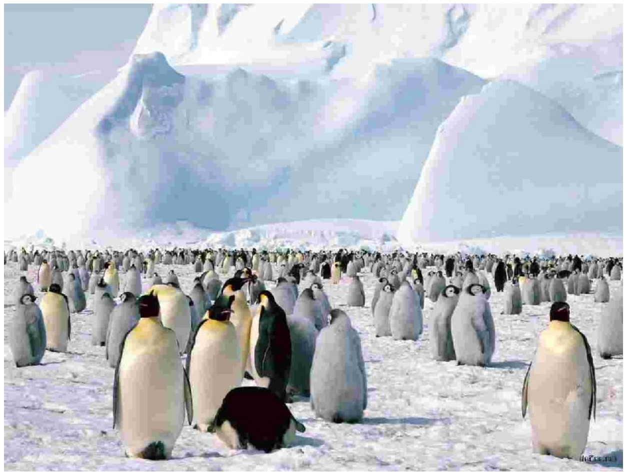
IMS 2009
MicroApps Workshop
Boston, 7-12 June

Fast component characterization using modern network analysis techniques



ROHDE&SCHWARZ

NMDG
LEADING BEYOND S-PARAMETERS

FOCUS MiCROWAVES

Outline

- Motivation
- The Market Trend
  - The Existing and New Characterization Techniques
- VNA Evolution
- The ZVxPlus and its capabilities
- ZVxPlus application example: **"On the fly"** PA design
  - Measurement setup
  - Calibration, de-embedding
  - Class A and AB design

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

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

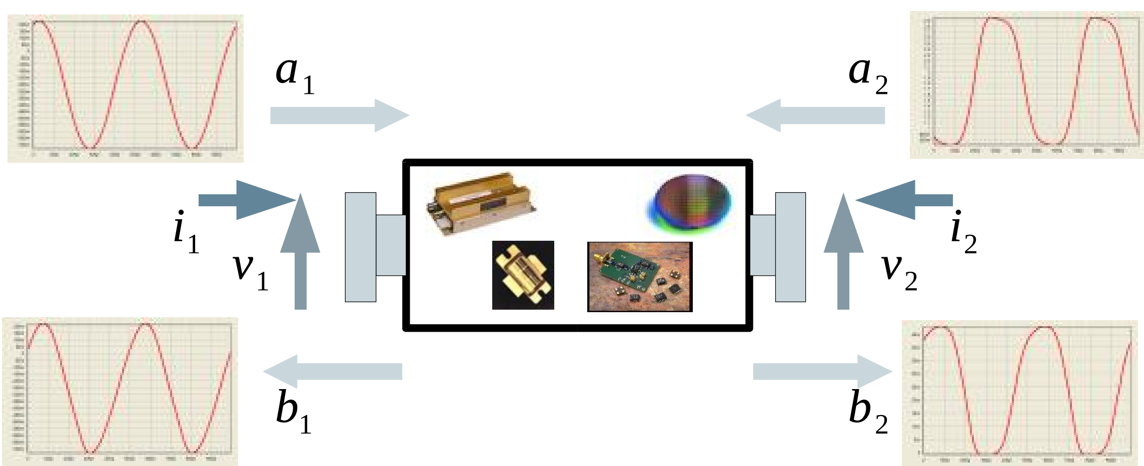
Existing Characterization Techniques

- 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

The New Characterization Technique

- **"Large-Signal Network Analysis"** is
  - Measuring the "complete" behavior 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

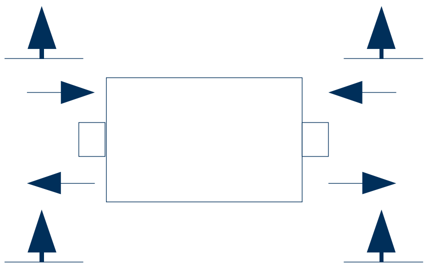
- Deal with the **“More for Less”** market trend
  - for diodes, transistors, amplifiers, multipliers, dividers, ...

- Better – More complete
  - better characterization = 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

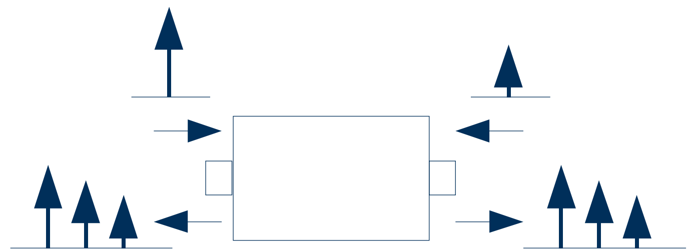
- Faster
  - single connection for small- and large-signal characterization
  - measuring basic information, i.e. PAE, Pin, Pout, ... are simple derived quantities

- At reduced cost
  - applicable from device to system level
  - from R&D to T&M

VNA Evolution



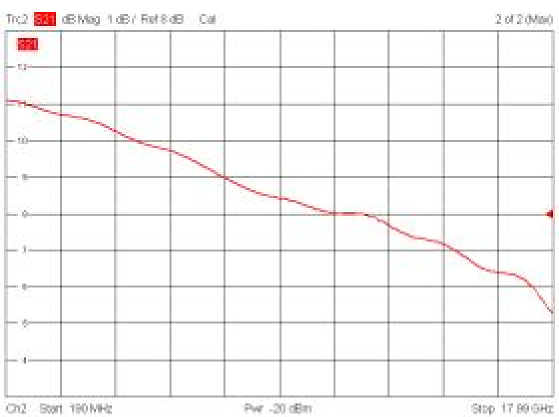
Linear



Nonlinear

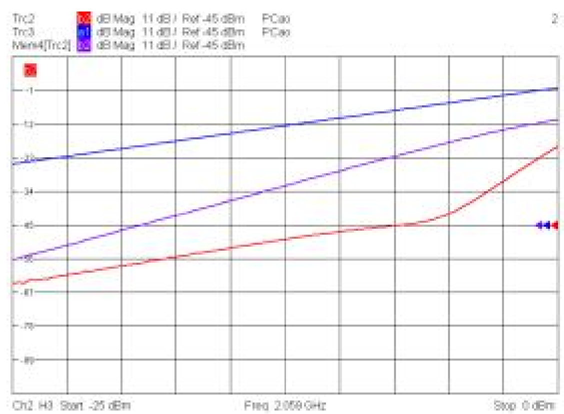
S-parameters → Power of Harmonics and Intermodulation → Phase of Harmonics

ZVxPlus



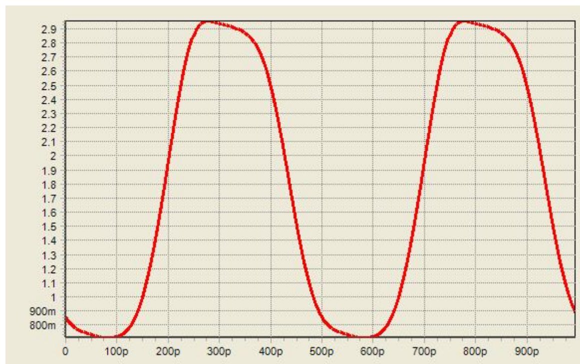
S_{21} (dB)

Frequency (Hz)



b_2 (dBm)

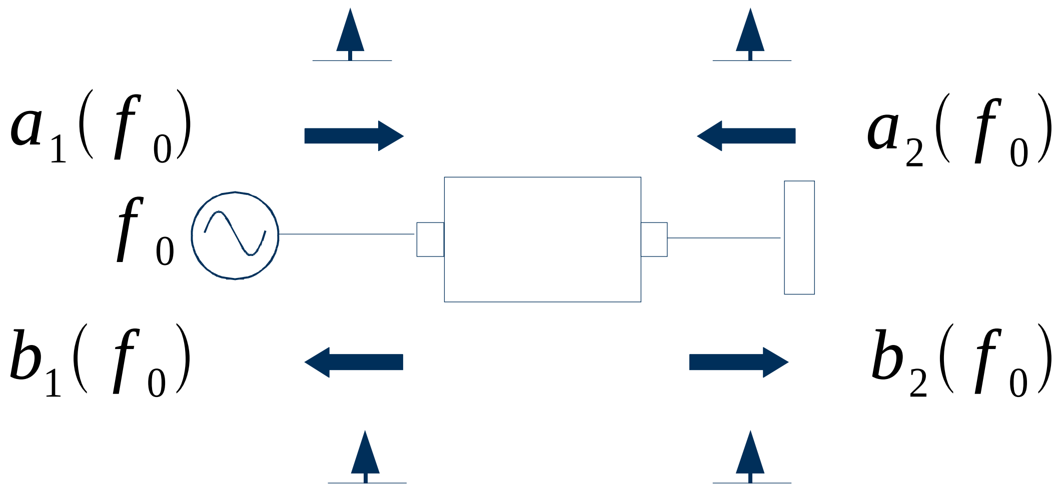
Pin (dBm)



v_2 (t)

time (s)

One VNA Measurement



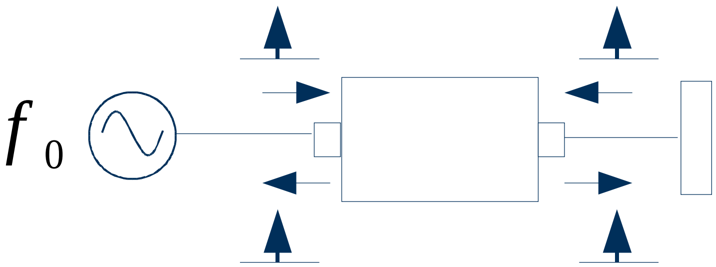
Measuring:

