Phase Calibration, an Overview from a Large-Signal Network Analysis Point of View

Frans Verbeyst

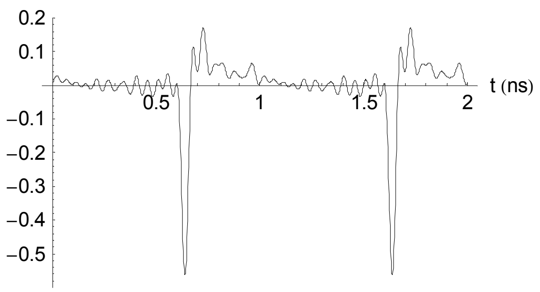
NMDG
LEADING BEYOND S-PARAMETERS

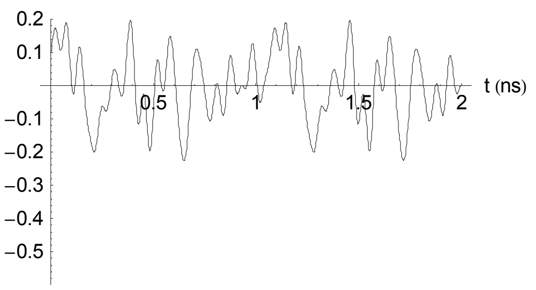
IEEE

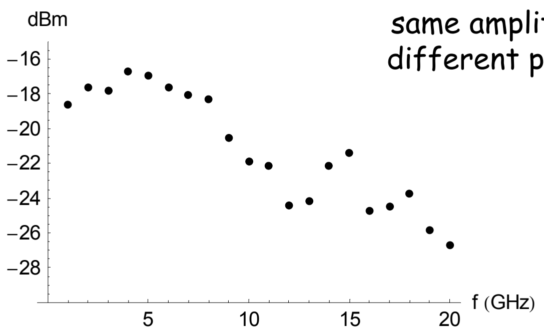
TARGET

Some slides courtesy of Agilent Technologies

Why accurate phase ?







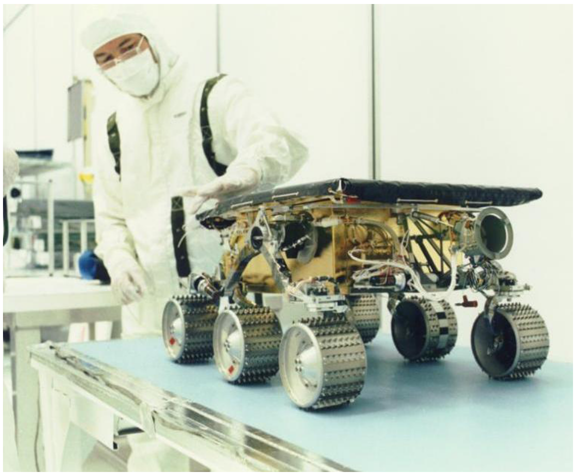
same amplitude
different phase

Large-signal network analysis: what?

accurate and **complete** measurement
of the nonlinear behaviour
of your active device
under **realistic conditions**

realistic with respect to:
- excitation
- mismatch conditions

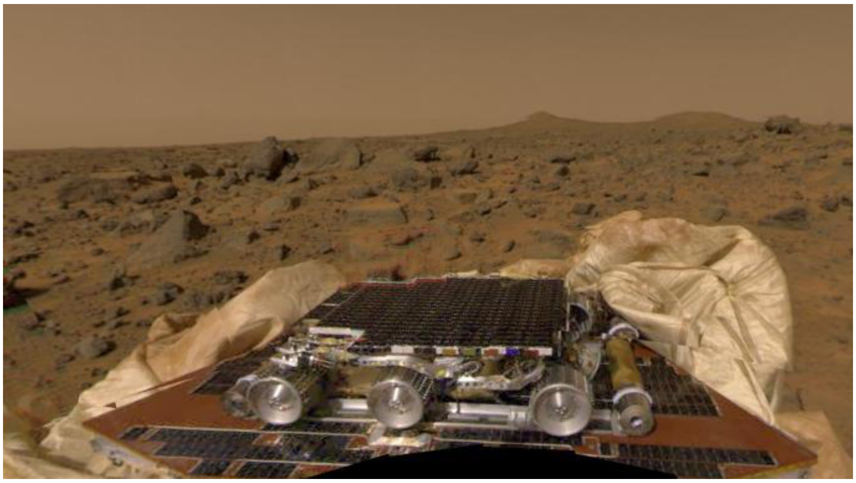
Why realistic conditions ?



picture courtesy of NASA

picture courtesy of NASA

Why realistic conditions ?



