Automatic vector signal generator calibration method suitable for multiport large-signal measurements

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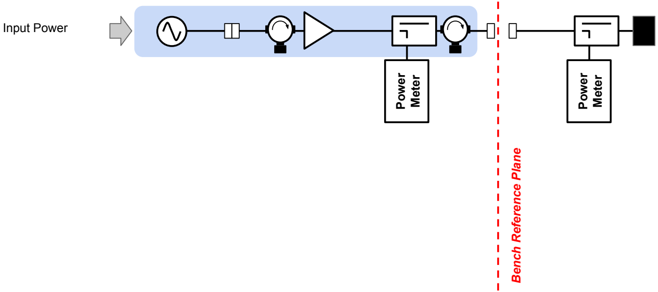
Introduction

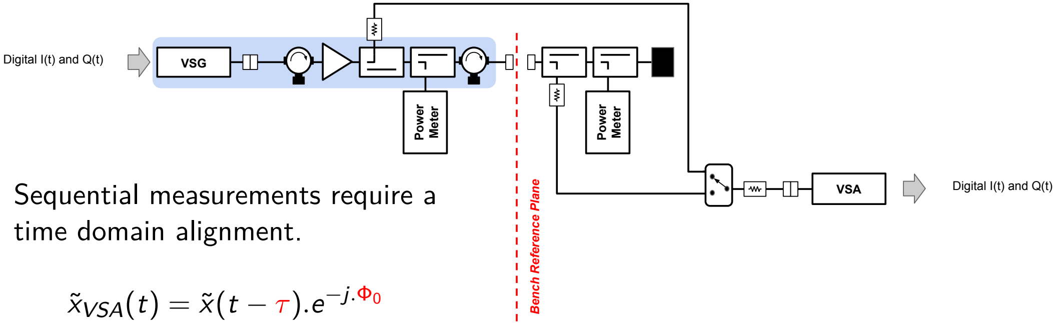
Standard CW measurements



- Static CW 50Ω available power measurements of a single input PA ;
- Source is calibrated by identifying the power offset between the user input and the available power at the DUT reference plane.

Introduction

Standard Modulated measurements

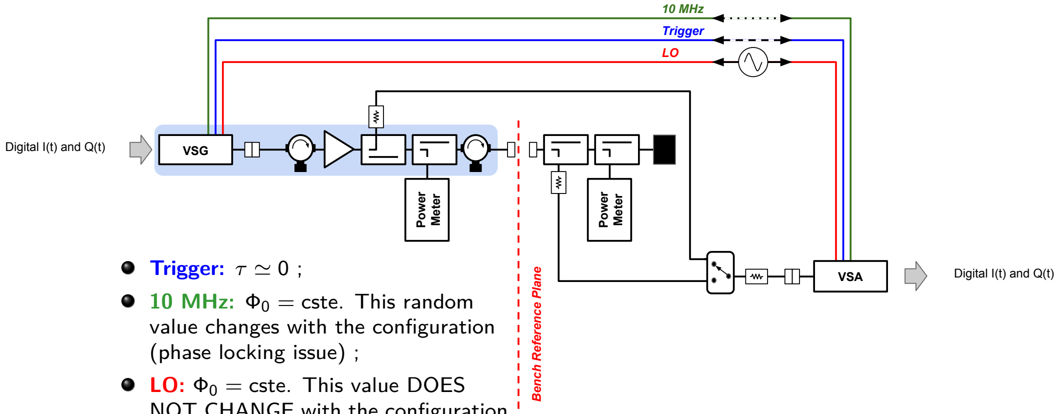


Sequential measurements require a time domain alignment.

$$\tilde{x}_{VSA}(t) = \tilde{x}(t - \tau).e^{-j.\Phi_0}$$

Introduction

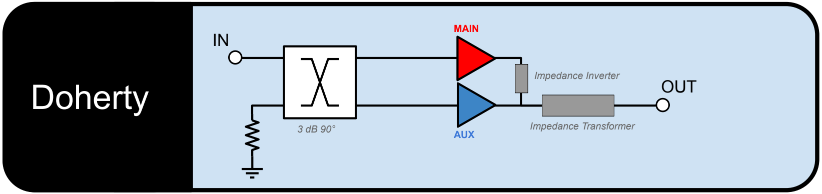
Standard Modulated measurements

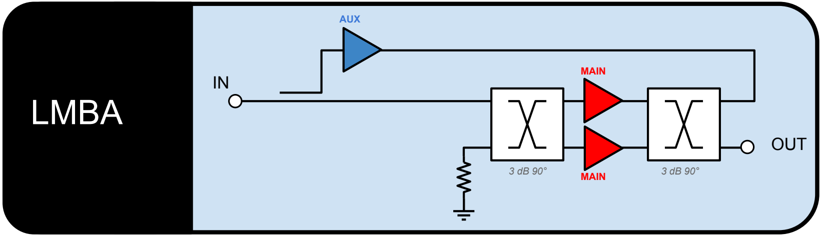


- **Trigger:** $\tau \simeq 0$;
- **10 MHz:** $\Phi_0 =$ cste. This random value changes with the configuration (phase locking issue) ;
- **LO:** $\Phi_0 =$ cste. This value DOES NOT CHANGE with the configuration.