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

but DUT doesn't see really 50 Ohm at its output

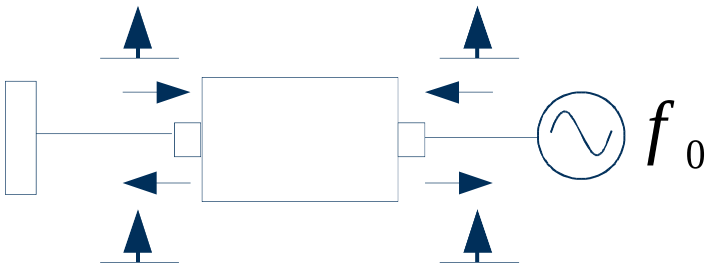
Basic quantities ≠ S-parameters

S-parameters



Forward Measurement

+



Reverse Measurement

+

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

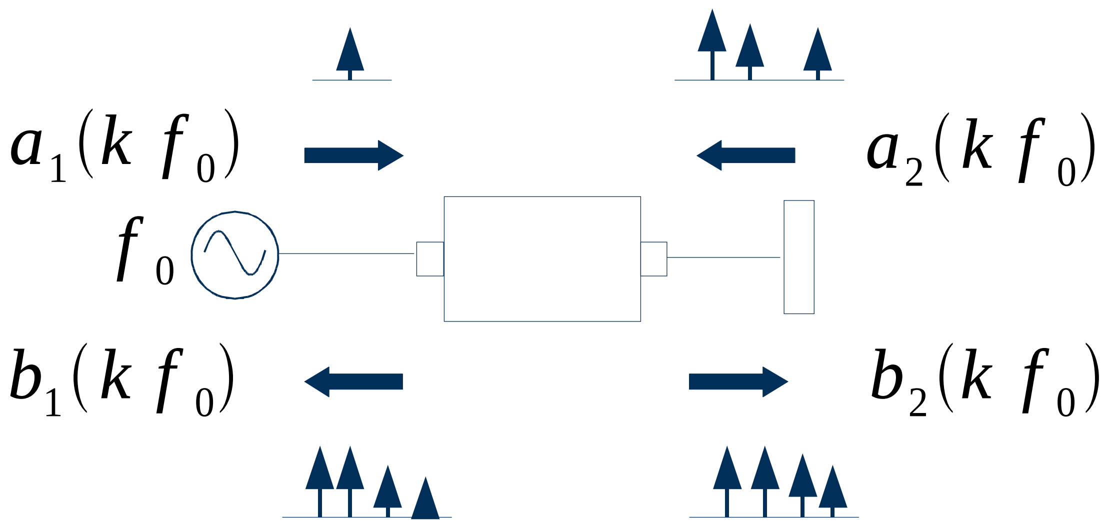
Mathematics
[Linear Model]
[**SUPERPOSITION**]

=

S-parameters

Behavioral Model

One LSNA Measurement



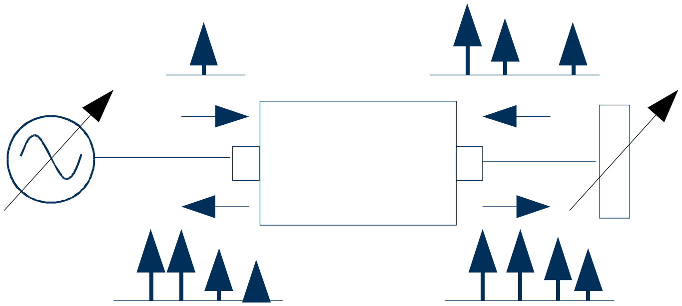
Measuring:

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

OR

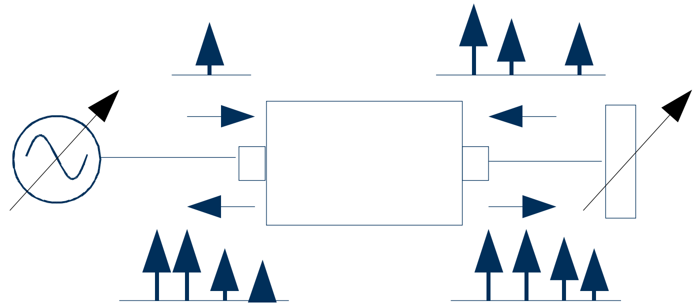
$$v_1(k f_0), i_1(k f_0), v_2(k f_0), i_2(k f_0)$$

???-parameters



Forward Measurement

\+



Another Forward Measurement

\+ ...

\+

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

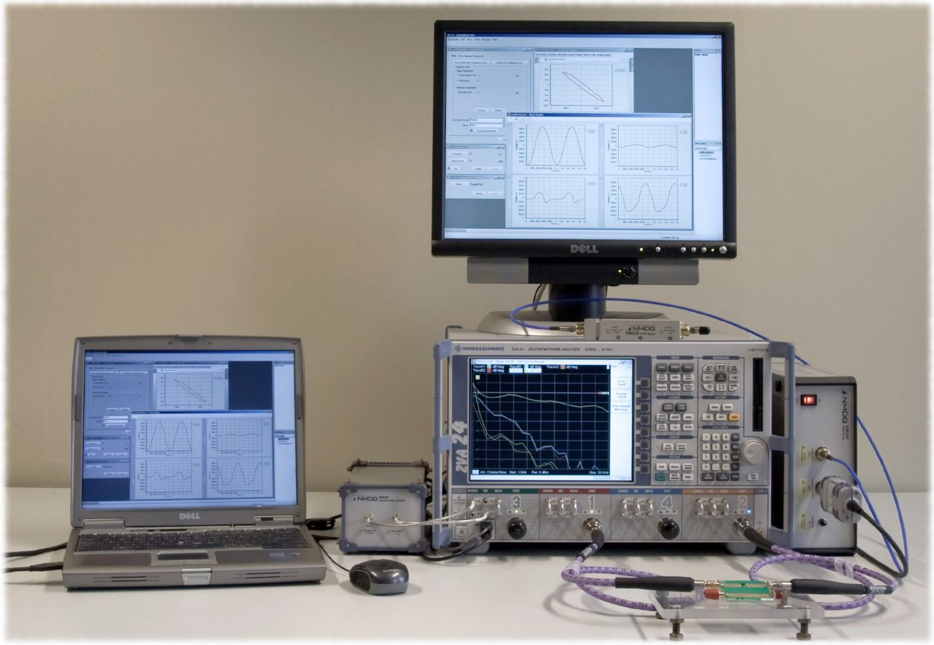
=

???-parameters

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

Behavioral Model
[**VALIDITY - BOUNDARIES**]

NM3xx ZVxPlus



ZVxPlus

=

4-port ZVA or ZVT	+	Hardware	+	Software
• direct gen. & rec. access (B16) • frequency conversion (K4) • meas. rec. step att. (opt.) (B3x)		• synchronizer • harmonic phase ref.		• configuration • absolute calibration • measurements

Key Capabilities

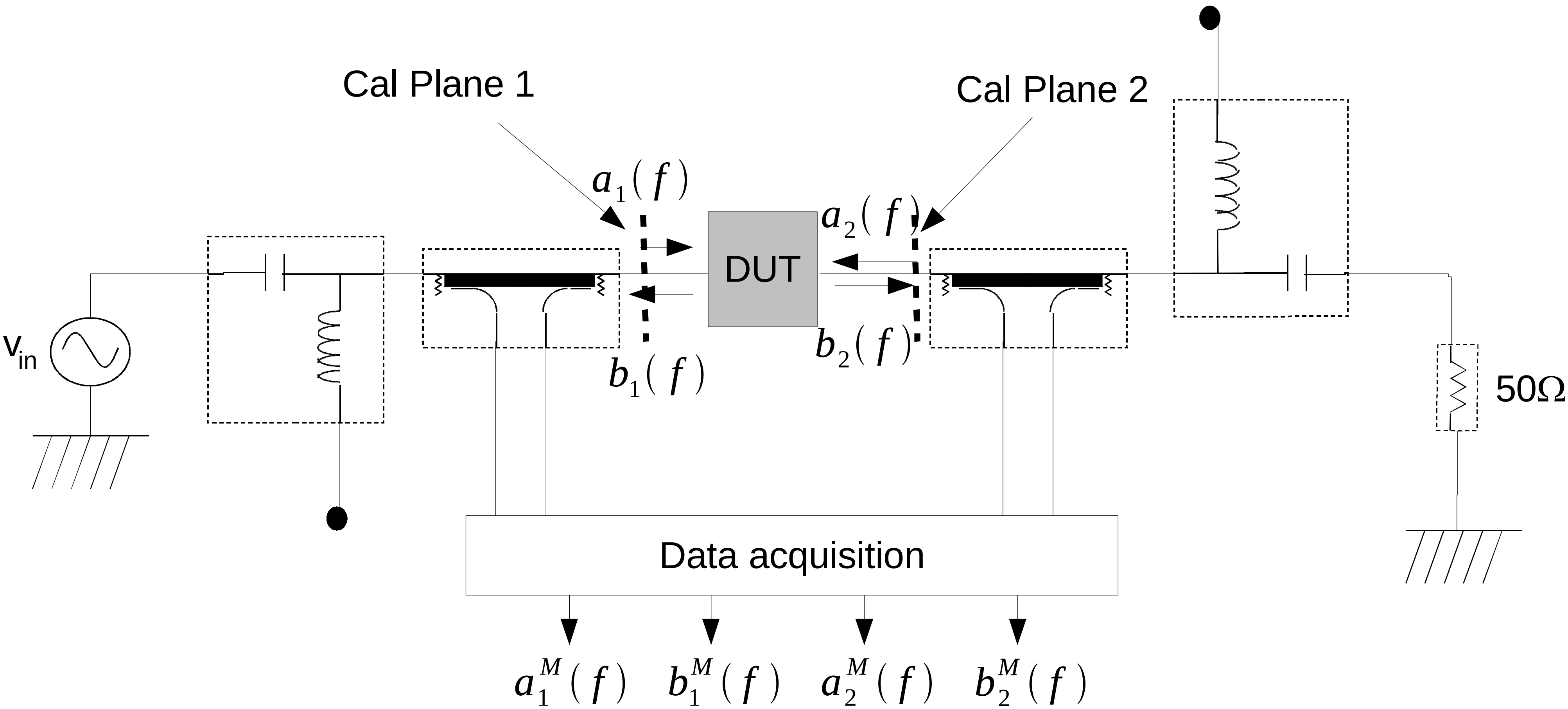
Aimed at the characterization of the nonlinear harmonic behavior of active components and circuits (e.g. diodes, transistors, amplifiers, multipliers, dividers)