picture courtesy of NASA

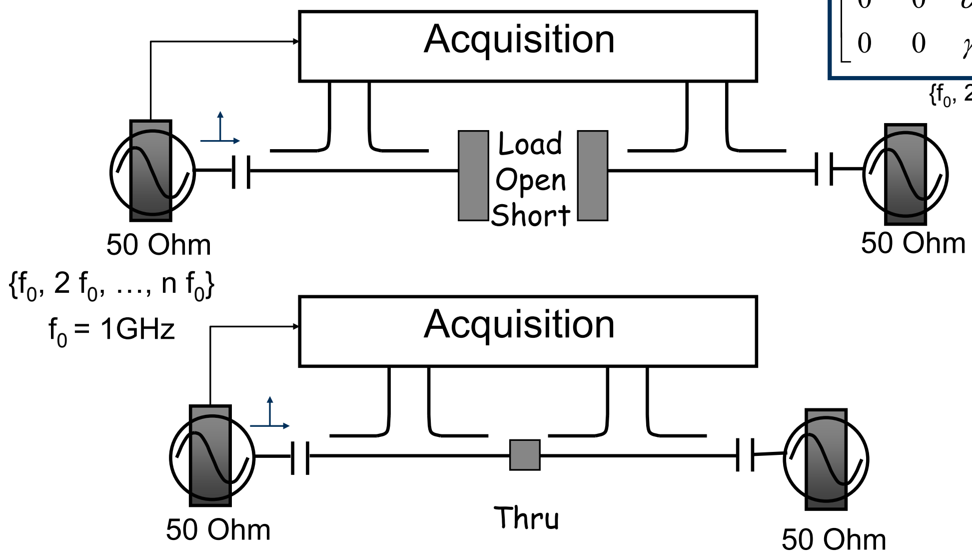
Why realistic conditions ?

the unreleased picture

LSNA relative calibration

$$K \begin{bmatrix} 1 & \beta_1 & 0 & 0 \\ \gamma_1 & \delta_1 & 0 & 0 \\ 0 & 0 & \alpha_2 & \beta_2 \\ 0 & 0 & \gamma_2 & \delta_2 \end{bmatrix}$$

$\{f_0, 2\,f_0, \ldots, n\,f_0\}$

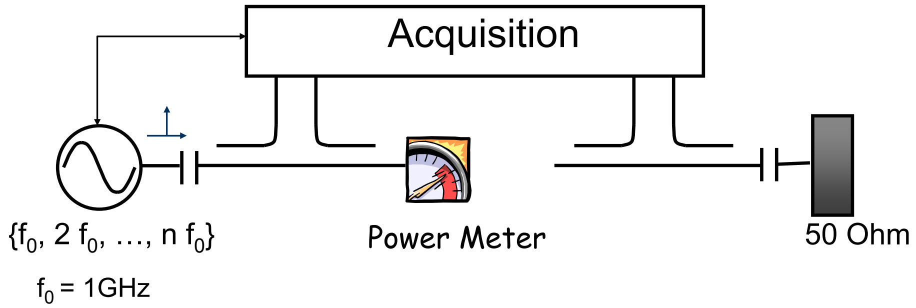


Calibration for fundamental and harmonics
One frequency at the time

LSNA power calibration

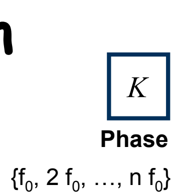
$$\boxed{K} \begin{bmatrix} 1 & \beta_1 & 0 & 0 \\ \gamma_1 & \delta_1 & 0 & 0 \\ 0 & 0 & \alpha_2 & \beta_2 \\ 0 & 0 & \gamma_2 & \delta_2 \end{bmatrix}$$