Introduction

The need for a multi-source environment: example of the digital spreading





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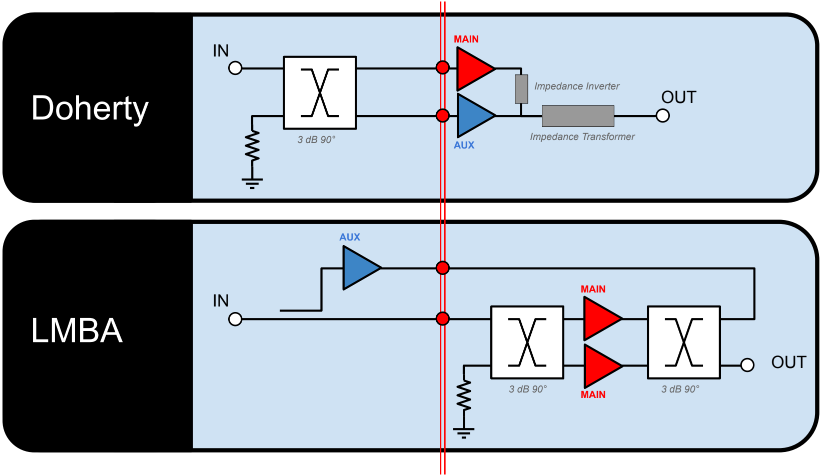
The need for a multi-source environment: example of the digital spreading



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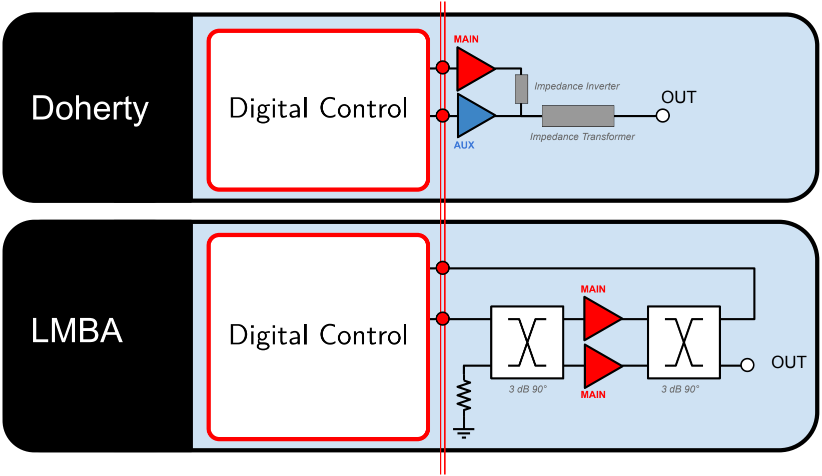
The need for a multi-source environment: example of the digital spreading



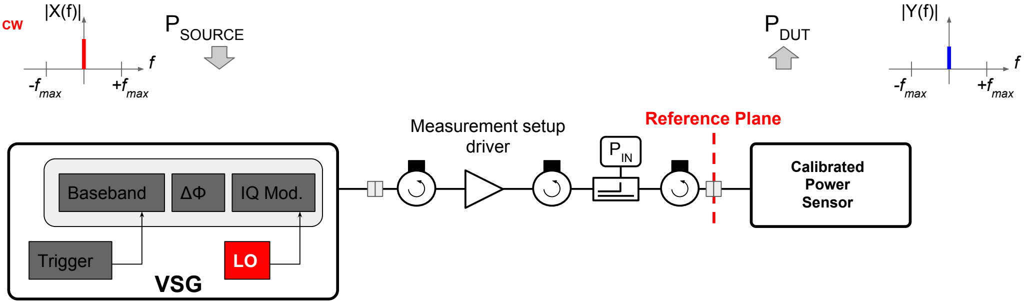
The presentation outline

Calibration algorithm and dual-input amplifier measurement applications

1. **1-Port Calibration**
   - CW mode
   - Modulation mode
2. **Multiport Calibration**
   - Algorithm
   - Verification on a passive device
3. **Digital Doherty Measurements**
   - Dual-input amplifier presentation
   - Optimizing the digital control
4. **LMBA Measurements**
   - Dual-input amplifier presentation
   - Optimizing the auxiliary RF path

1-Port Calibration

CW mode with a standard RF source

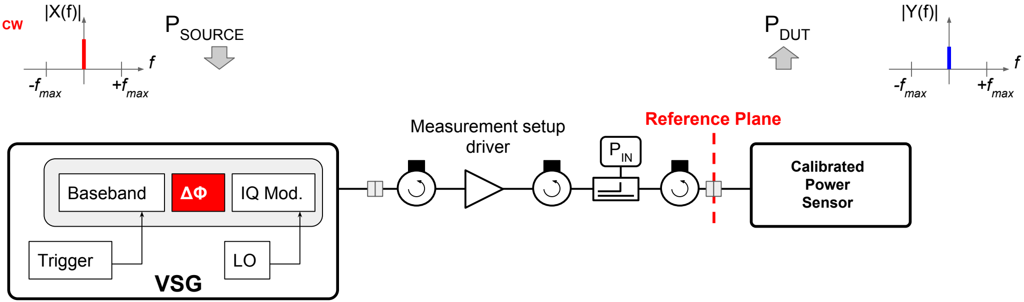


Power offset between the DUT reference plane and the user input at each frequency of interest:

$$|G_1|^2 = \Delta P = \frac{P_{DUT}}{P_{SOURCE}}$$

1-Port Calibration

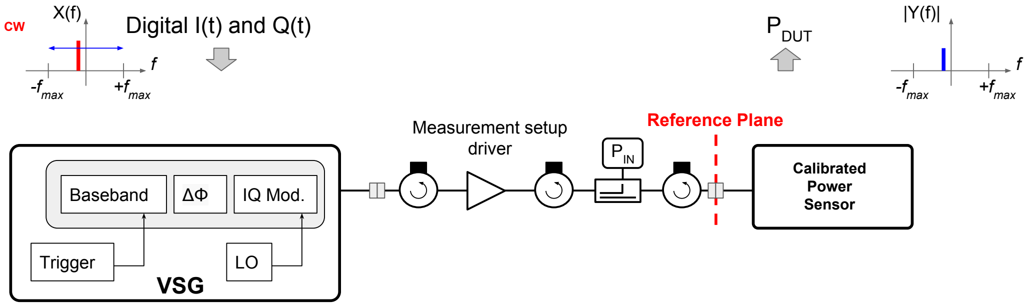
CW mode with VSG



- CW signal can be obtained from a time constant complex envelope. Control of the phase of the carrier (LO) is performed by applying a phase offset on the frequency domain IQ modulation. This phase control is essential for the "Multiport Source".
- Magnitude calibration procedure consists in identifying $|G_1|^2 = \Delta P = \frac{P_{DUT}}{P_{SOURCE}}$.

1-Port Calibration

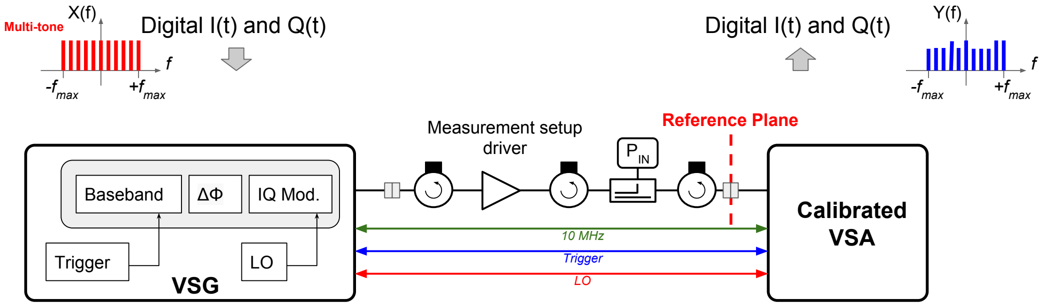
Modulation mode: Amplitude calibration of a VSG



- An envelope CW frequency sweep is done over the bandwidth of interest by creating a single tone complex modulation : $\tilde{x}(t) = |X|.e^{j.2\pi.f.t}$;
- Magnitude calibration procedure is based on a power sensor (traceable standard). The power offset is $|G_1|^2 = \Delta P = \frac{P_{DUT}}{P_{SOURCE}} = 50\frac{P_{DUT}}{|X|^2}$.

1-Port Calibration

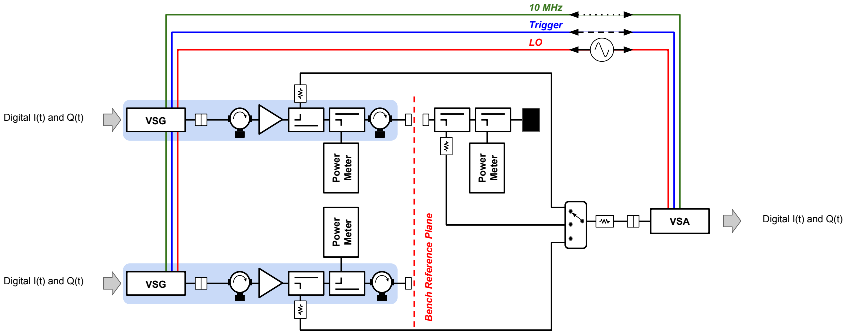
Modulation Mode: Phase calibration of a VSG



- Phase offset calibration procedure is performed with a synchronized and calibrated VSA at the DUT reference plane. G_1 is the ratio between power waves at the DUT reference plane and the user input control.
- The phase offset is $\text{Arg}\{G_1\} = \text{Arg}\{\frac{Y(f)}{X(f)}\}$ obtained from a single multi-tone modulation.