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)
- Connectorized and on-wafer measurement and calibration
- Overrange detection and autoranging capability
- **3D Dynamic load line**, mapping DC and HF conditions
- Derived quantities: Pin, Pout, Gain, PAE, input & output impedances, ...
- Integration with Source – and Load-pull: fundamental and harmonic tuning
- Customization for power applications
- Customization to solve a customer problem

Some words about calibration

$$V = A + B \quad I = \frac{A - B}{Z_c}$$



Measurement system itself must remain linear!

Some words about calibration

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

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

R&S ZV-Z51 Calibration Unit

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

R&S NRP Series Power Meters

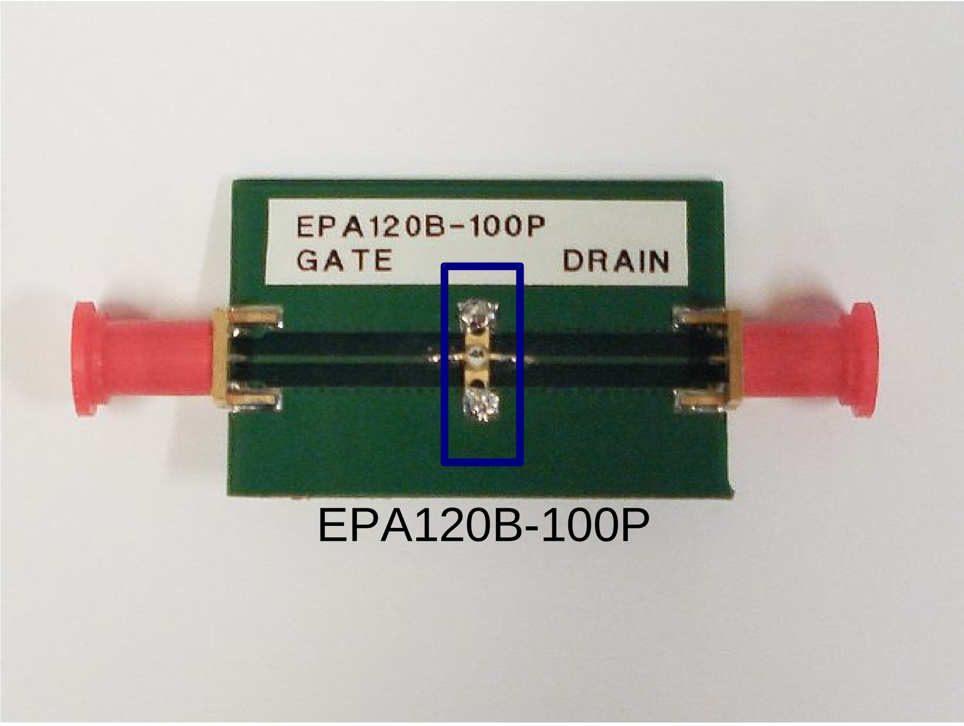
- Step 3: Phase calibration **$\Phi(K)$**
  - Phase reference generator
  - Characterization of phase distortion
  - Traceable to NIST standard

NM200 Harmonic Phase Reference

“On the fly” PA design

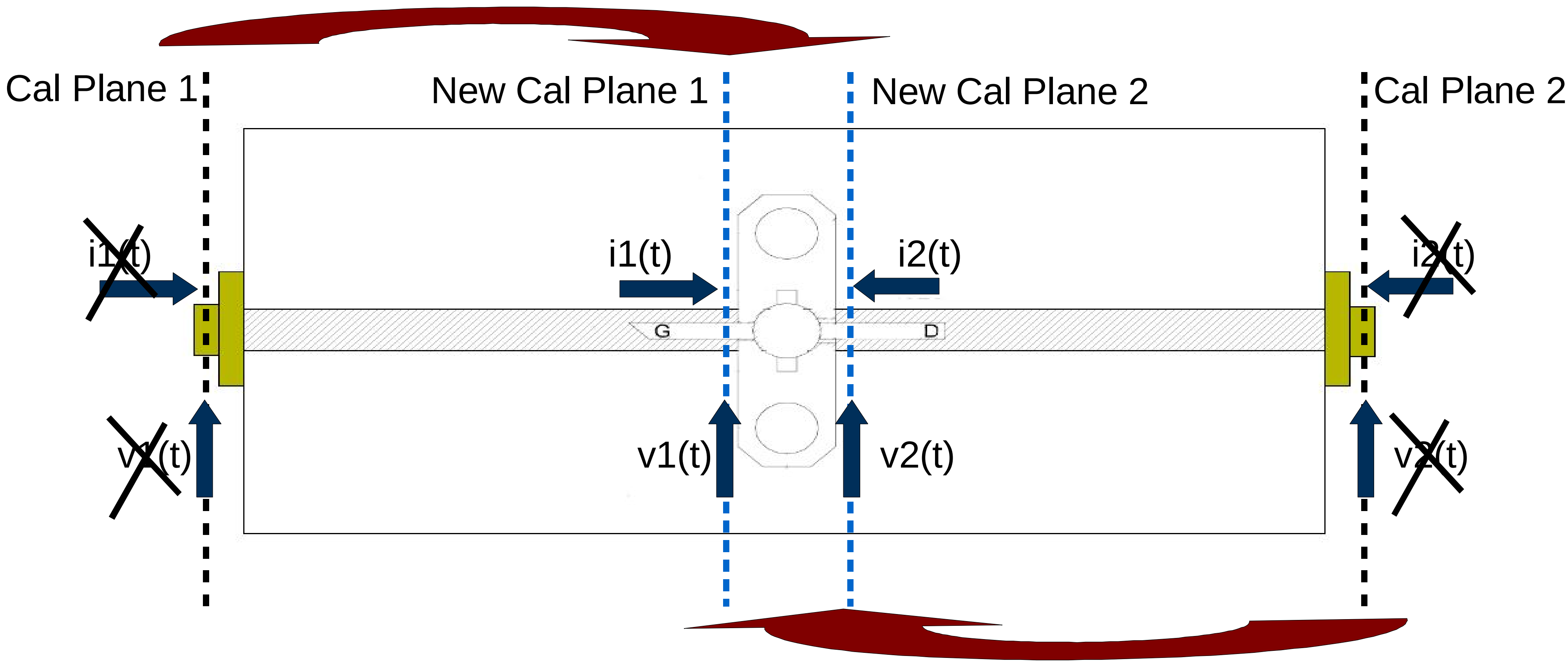
FET

- EPA120B-100P
  - high efficiency heterojunction power FET
  - power output: + 29.0dBm typ. @ 12GHz
  - power gain at 1 dB compression: 11.5dB typ. @ 12GHz