Amplitude
$\{f_0, 2\,f_0, \ldots, n\,f_0\}$

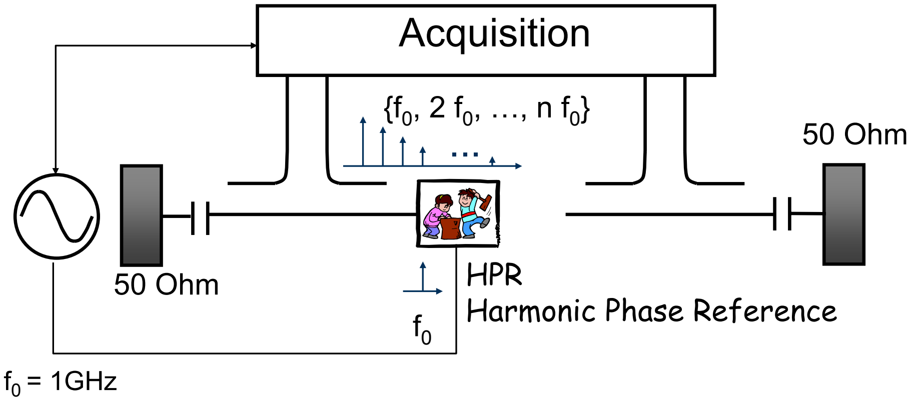


Calibration for fundamental and harmonics
One frequency at the time

LSNA phase calibration

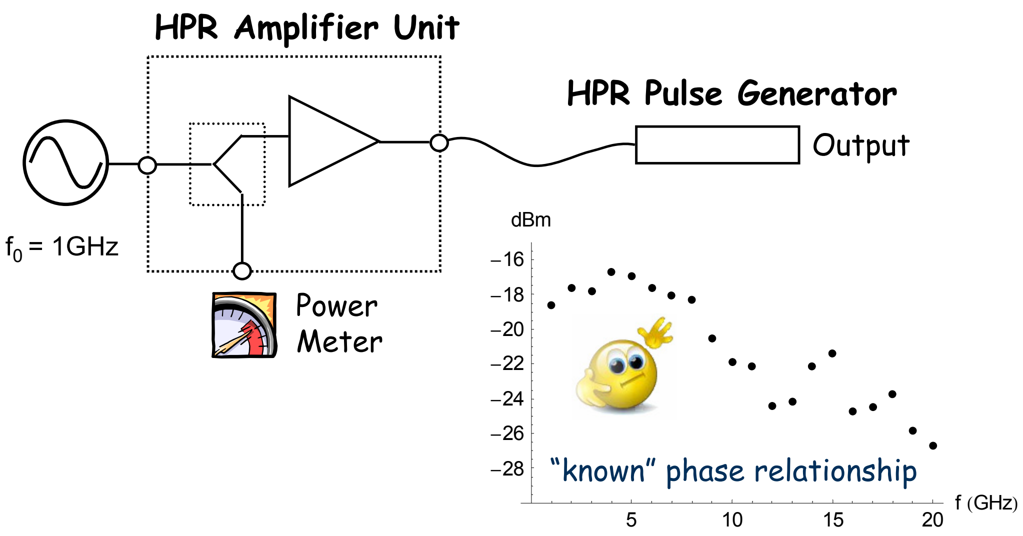


$$\begin{bmatrix} 1 & \beta_1 & 0 & 0 \\ \gamma_1 & \delta_1 & 0 & 0 \\ 0 & 0 & \alpha_2 & \beta_2 \\ 0 & 0 & \gamma_2 & \delta_2 \end{bmatrix}$$



Calibration for fundamental and harmonics
All frequencies applied simultaneously !

Harmonic Phase Reference



LSNA and phase calibration

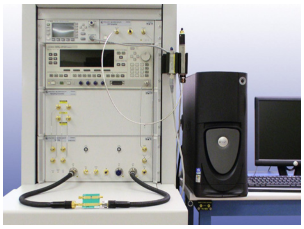
LSNA phase calibration

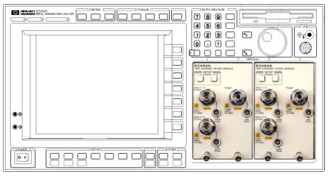
requires

a calibrated HPR

requires

a calibrated oscilloscope

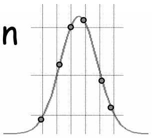




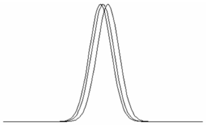
Sampling oscilloscopes "reality"