1-Port Calibration

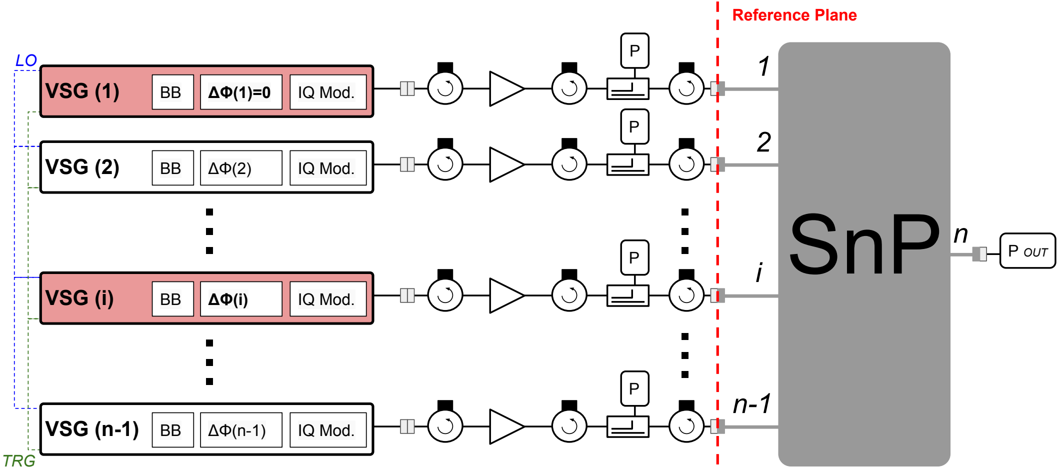
Extension to multi-source environment



- One port of the source is fully calibrated. Calibration of a complete multiport source can be automated and will require a single standard : a multiport passive device already pre-characterized ([S] ensures traceability).
- Synchronization between VSG is mandatory to ensure repeatability of the calibration.

Multiport Calibration

Principle: Using a precharacterized SnP to calibrate a multi-source generator



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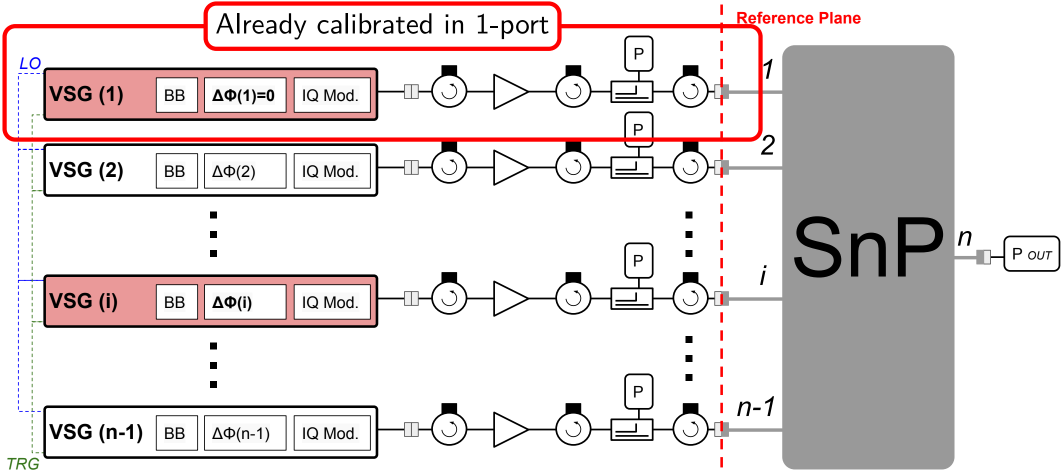

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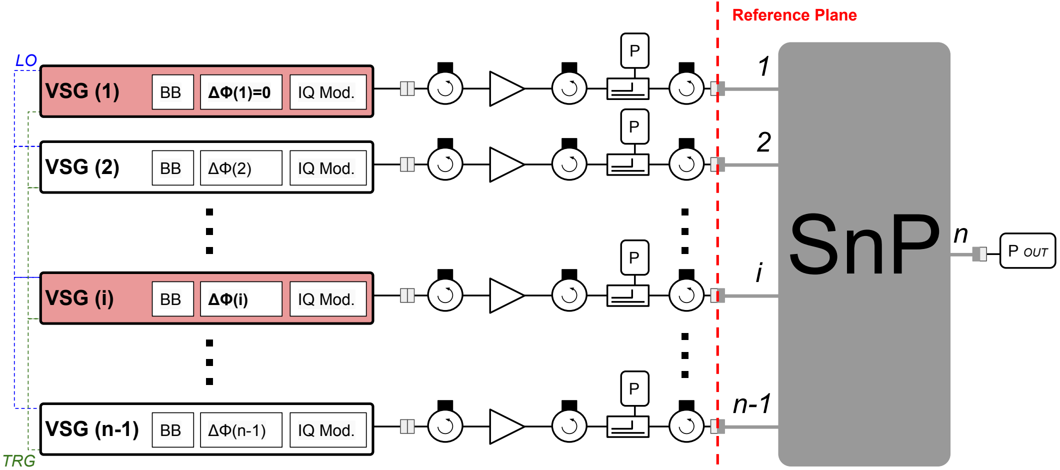