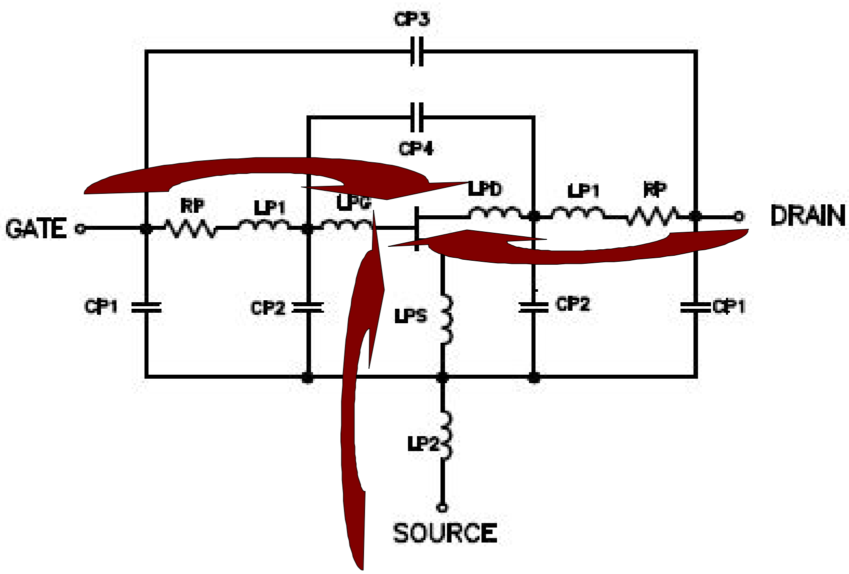
Some words about deembedding

- De-embedding of the test fixture



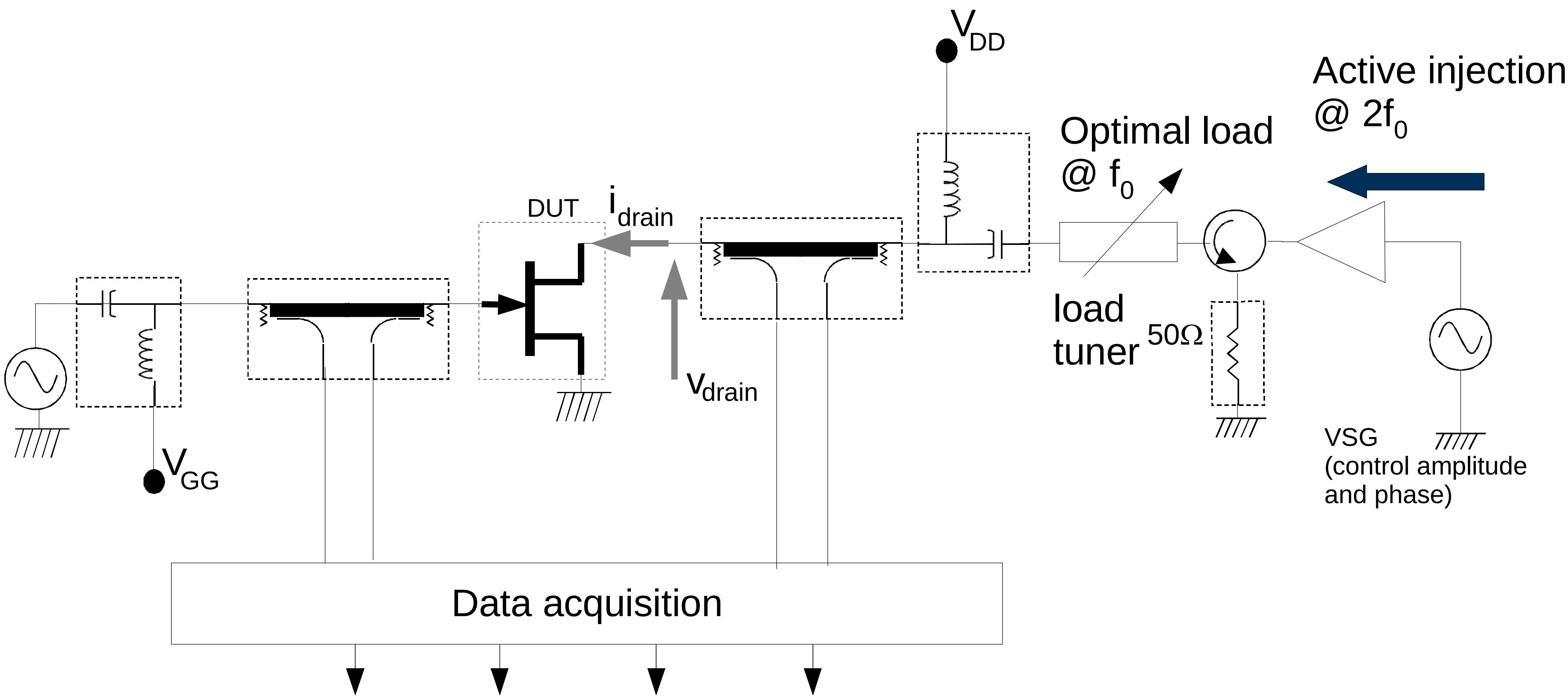
Some words about deembedding

- De-embedding of the package



PACKAGED FET MODEL

Measurement Setup



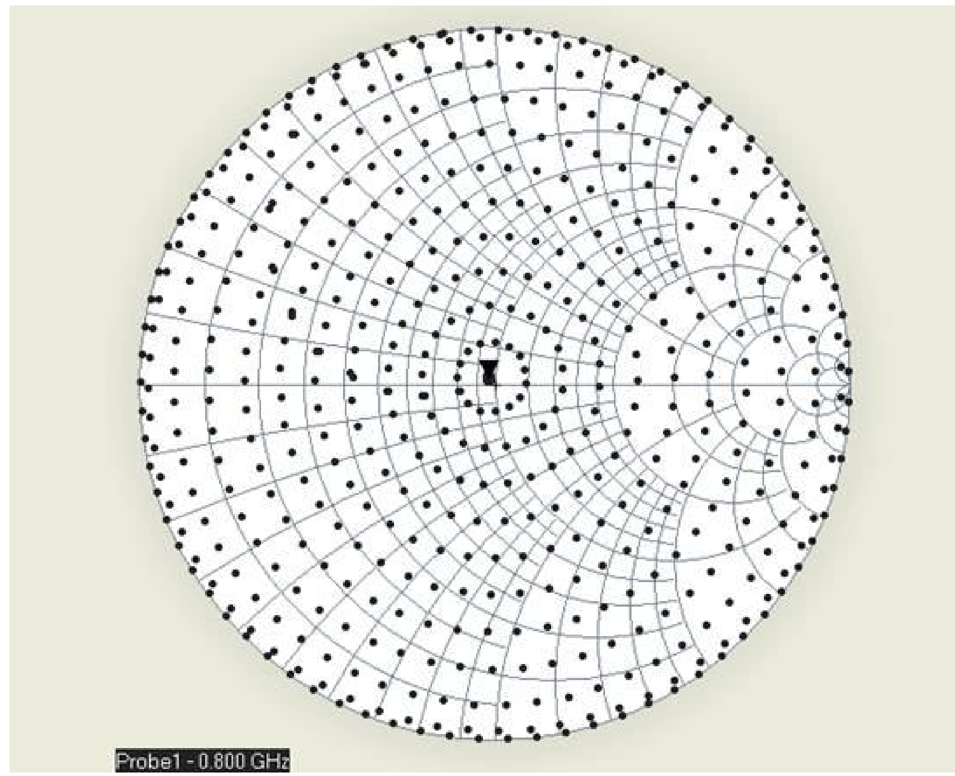
No power meter needed
No spectrum analyzer needed

→

This can be done using the ZVxPlus
and we get the waveforms for free

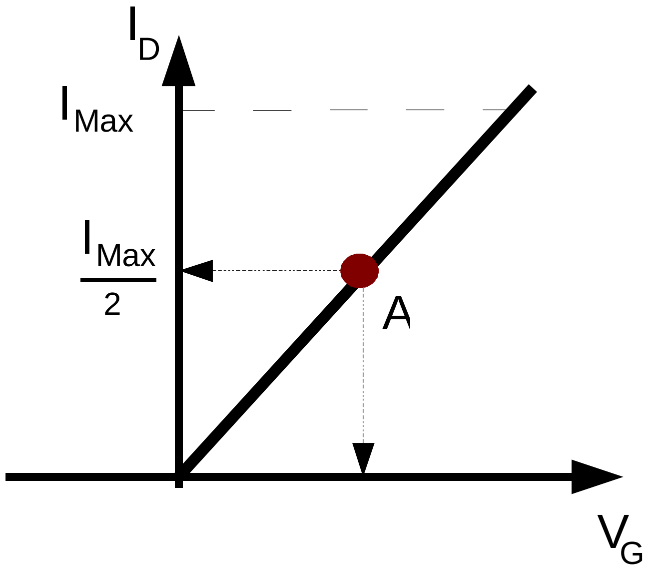
Focus Tuner iCCMT 1804-3C

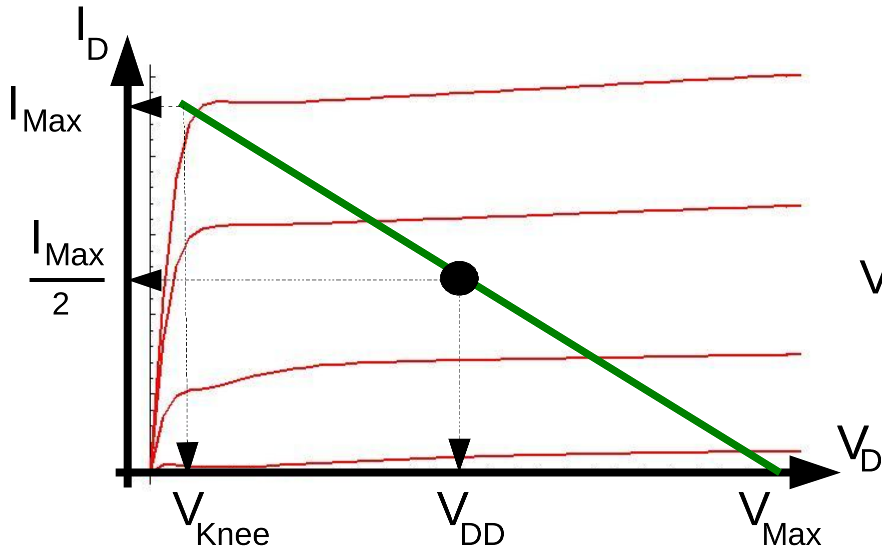
Frequency Range	0.4 – 18 GHz
VSWR	min. 12:1 typ. 20:1
Insertion Loss	0.20 dB @ 3 GHz 0.65 dB @ 18 GHz
Repeatability	min. -40 dB typ. -50 dB