time base errors

distortion
$t_k \neq k.\Delta t$

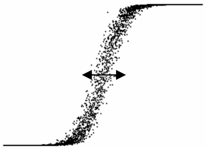


drift



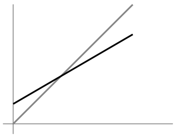
measure,
estimate,
compensate

jitter



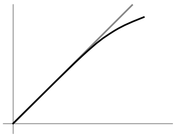
vertical errors

offset



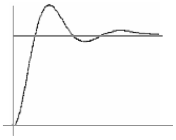
vertical cal
plug-in

nonlinearity



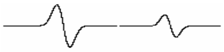
avoid: use
small signal

dynamics



nose2nose
EOS

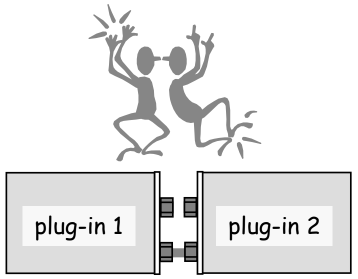
mismatches, connector saver



measure and compensate

Sampling oscilloscope calibration

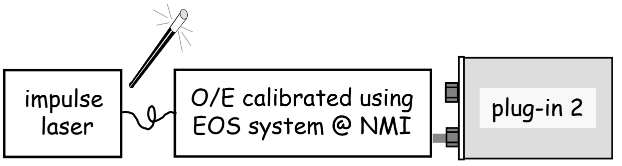
nose2nose



assumption:
kickout pulse ÷ impulse response

$$H_{meas}(f) \div H_1(f).\ H_2(f)$$

EOS-based

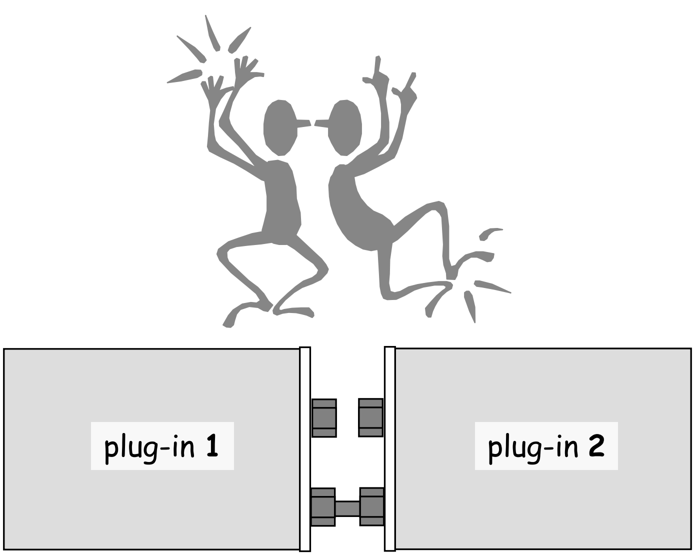


assumption:
no anomalies in O/E calibration

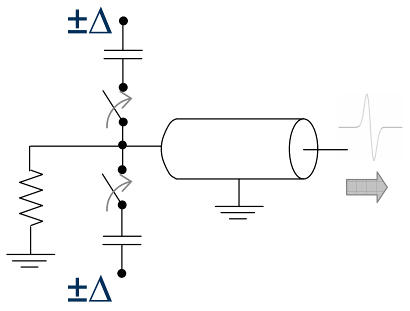
$$H_{meas}(f) = H_{O/E}(f).\ H_2(f)$$

after compensation of time base errors
(and mismatches)

More details on nose2nose

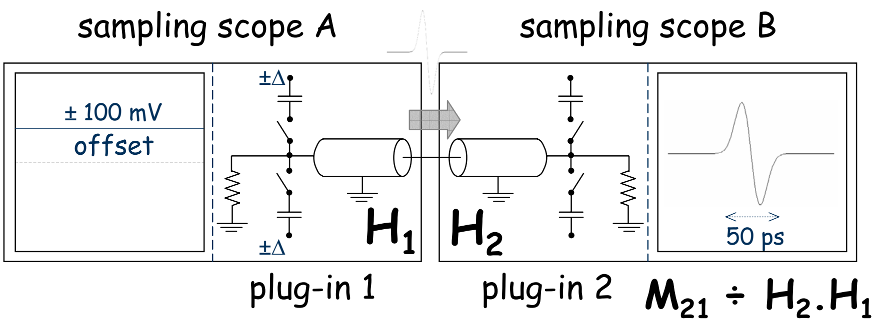


Origin of nose2nose



- **sampler** topology 👓 **pulse generator** topology
- **offset** applied to sampler
  - ⇒ unbalance
  - ⇒ generation of pulse: **"kickout"**
- **"kickout"** proportional to **"impulse response"** of plug-in