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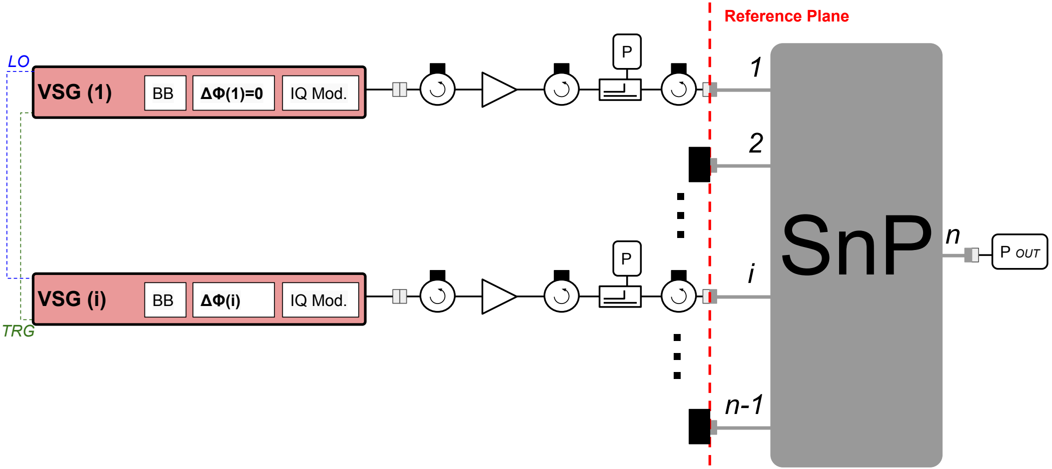

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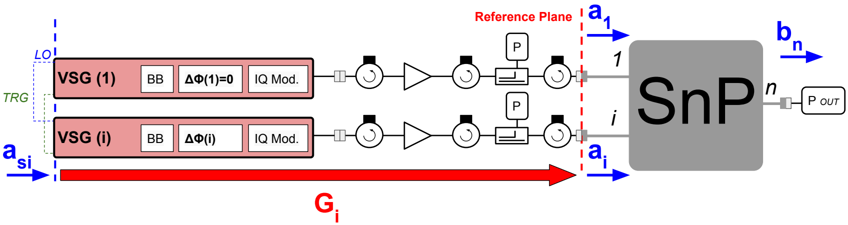

$$b_n = S_{n1}.a_1 + S_{ni}.a_i$$

Multiport Calibration

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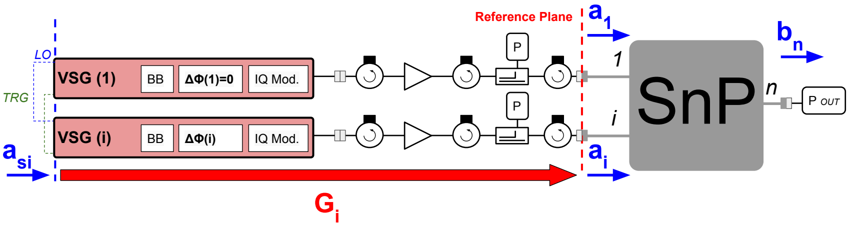
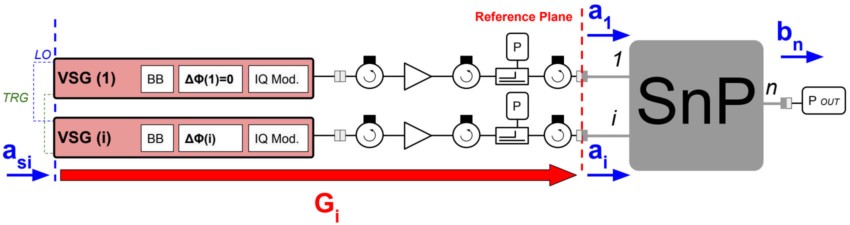


$$b_n = S_{n1}.a_1 + S_{ni}.a_i$$

$$|b_n|^2 = |S_{n1}.a_1 + S_{ni}.G_i.a_{si}|^2$$

Multiport Calibration

Principle: Using a precharacterized SnP to calibrate a multi-source generator



$$b_n = S_{n1}.a_1 + S_{ni}.a_i$$

$$|b_n|^2 = |S_{n1}.a_1 + S_{ni}.G_i.a_{si}|^2$$

$$A.|G_i|^2 + B.\Re\{G_i\} + C.\Im\{G_i\} = D$$

with

$$A = |S_{ni}.a_{si}|^2$$

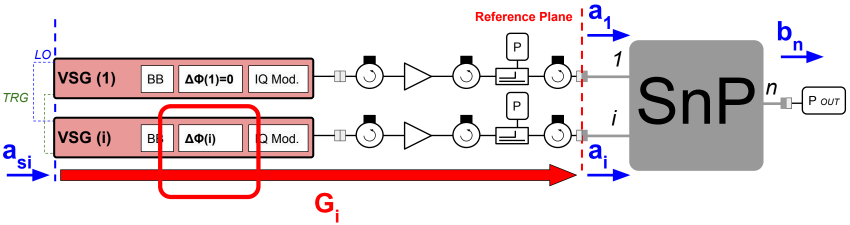
$$B = 2.\Re\{S_{n1}^*.a_1^*.S_{ni}.a_{si}\}$$

$$C = -2.\Im\{S_{n1}^*.a_1^*.S_{ni}.a_{si}\}$$

$$D = |b_n|^2 - |S_{n1}.a_1|^2$$

Multiport Calibration

Principle: Using a precharacterized SnP to calibrate a multi-source generator



$$b_n = S_{n1}.a_1 + S$$

$$\boxed{\Delta\Phi = \{\phi_A, \phi_B, \phi_C, \ldots\}}$$

$$_i.a_{si}|^2$$

$$|b_n|^2 = |S_{n1}.a_1 + S_{ni}.G_i.a_{si}|^2$$

$$A.|G_i|^2 + B.\Re\{G_i\} + C.\Im\{G_i\} = D$$

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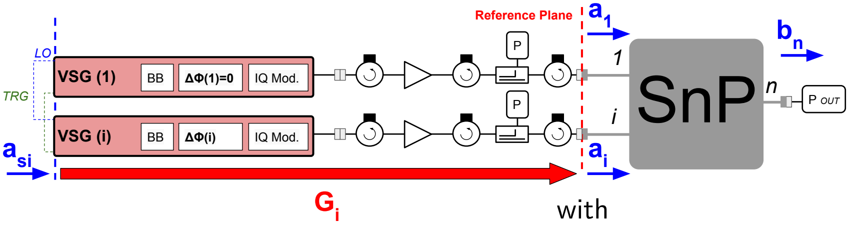