Calibrated points @ 0.8GHz

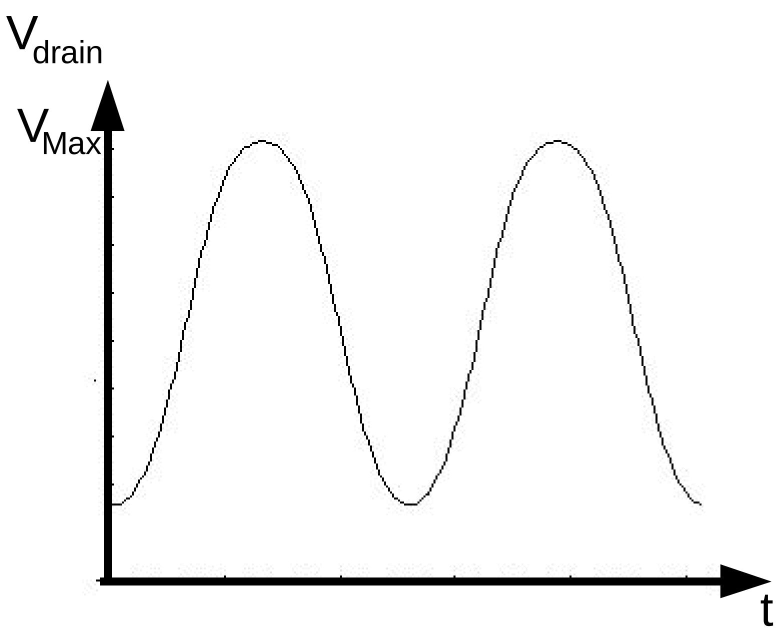
Class A design

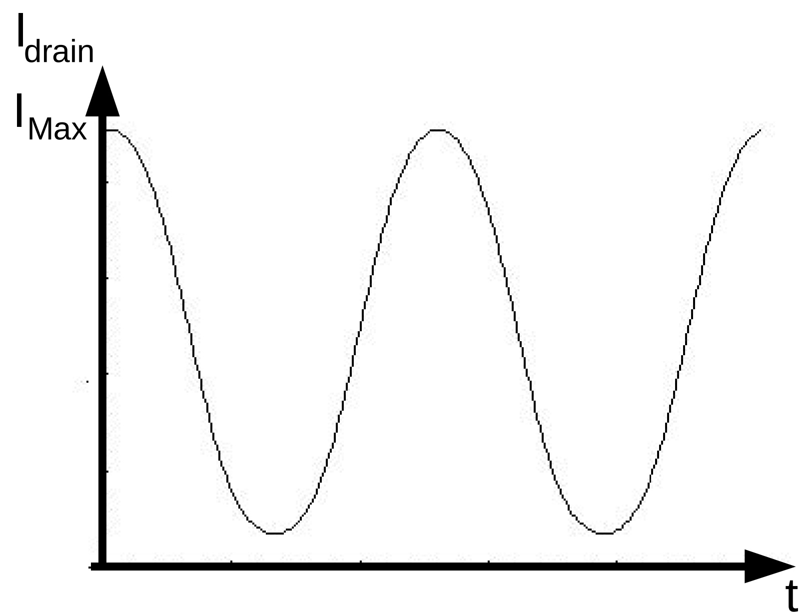




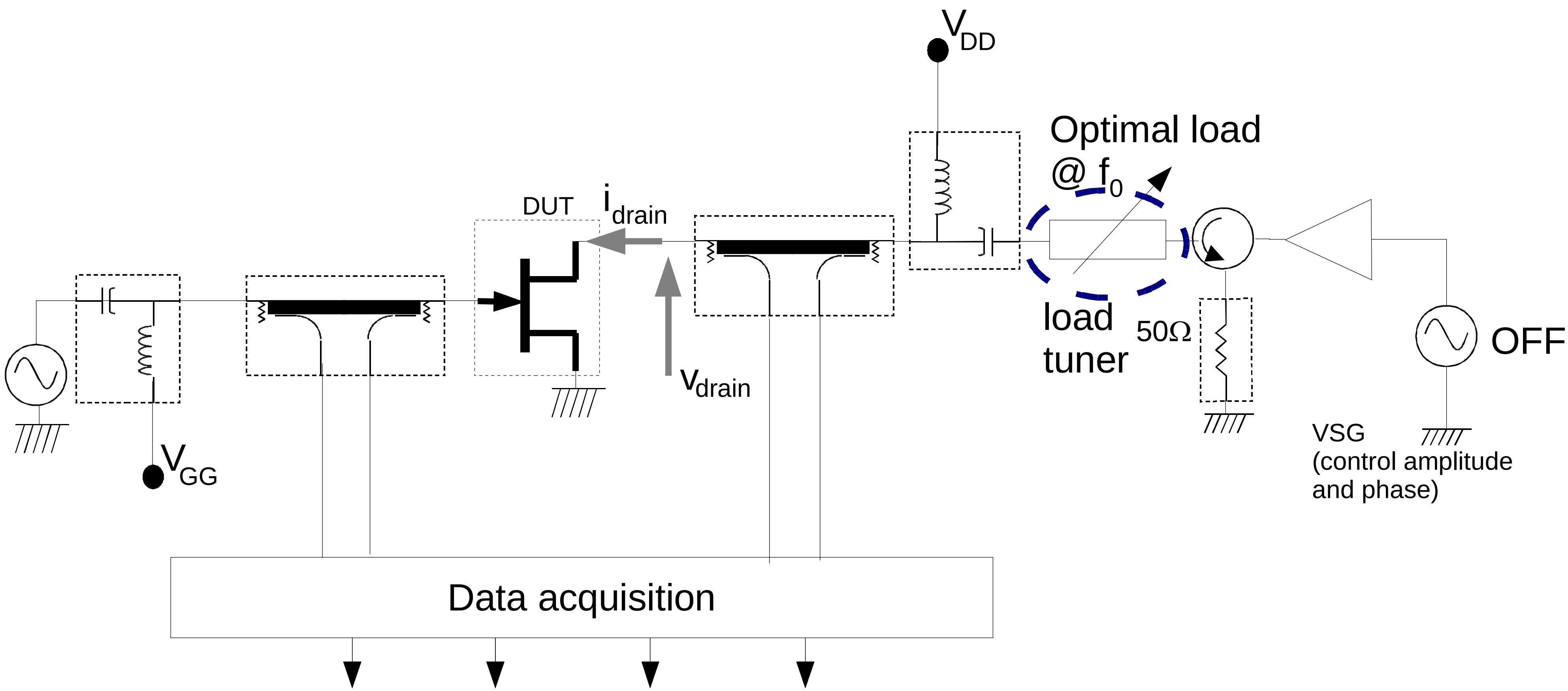
$$R_L = \frac{V_{DD}}{0.5\, I_{Max}}$$

$$V_{DD} \approx \frac{V_{max} - V_{Knee}}{2} + V_{Knee}$$

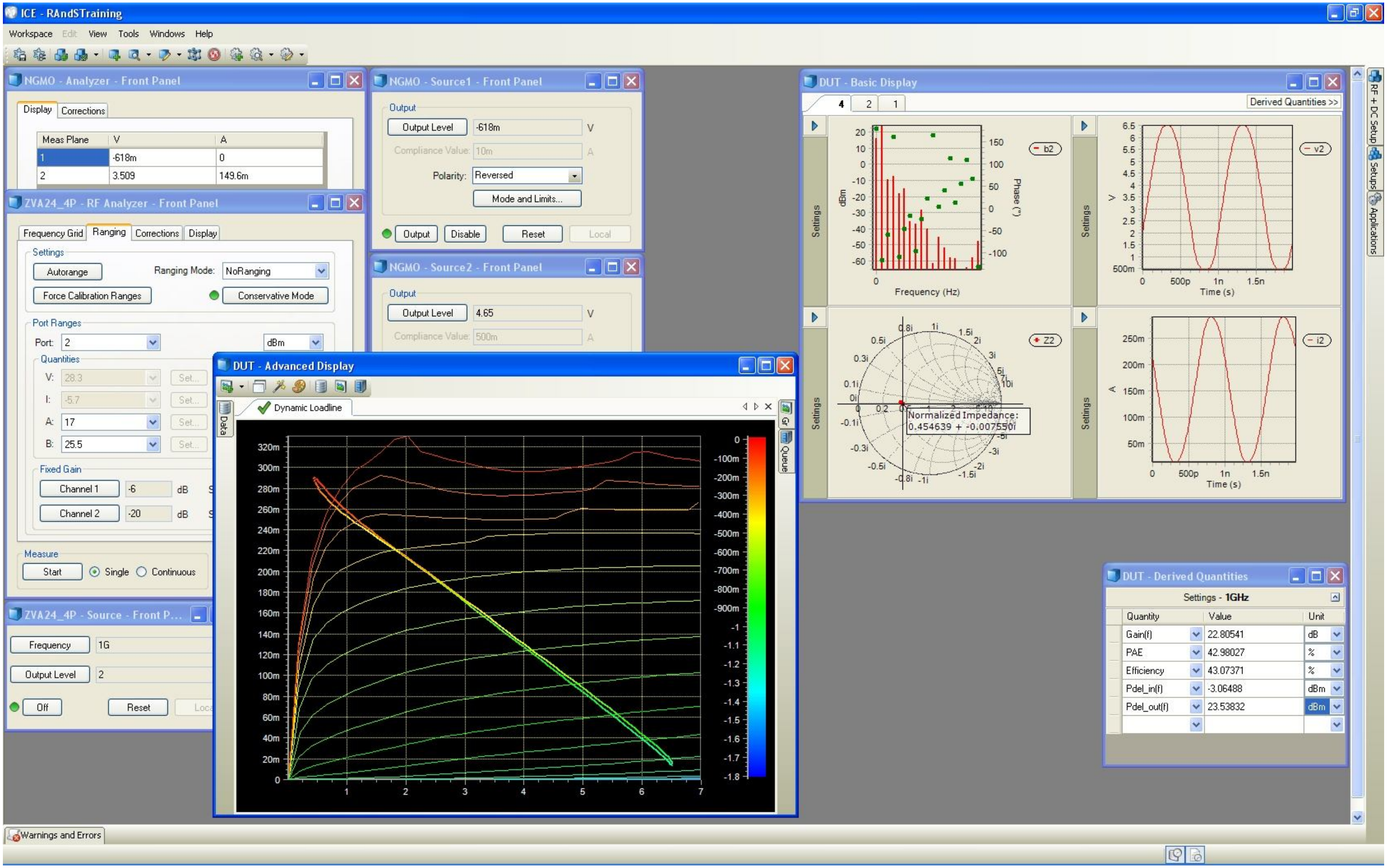




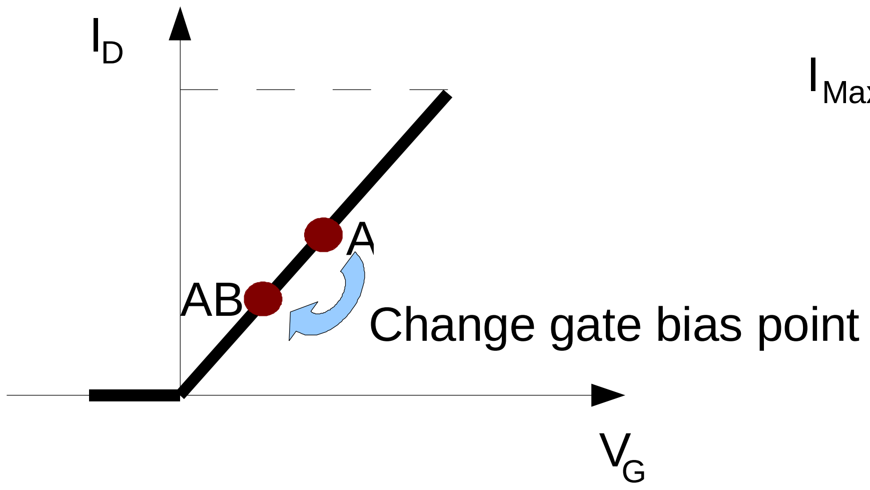