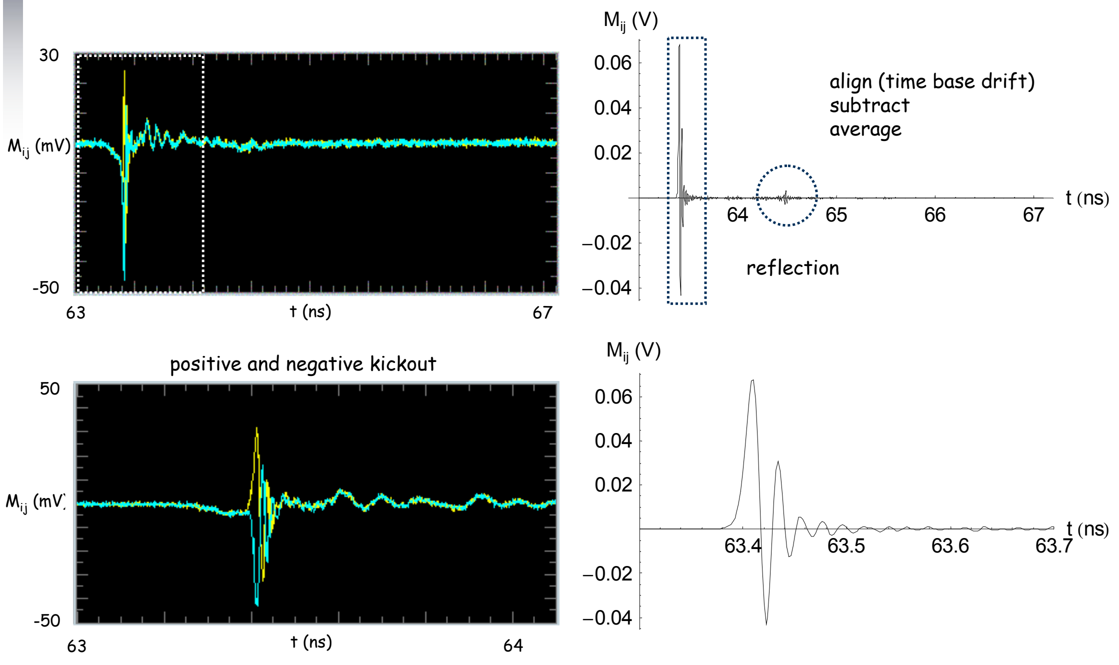
Basic setup for nose2nose



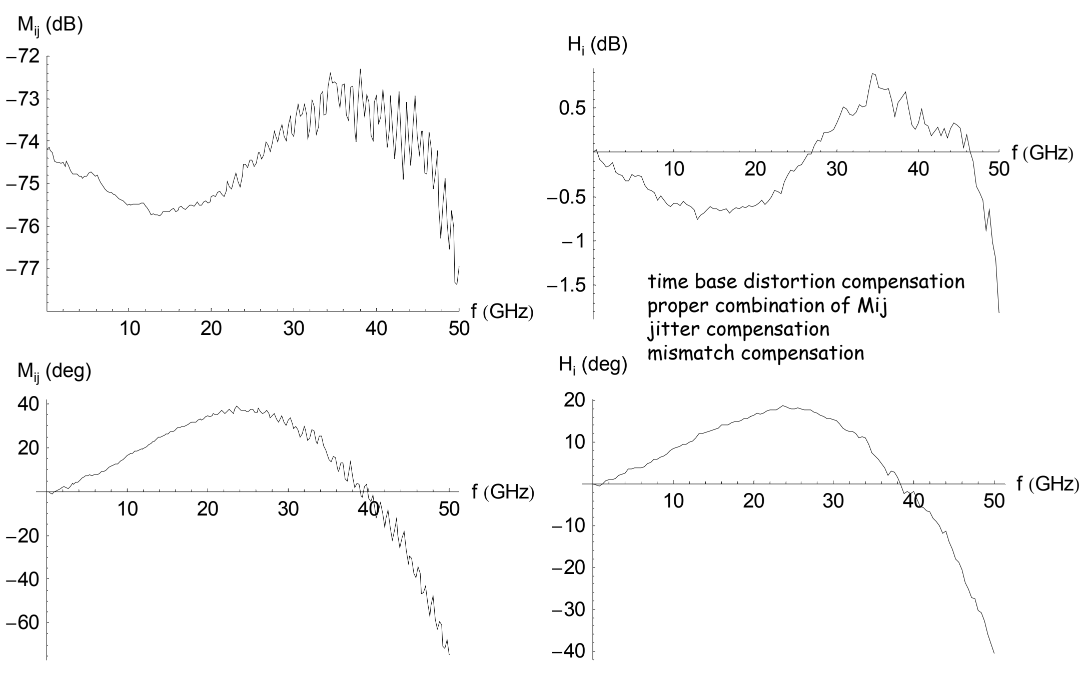
$$M_{21} \div H_2.H_1$$
$$M_{23} \div H_2.H_3$$
$$M_{13} \div H_1.H_3$$

$$\Rightarrow \quad \sqrt{\frac{M_{21}.M_{13}}{M_{23}}} \div H_1$$

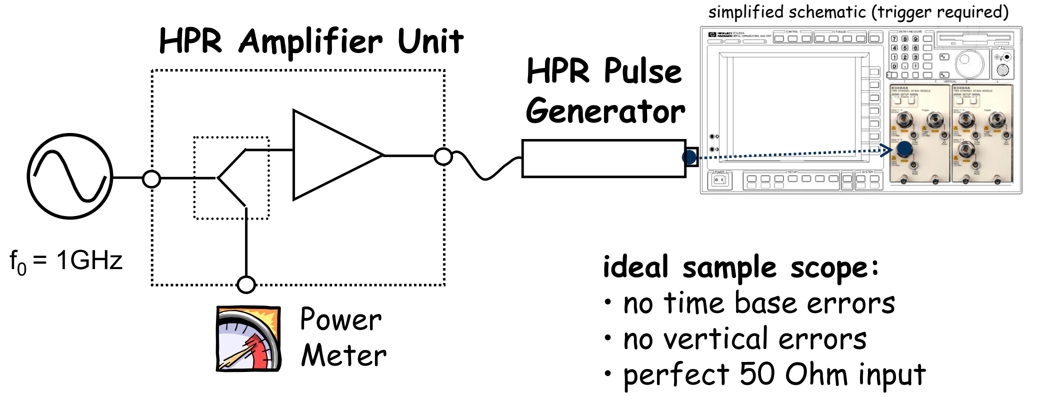
nose2nose in practice: from M_{ij} …



nose2nose in practice: from M_{ij} to H_i



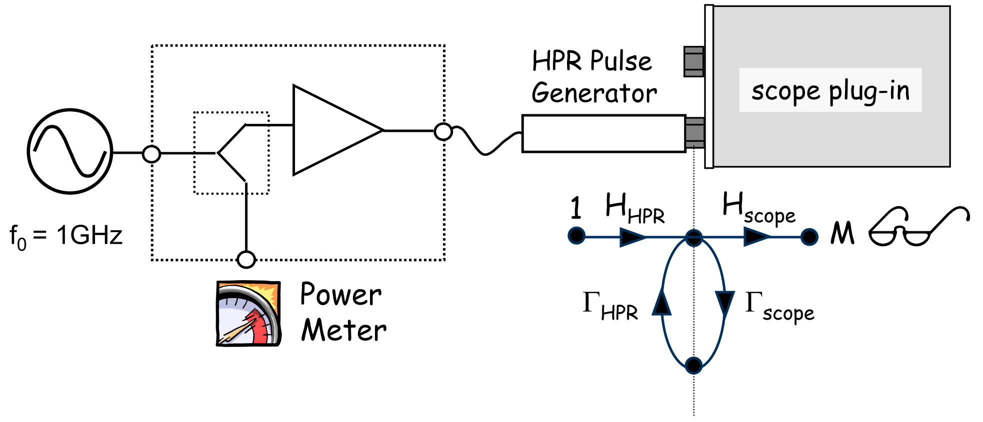
Appl#1: Harmonic Phase Reference



ideal sample scope:
- no time base errors
- no vertical errors
- perfect 50 Ohm input