$$\begin{pmatrix} |G_i|^2 \\ \Re\{G_i\} \\ \Im\{G_i\} \end{pmatrix} = \begin{bmatrix} A(\phi_A) & B(\phi_A) & C(\phi_A) \\ A(\phi_B) & B(\phi_B) & C(\phi_B) \\ A(\phi_C) & B(\phi_C) & C(\phi_C) \\ \vdots & \vdots & \vdots \end{bmatrix}^{\dagger} . \begin{pmatrix} D(\phi_A) \\ D(\phi_B) \\ D(\phi_C) \\ \vdots \end{pmatrix}$$

where $\bullet^{\dagger}$ denotes the pseudo-inverse operator.

with

$$A = |S_{ni}.a_{si}|^2$$

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Multiport Calibration

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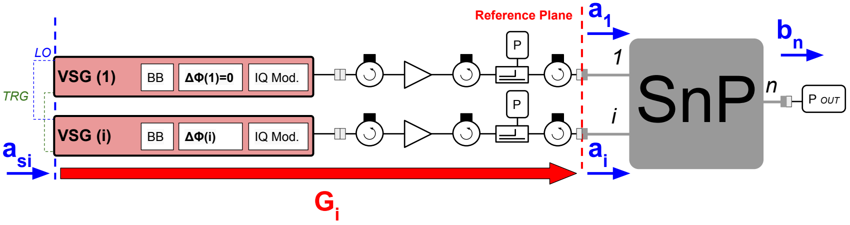

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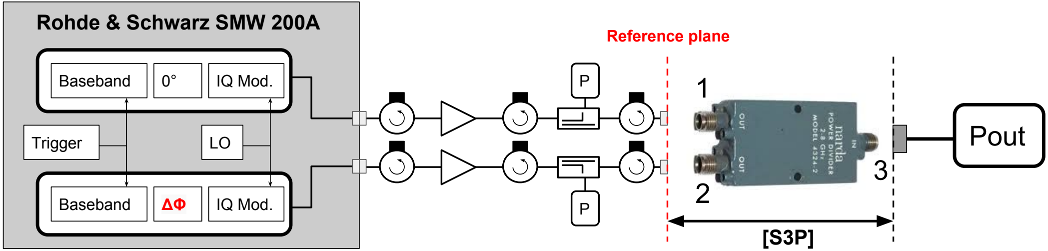
where $\bullet^{\dagger}$ denotes the pseudo-inverse operator.

Least-square solution of G_i in magnitude and phase for each frequency.

Port i has an absolute calibration according the phase reference $\mathrm{Arg}\{a_1\}$

Validation of the multi-source calibration

CW mode with a calibrated power sensor



- CW frequency will be swept ;
  (Multitone validation requires a VSA instead of a power sensor)
- Input and output CW average power measurements: $\frac{1}{2}|a_1|^2$, $\frac{1}{2}|a_2|^2$ and $\frac{1}{2}|b_3|^2$;
- Port 1 is the phase reference: $\mathrm{Arg}\{a_1\} = 0$ and $\mathrm{Arg}\{a_2\} = \Delta\Phi$.

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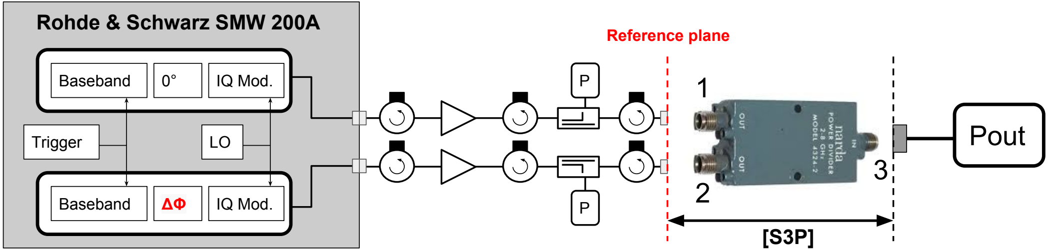


- **Uncalibrated phase:** $\mathrm{Arg}\{a_2\} = \Delta\Phi$ is entered in the instrument ;
- **Calibrated phase:** $\mathrm{Arg}\{a_2\} = \Delta\Phi$ is referenced at the DUT reference plane. The instrument value takes into account the phase shift between the digital command and the RF reference plane ;
- **Simulation:** $\mathrm{Arg}\{a_2\} = \Delta\Phi$ is calculated from the measured powers and the S3P file assuming $\mathrm{Arg}\{a_1\} = 0$.

