

Assumptions of S-Functions



Large-Signal Operating Point (LSOP)

$a_1(f_0), a_2(f_0)$ and v_{dc}

Tickle or probing tones

$a_1(k f_0), a_2(l f_0)$ with $l, k \neq 0,1$

S-Functions – Key Benefits

S-Functions are for nonlinear components ...

... what S-parameters are for linear components

- **Simplify the use of HF components and circuits**
  - Complement limited data sheets with more complete system-level models
  - Complement evaluation boards, enabling upfront more realistic simulations
- **Improve and speed up the design process**
  - Adequate replacement when the circuit model fails or is not trusted
  - Simulate with a behavioral model, optimized for your design problem
  - Similar to S-parameters: measure, model, verify and simulate

S-Functions - Key Capabilities

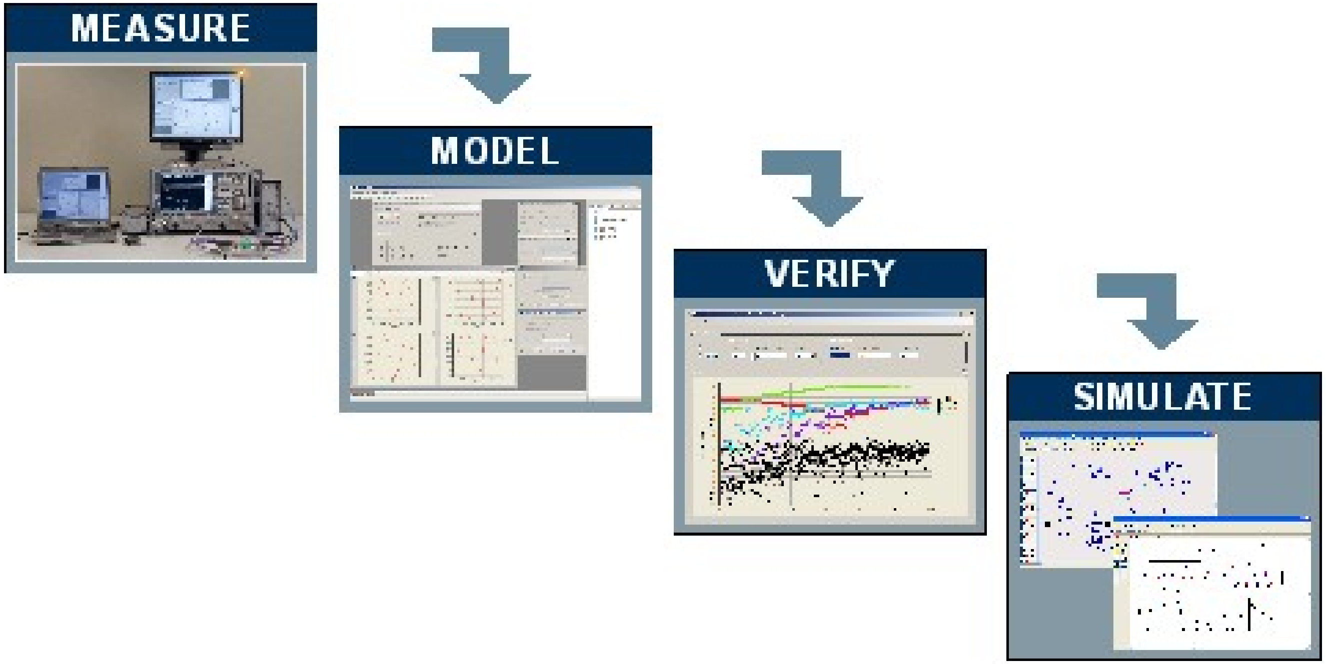
- **Natural extension of S-parameters**
  - Reduce to S-parameters for small-signal excitation
  - S-parameters are cascadeable, S-Functions are cascadeable too
- **Predict harmonic behavior of components under different impedances**
  - Source – Pull
  - Load – Pull
  - Waveforms
- **Predict modulation behavior of components under different impedances**
  - Under pseudo-static assumption
- **Predict component behavior under arbitrary small-signal spurious signals in different impedances**
- **Valid for multi-ports, applicable to differential components**

Come and see us

Rohde&Schwarz Booth 2519:

- **NM600 Fast Source- & Load-pull** with a R&S VNA only
  - Fundamental S-Functions

- **NM300 ZVxPlus** @ R&S Network Analyser
  - **S-Functions** in non-50 Ohm conditions



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Thank you

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