capture time-domain signal
apply Fourier transform
to obtain phase relationships

Appl#1: Harmonic Phase Reference

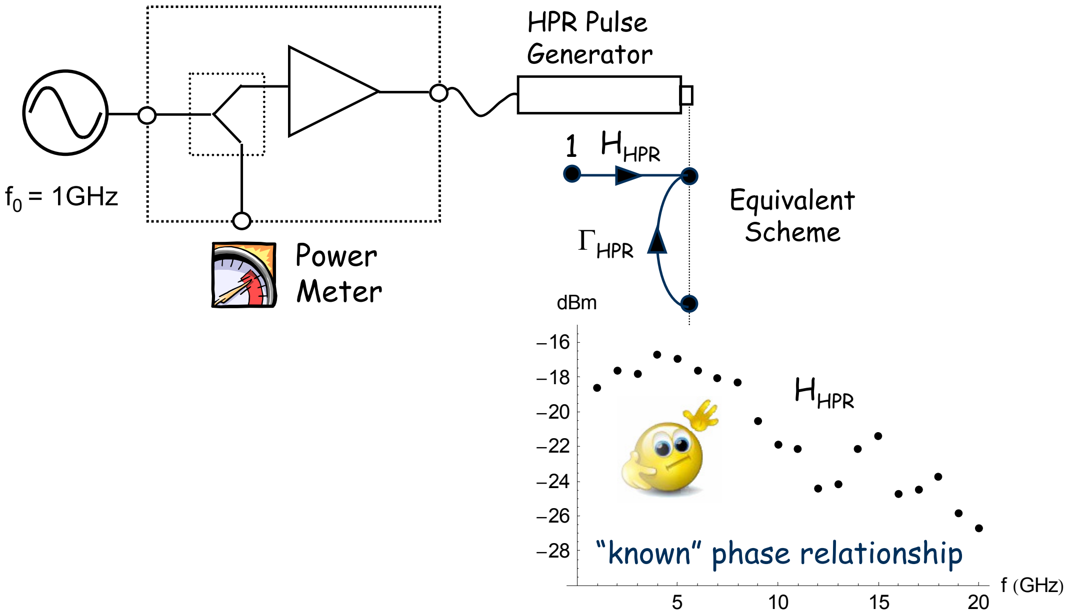


real sample scope:
after compensation of time base errors (!)

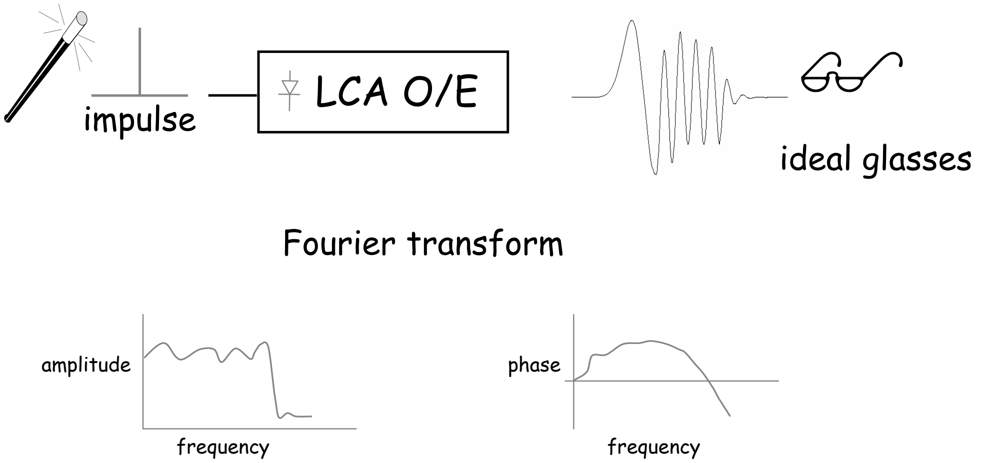
$$M = \frac{H_{HPR} \cdot H_{scope}}{1 - \Gamma_{HPR} \cdot \Gamma_{scope}}$$

