On-Wafer LSNA Measurements
Including Dynamic-Bias

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Motivation

- Worldwide growth of wireless communications services
- High data rate required
- **Multi-carrier, Wideband** systems
- **Complex digital modulations** involved
Outline

- Introduction
- Measurement set-up
- Case study
- Conclusions
Two-Tone Test

\[ \Delta \omega = \omega_2 - \omega_1 \]

\[ s(t) = V \cos(\omega_1 t + \phi_1) + V \cos(\omega_2 t + \phi_2) \]

\[ \omega_m = (\omega_2 - \omega_1)/2 \]
\[ \omega_c = (\omega_2 + \omega_1)/2 \]
\[ \phi_1, \phi_2 = 0 \]

\[ s(t) = 2V \cos(\omega_m t) \cos(\omega_c t) \]
‘Dynamic Bias’: Why?

One-tone excitation
- Harmonic generation
- Self-biasing

Modulated excitation
- IMD

CORE LSNA SET-UP

IF down-convertor

CALIBRATED VECTOR MEASUREMENTS
(600 MHz-50 GHz with 20 MHz IF BW)
Outline

✓ Introduction

✓ Measurement set-up

✓ Case study

✓ Conclusions
‘Dynamic Bias’ extension

Additional ADC channels
Additional modules
Additional bias-tees
Additional software

VECTOR MEASUREMENTS
LF BW  10 kHz-24 MHz
RF BW  600 MHz-50 GHz
Hardware

- Broad-band diplexer
  - Isolation between RF and DC+LF path;
  - LF BW DC to 24 MHz, RF BW 90 MHz to 45 GHz

- LF bias-T
  - Isolation between DC path and LF-termination;
  - Cut-off ~ 10 kHz;

- LF sensing board
  - Interface between DUT plane and ADC channels;
  - ±30 V, ± 2A DC operation;

- LF test-set
  - Software controlled to switch between calibration and measurement mode;
  - Provides the auxiliary port for LF absolute calibration;

- LF Test-set

![Diagram of hardware components]

- SRC
- RF
- DC port1
- LF Test-set
- LF bias-T
- LF port1
- LF load
- LF sensing board
- LF+DC
- sensing board
- LF Test-set
- diplexer
- RF+LF+DC
- v1LF
- i1LF
- V1LF
- i1LFM
- v1LFM
- DC port1
- RF+LF+DC
Calibration

1) RF path (LRRM)
\[
\begin{bmatrix}
a_{1D} \\
b_{1D} \\
a_{2D} \\
b_{2D}
\end{bmatrix}
= Ke^{j\varphi}
\begin{bmatrix}
1 & \beta_1 & 0 & 0 \\
\delta_1 & \gamma_1 & 0 & 0 \\
0 & \alpha_2 & \beta_2 \\
0 & \delta_2 & \gamma_2
\end{bmatrix}
\begin{bmatrix}
a_{1M} \\
b_{1M} \\
a_{2M} \\
b_{2M}
\end{bmatrix}
\]
\[\alpha, \beta, \gamma, \delta \Rightarrow \text{relative calibration}\]
\[K, \varphi \Rightarrow \text{absolute calibration}\]

2) LF path (SOLT)
\[
\begin{bmatrix}
v_{1D} \\
i_{1D} \\
v_{2D} \\
i_{2D}
\end{bmatrix}
= K_{LF}e^{j\varphi_{LF}}
\begin{bmatrix}
1 & b_1 & 0 & 0 \\
c_1 & d_1 & 0 & 0 \\
0 & a_2 & b_2 \\
0 & c_2 & d_2
\end{bmatrix}
\begin{bmatrix}
v_{1M} \\
i_{1M} \\
v_{2M} \\
i_{2M}
\end{bmatrix}
\]
\[a, b, c, d \Rightarrow \text{relative calibration}\]
\[K_{LF}, \varphi_{LF} \Rightarrow \text{absolute calibration}\]

3) delay compensation
\[
Ke^{j\varphi}e^{j(2\pi*\tau_{RF})}
K_{LF}e^{j\varphi_{LF}}e^{j(2\pi*\tau_{LF})}
\]
\[\tau_{RF} - \tau_{LF} \Rightarrow \text{alignment}\]
Delay compensation requires a common plane for RF and LF.
Phase alignment: procedure

Modulated signal uploaded into the ESG

Measurement aligned with the ESG signal

Triggered measurements connecting ESG at a reference plane

(a through is placed at probe tips)
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Measurement

- FinFET L=0.13um
- $V_G=0.3$ V, $V_D=0.9$V

- $f_c = 4$ GHz
- Pin= -4 dBm for each input tone

- $f_c = 4$ GHz
- Pin= -4 dBm for each input tone

output impedance
Measured response

Δf=6 MHz

DUT

freq (MHz)

i_2 (mA)

freq (GHz)

i_2 (mA)

DUT

Δf=6 MHz
$\Delta f$ sweep

**LF response**

- $i_{2LF}$ (A)
- $\Delta f$ (MHz)

**RF response**

- $i_{2RF}$ (mA)
- $\Delta f$ (MHz)
Time domain: RF response

Only IMDs in the RF BW

Current does not clip
Time domain: LF response

Significant self-biasing
The missing information

LF information is fundamental in this case
i-v trajectories

(i, v) trajectories

(v₁, v₂) coverage plane shifted by LF components

includes LF
Further validation

Comparison between experiments and model
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Conclusions

- LSNA extension in the LF bandwidth has been presented
  - Fundamental to study non-linear dynamics under modulated excitation

- More complete information gathered from non-linear measurements
  - Useful to extend behavioral models
  - Useful for models validation
  - Useful to study LF dynamics (e.g., memory effects)
Thanks for your attention!