Validation of the multi-source calibration

CW mode with a calibrated power sensor (2.2-2.8 GHz with a 100 MHz step)

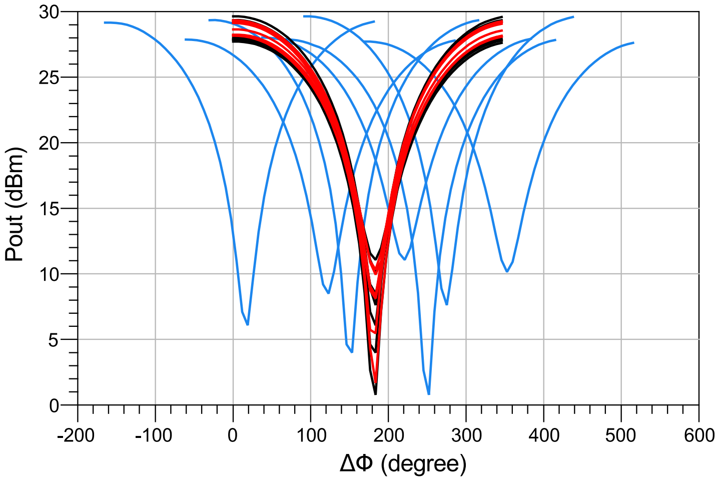
Measurements:

Uncalibrated phase

Calibrated phase

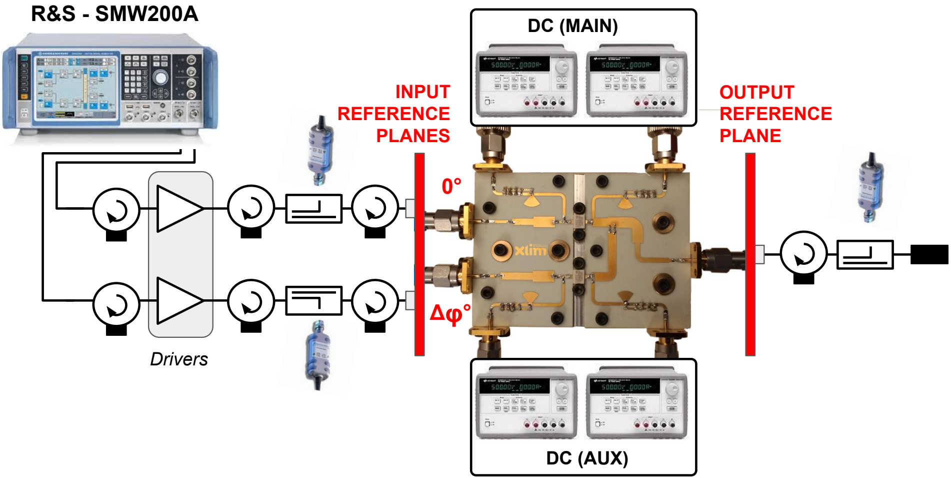
Simulation:

ΔΦ calculated from Pin1, Pin2, Pout and S3P file



Digital Doherty Measurements

The bench and the amplifier under test for CW measurements



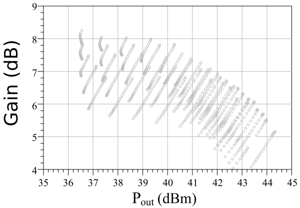
Digital Doherty Measurements

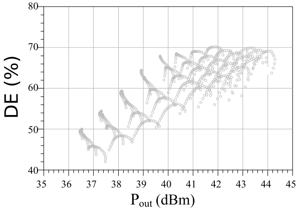
Optimizing the digital control (example at 2.3 GHz)

P_{in} is the available power at the input of the **Main** amplifier.

We focus on the magnitude and phase imbalance between the two inputs.

ΔP and $\Delta\varphi$ are swept for each value of P_{in}





Then, we can sort out the best digital control of the Doherty in term of:

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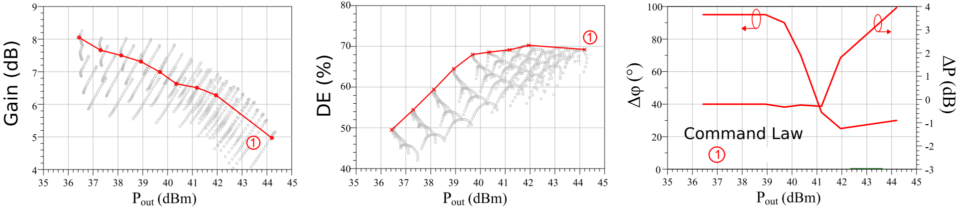

Then, we can sort out the best digital control of the Doherty in term of:

- **efficiency** ;