Measurement Setup

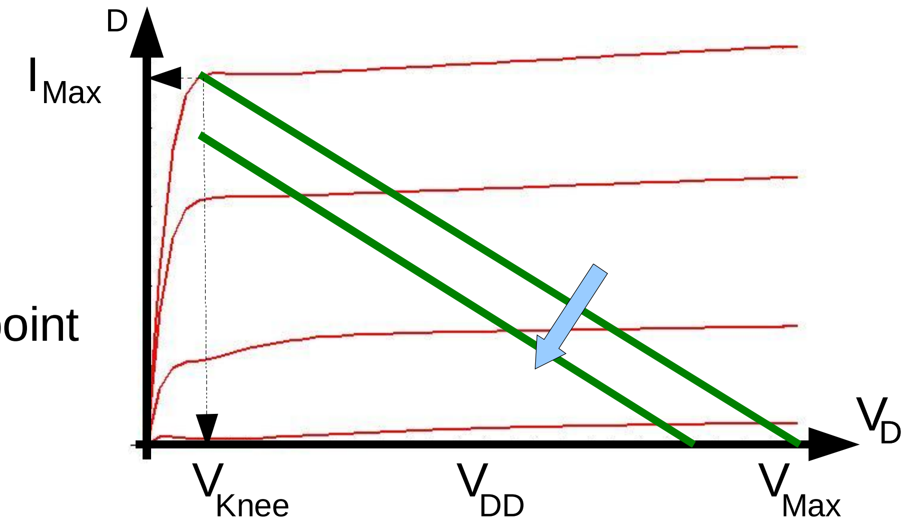


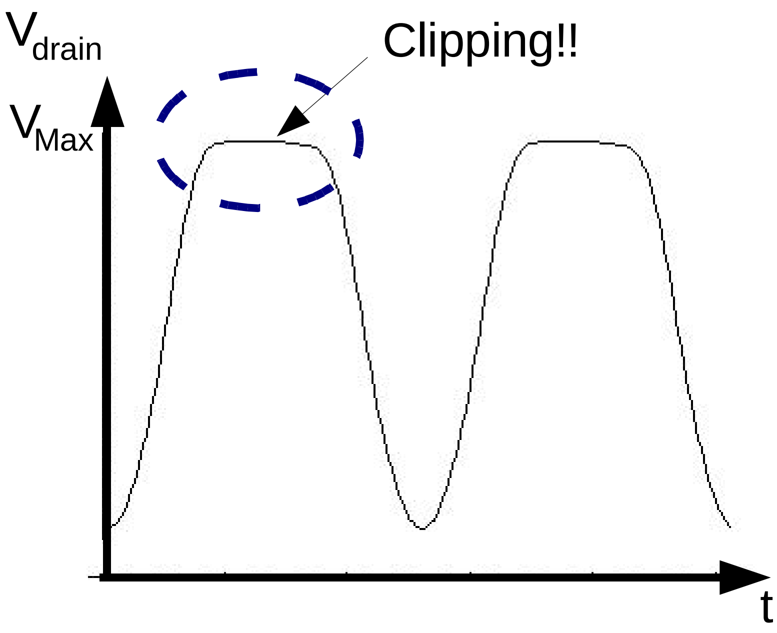
Class A design in practice

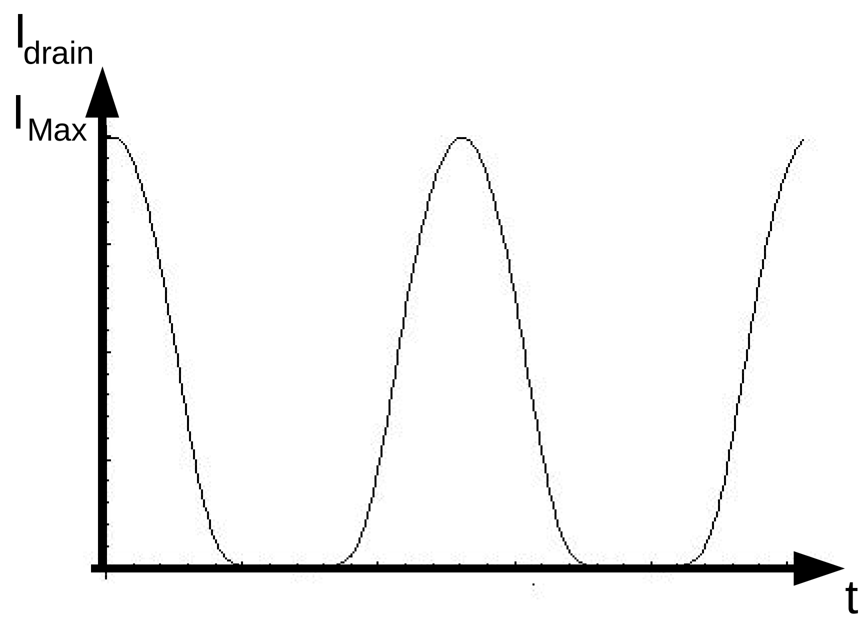


Class AB design, first steps

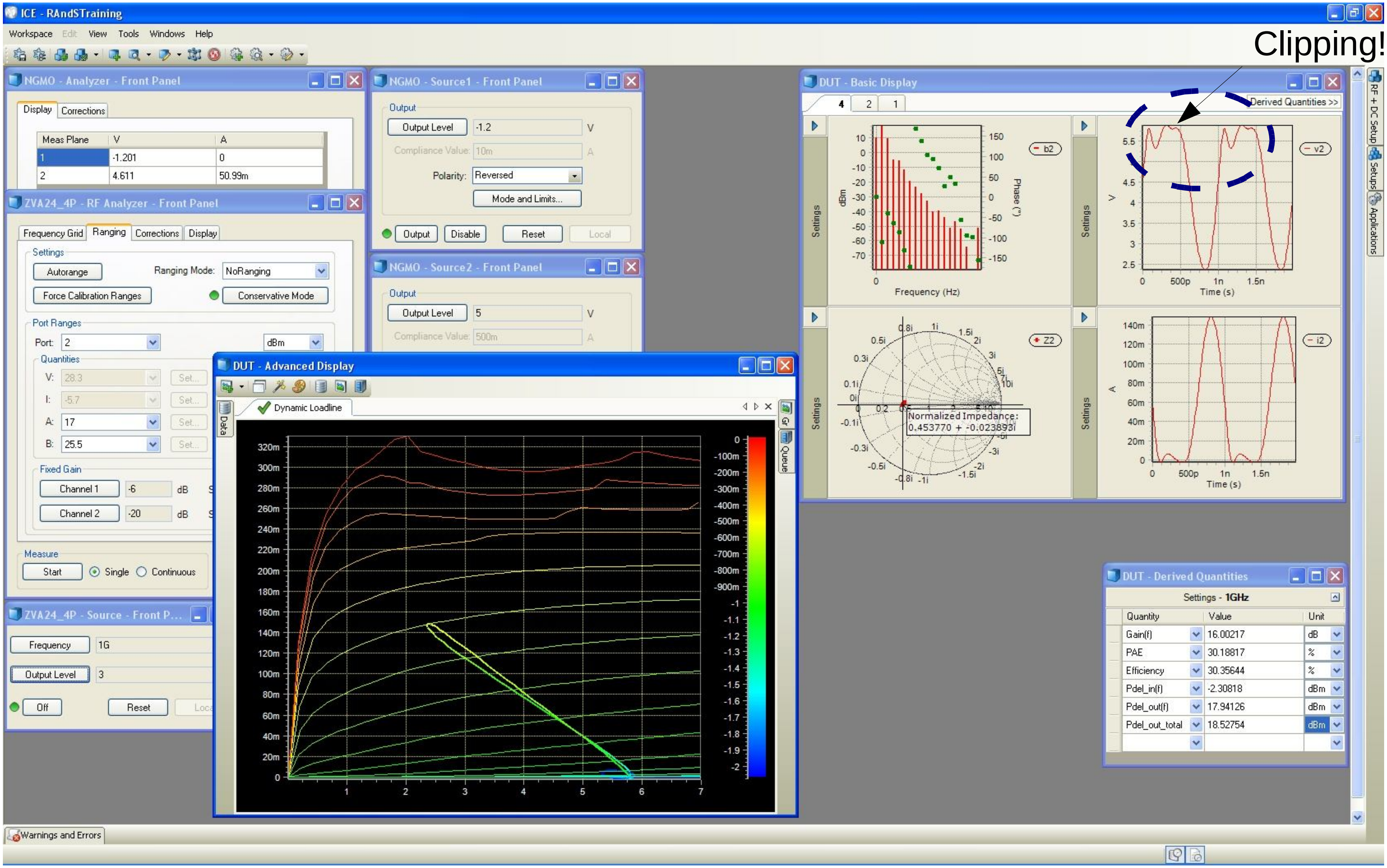




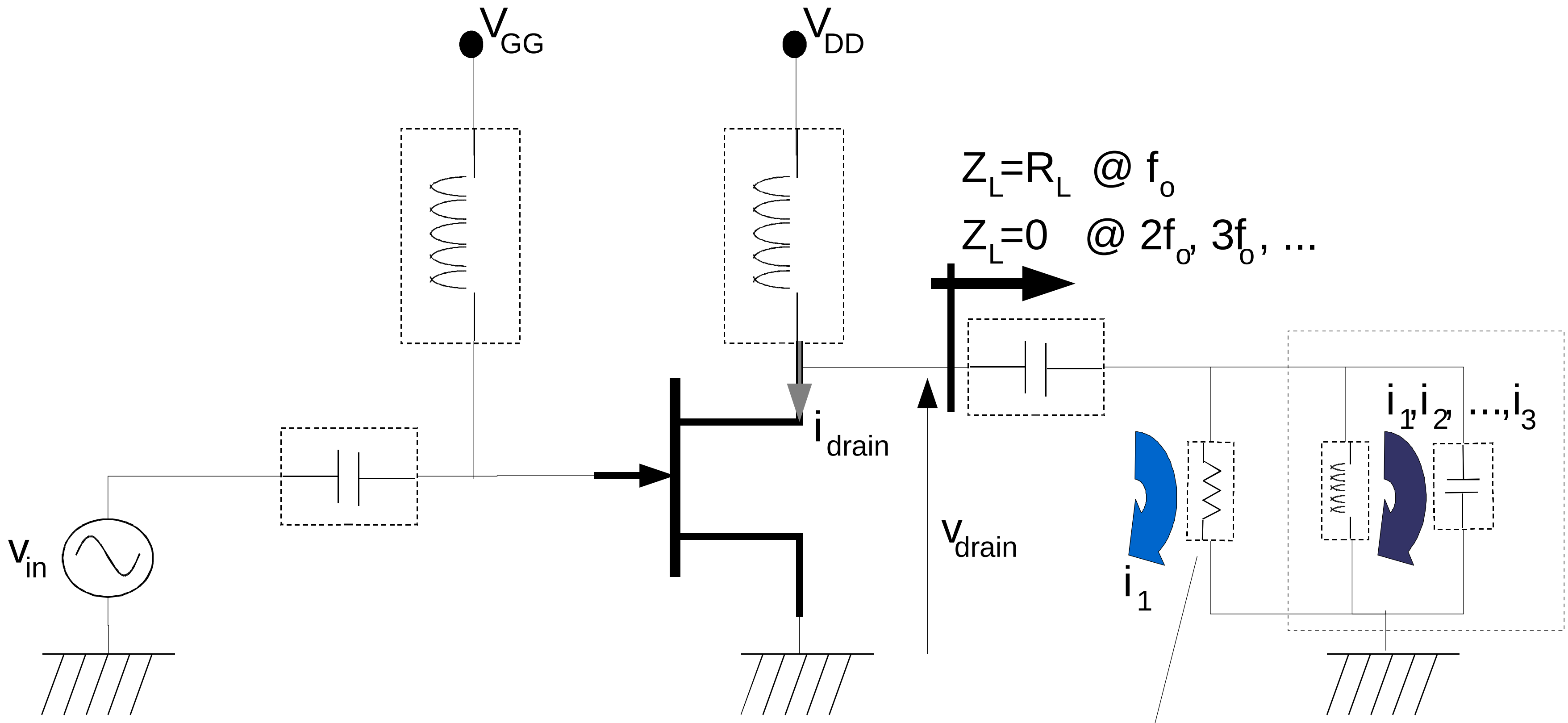




Class AB design, first steps in practice