n2n

Appl#1: Harmonic Phase Reference

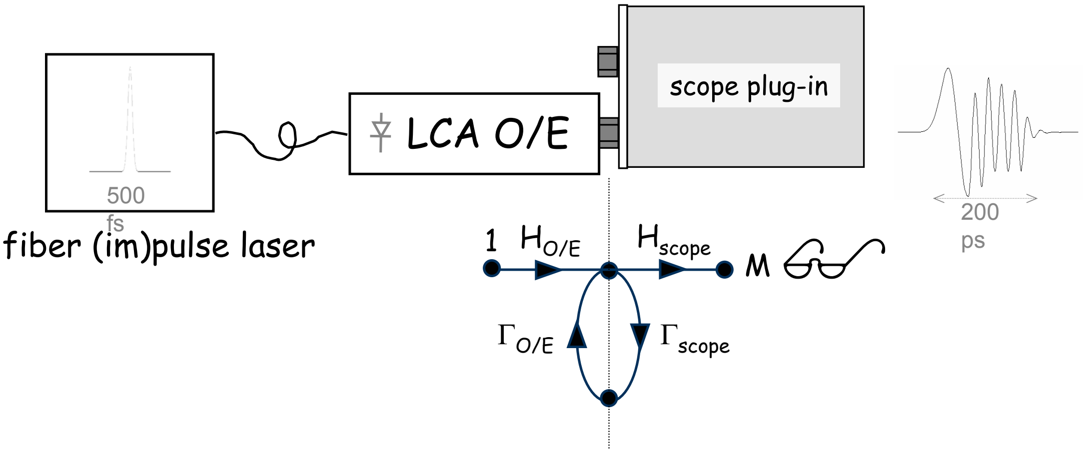


Appl#2: LCA O/E



$H_{O/E}$: O/E impulse response

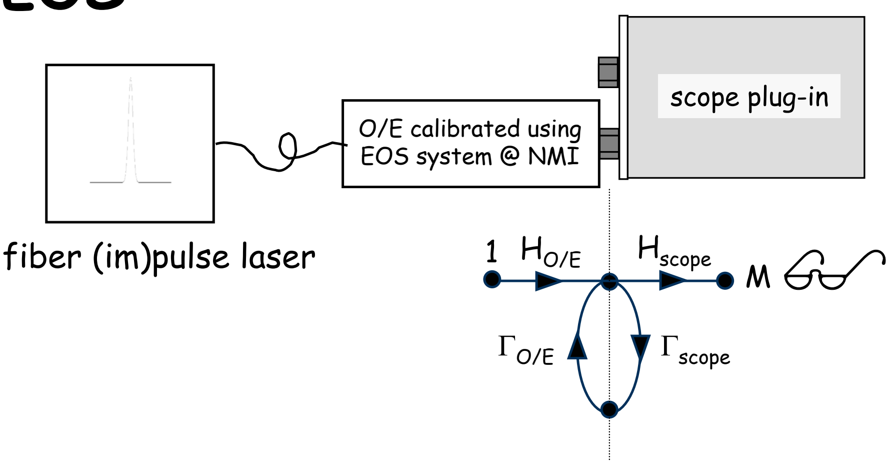
Appl#2: LCA O/E



real sample scope:
after compensation of time base errors (!)

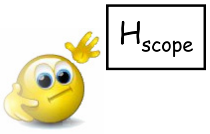
$$M = \frac{H_{O/E} \cdot H_{scope}}{1 - \Gamma_{O/E} \cdot \Gamma_{scope}}$$ n2n

EOS

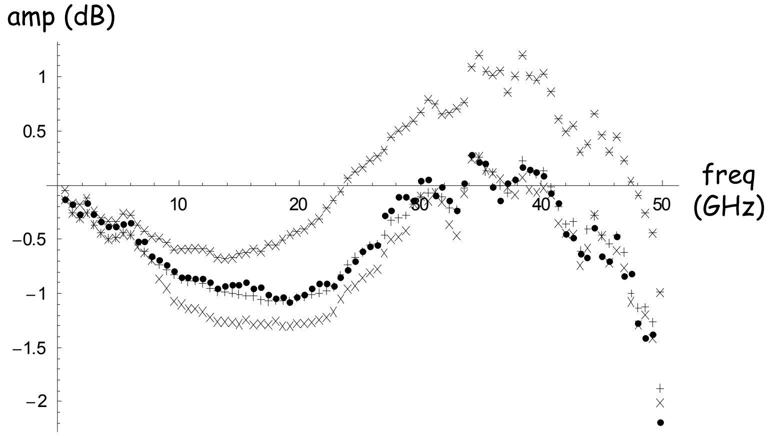


real sample scope:
after compensation of time base errors (!)

$$M = \frac{H_{O/E} \cdot H_{scope}}{1 - \Gamma_{O/E} \cdot \Gamma_{scope}}$$ EOS

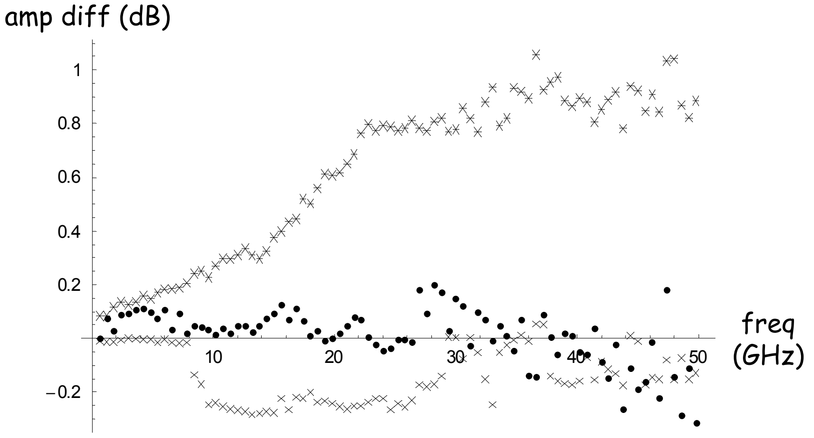


Ampl. characteristic verification (1)