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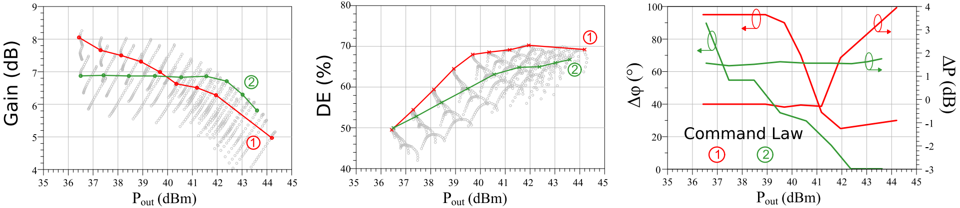
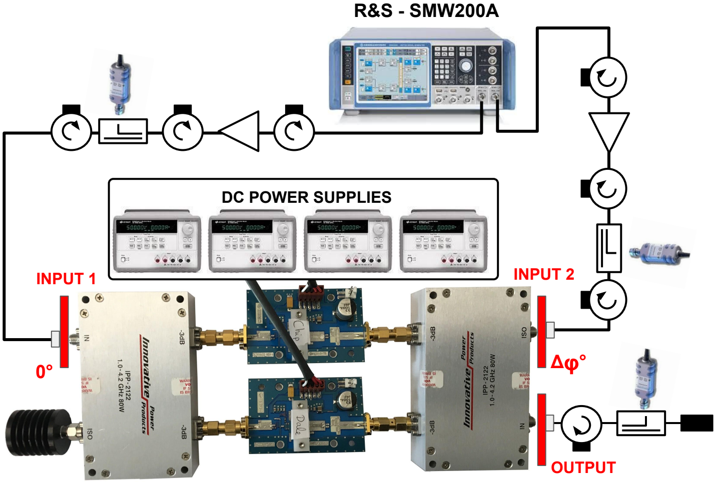


Then, we can sort out the best digital control of the Doherty in term of:

- efficiency ;
- linearity.

LMBA Measurements

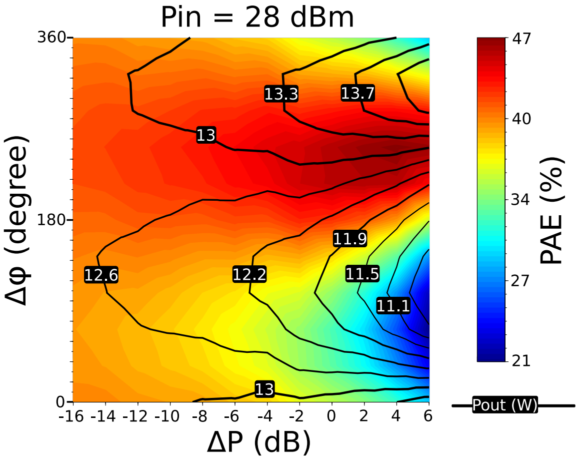
Measurement setup



LMBA Measurements

Measurement results at 2.4 GHz and discussion

- Direct performance plot at each CW input power ;



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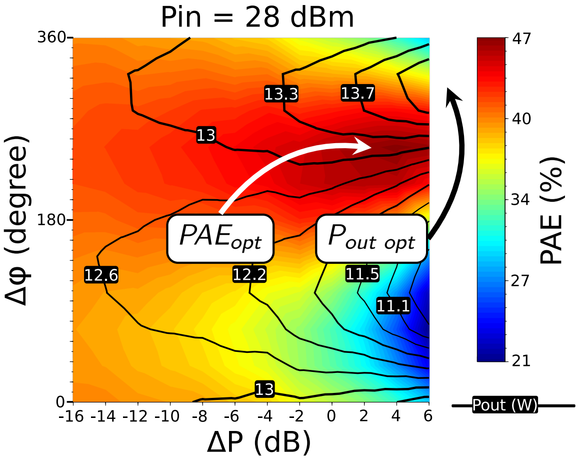
Measurement results at 2.4 GHz and discussion

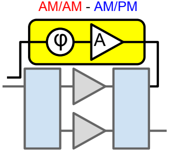
- Direct performance plot at each CW input power ;
- Investigate internal Load-Pull effect ;

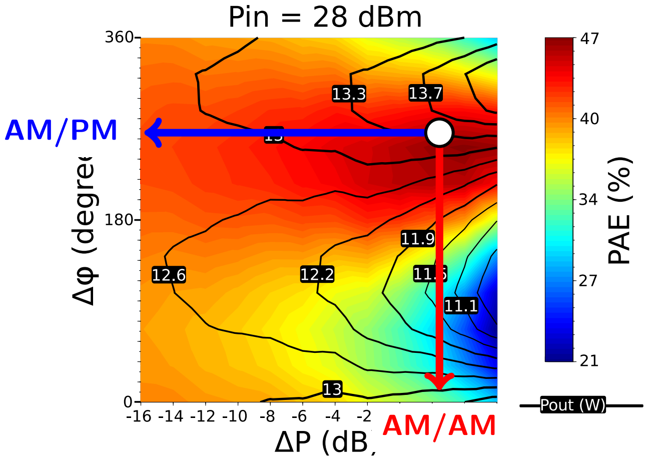


LMBA Measurements

Measurement results at 2.4 GHz and discussion

- Direct performance plot at each CW input power ;
- Investigate internal Load-Pull effect ;
- Visual extraction of **AM/AM** and **AM/PM** of the RF auxiliary path according to the selected trade-off.





Conclusion

Multi-source calibration method

- Automated calibration method suitable for a multi-source environment ;
- Simple standard : pre-characterized SnP ;
- Analytically detailed ;
- Calibration method experimentally validated ;

Large signal measurements of two dual-input power amplifiers in S-band

- Digital Doherty
- LMBA

The goal is to optimize the amplifiers behaviors in terms of efficiency or linearity. Such measurements are possible with the proposed calibration method and offer an experimental tool to aid in designing multi-input PAs.