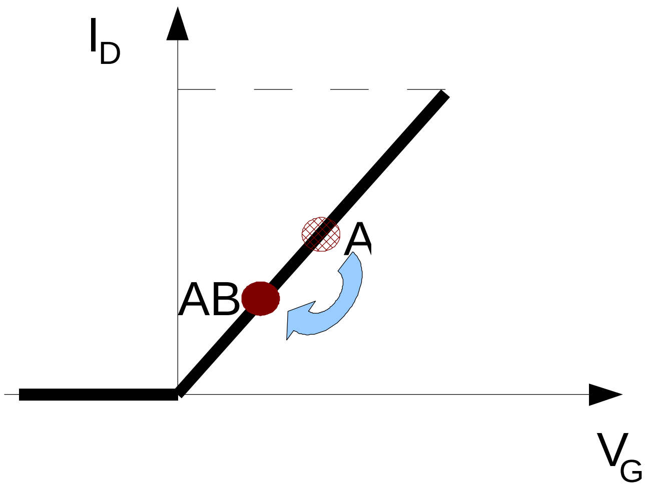
Harmonic output termination: tuned load

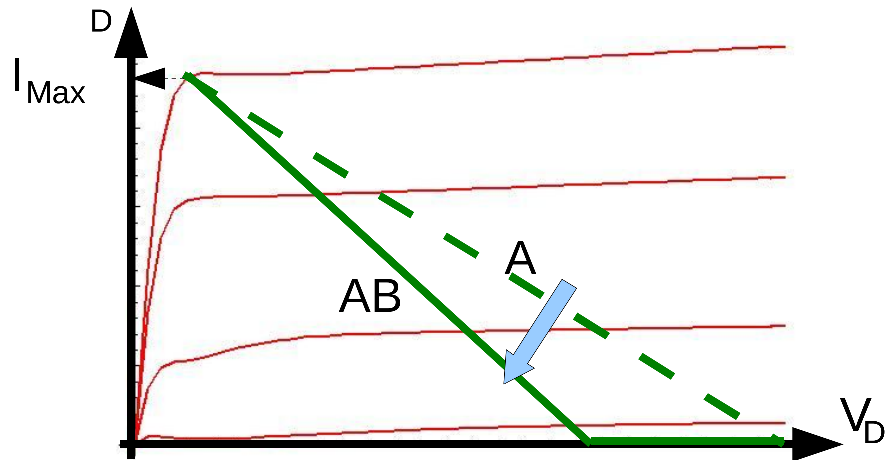


In case of :
- a perfect harmonic short
- maximum voltage swing of $2V_{DD}$
- no knee region

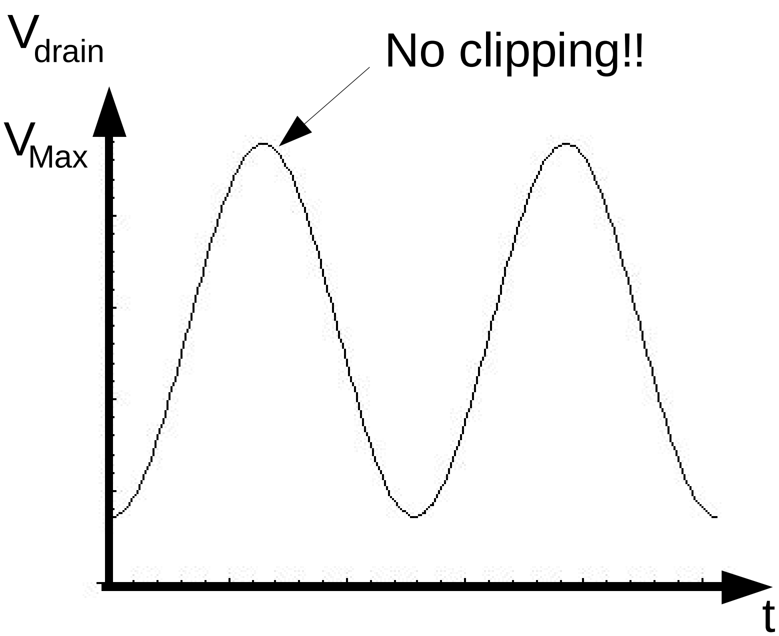
the optimum value of load resistance will be: $R_L = \frac{V_{DD}}{I_{@f0}}$