-X- nose2nose
● EOS
X power meas – freerun trigger – histogram meas
+ power meas – triggered mode - normal meas

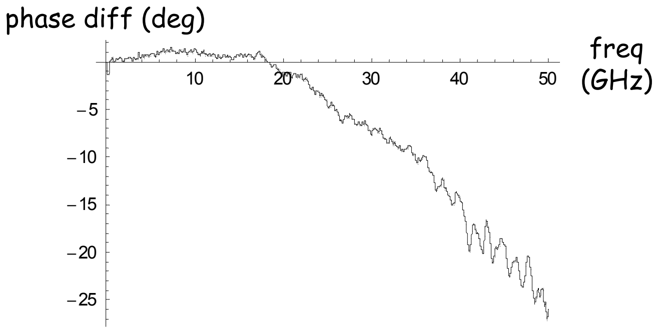
Ampl. characteristic verification (2)



-X- nose2nose
● EOS
X power meas – freerun trigger – histogram meas
+ power meas – triggered mode - normal meas

Phase characteristic comparison

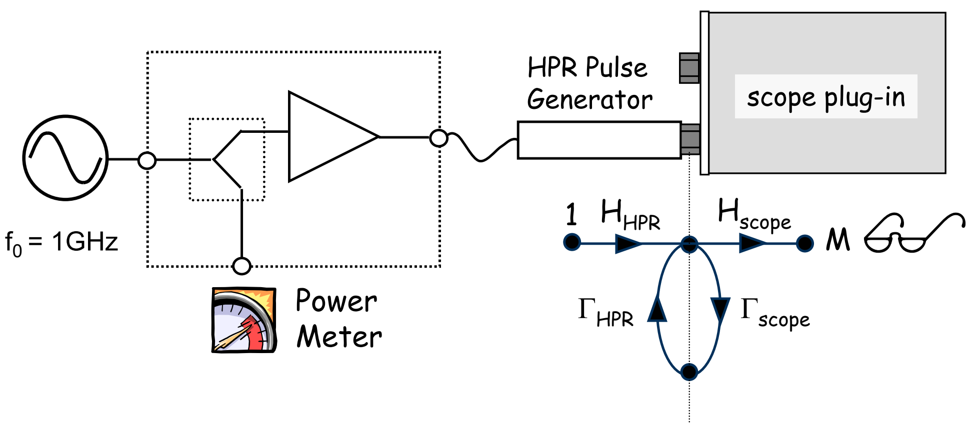
nose2nose versus EOS



Δ within 95% conf. interval up to 20 GHz

Δ ≈ 25 degrees @ 50 GHz

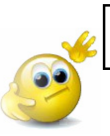
Harmonic Phase Reference



real sample scope:
after compensation of time base errors (!)

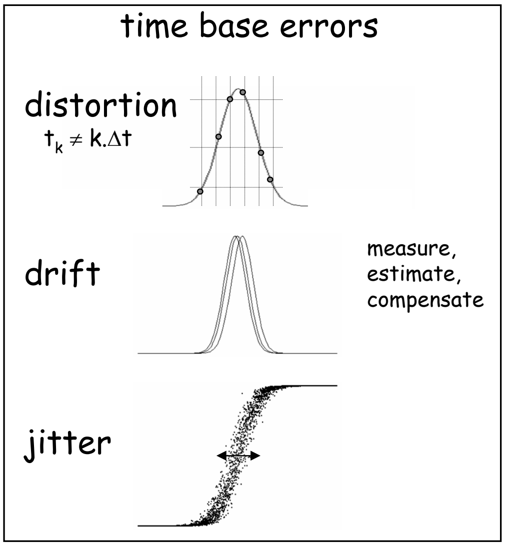
$$M = \frac{H_{HPR} \; H_{scope}}{1 - \Gamma_{HPR} \cdot \Gamma_{scope}}$$

EOS

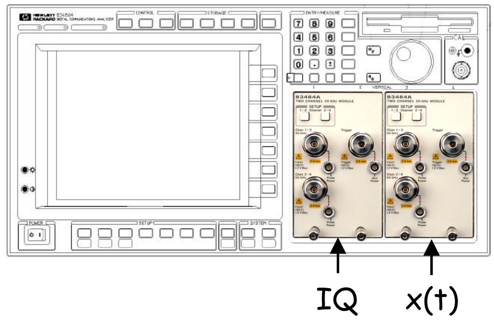


H_{HPR}

Time base error compensation



methods enhanced over time



type #1: no additional channels
perform separate measurements
e.g. to estimate time base distortion

type #2: additional channels
IQ detection to retrieve time
time base distortion + jitter
starting values by type #1

Summary

- Phase is important
- Large-Signal Network Analysis is important
  "We cannot afford to destroy life on Mars"
- Phase calibration of LSNA requires
  - Calibrated HPR
  - Calibrated sample scope
- Deal with
  - Time base errors
  - Vertical errors
    Vertical dynamics = n2n → EOS
  - Mismatch (reflections)