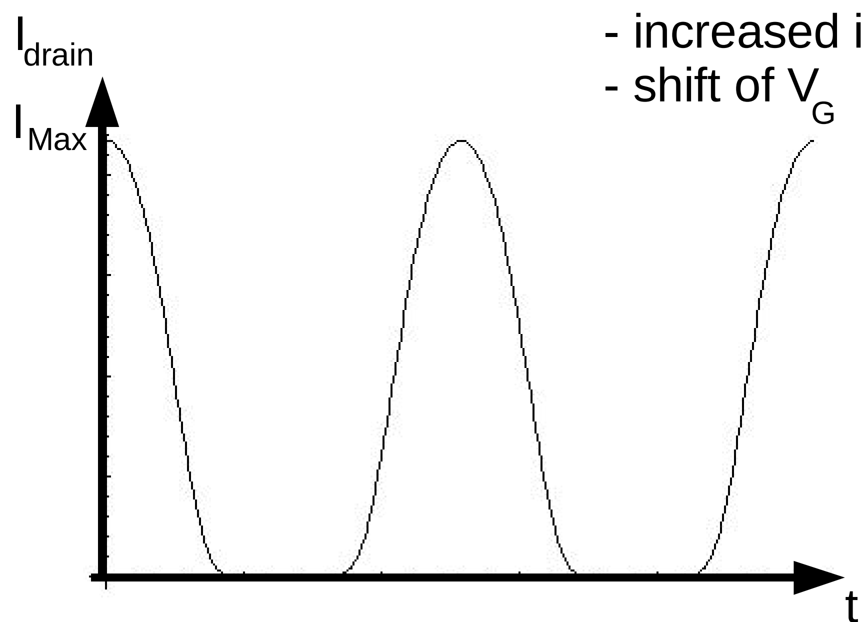
Class AB design



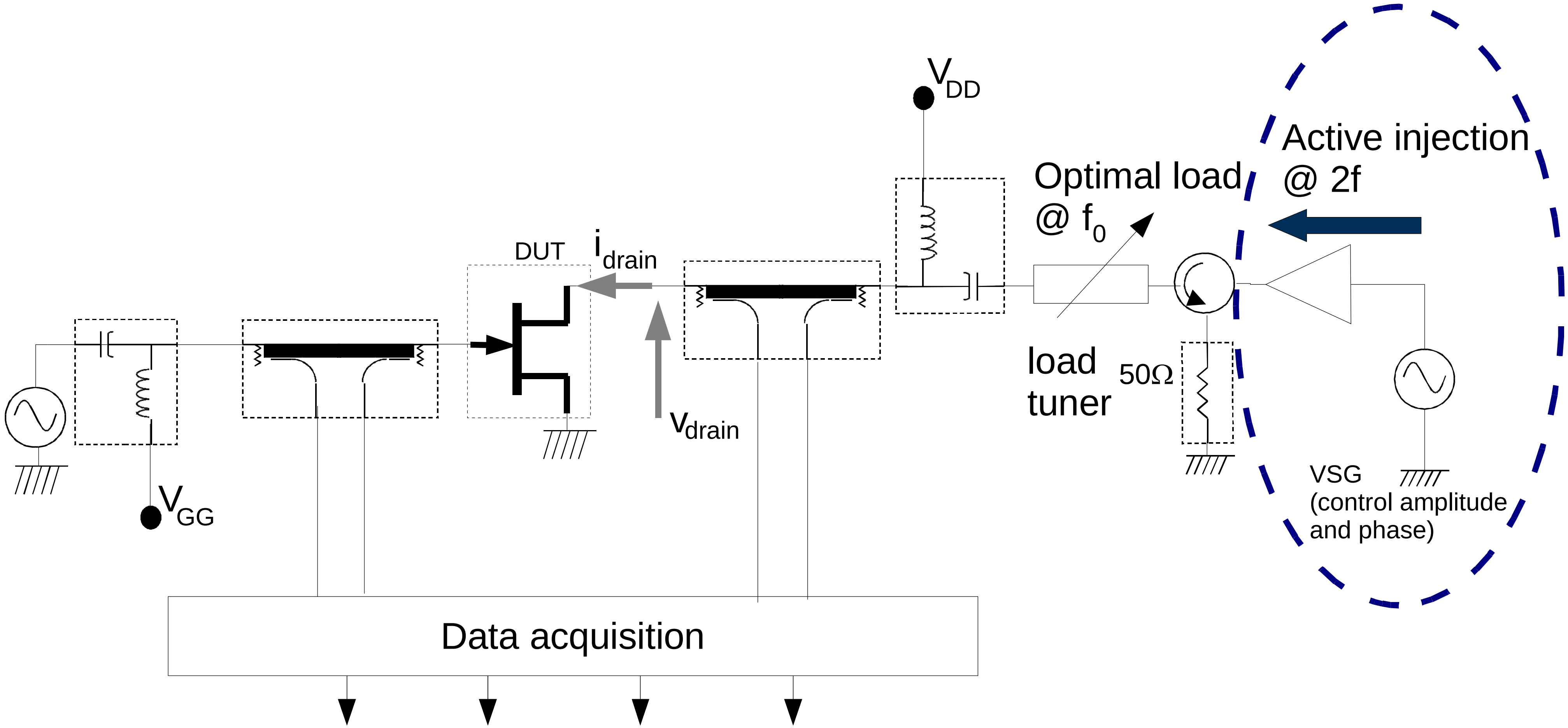


due to:
- termination at harmonics
- increased input signal
- shift of V_G

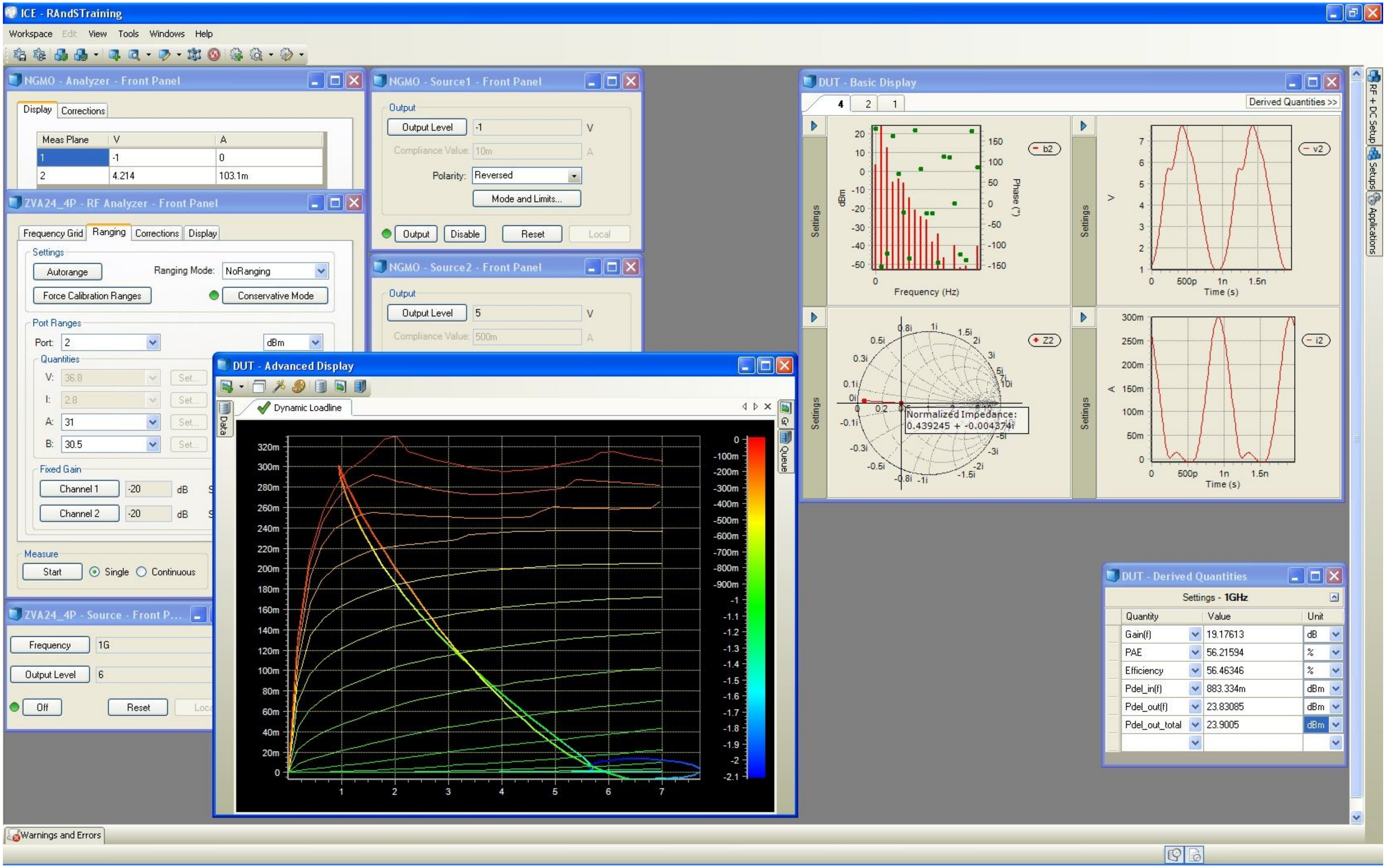




Harmonic active tuning



Class AB in practice



Conclusion

- We have shown:
  - The evolution in the market and characterization techniques
  - Going beyond S-parameters with the ZVxPlus
  - Application example: PA design

Combining the LSNA technology and state-of-the-art tuning technologies, a RF Design Engineer can

on the fly design an application,

using one tool,

that gives all the information needed for the design.

It will surely open new domains and applications.

Contact information

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