On-Wafer LSNA Measurements Including Dynamic-Bias

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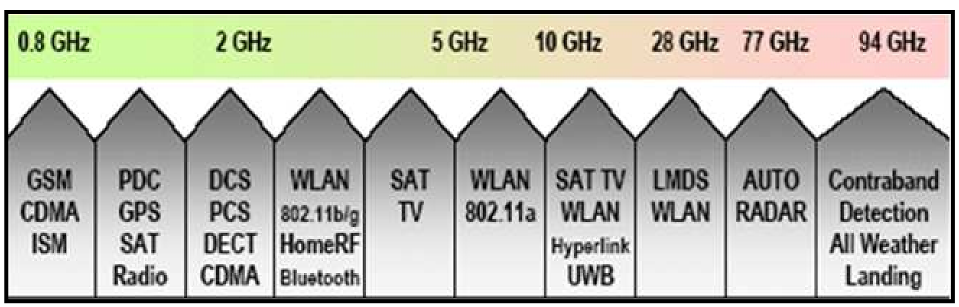
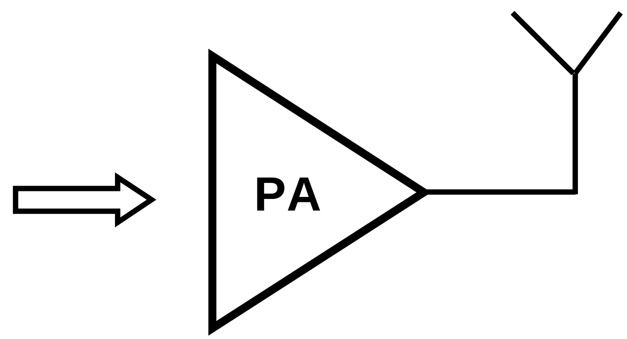
European Microwave Week 2009
Nuova Fiera di Roma, Rome, Italy
28 September through 2 October 2009

Motivation

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

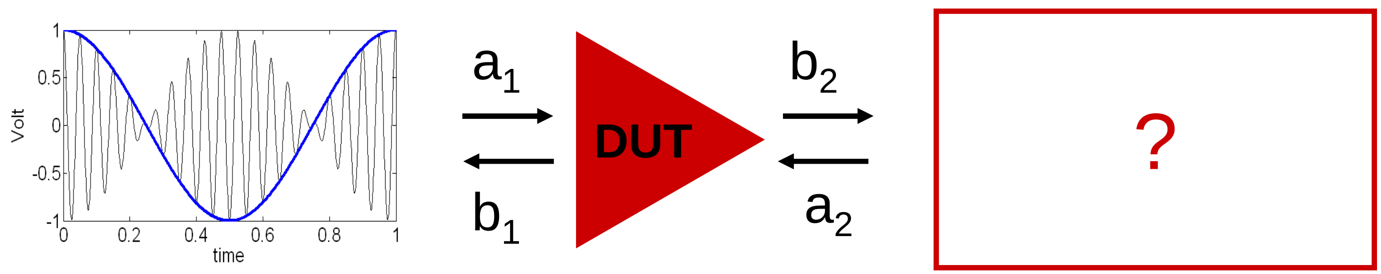




Outline

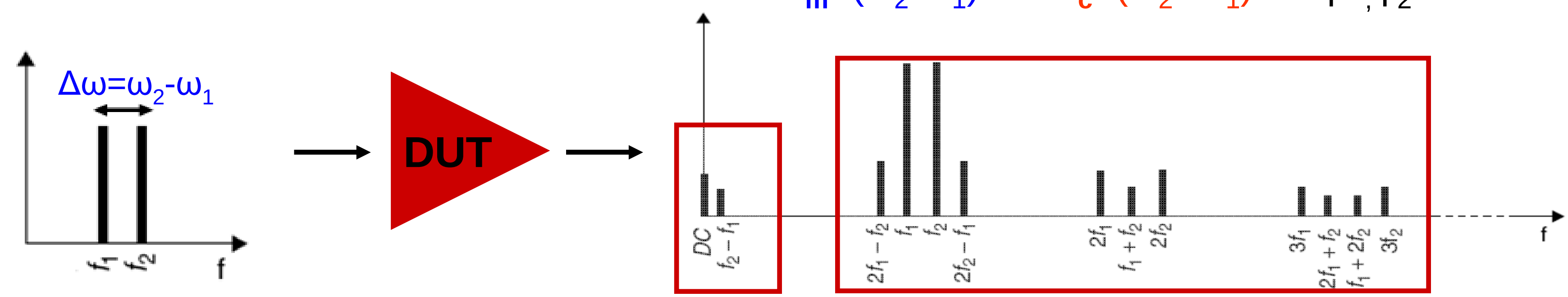
- ✓ **Introduction**
- ✓ Measurement set-up
- ✓ Case study
- ✓ Conclusions

Two-Tone Test

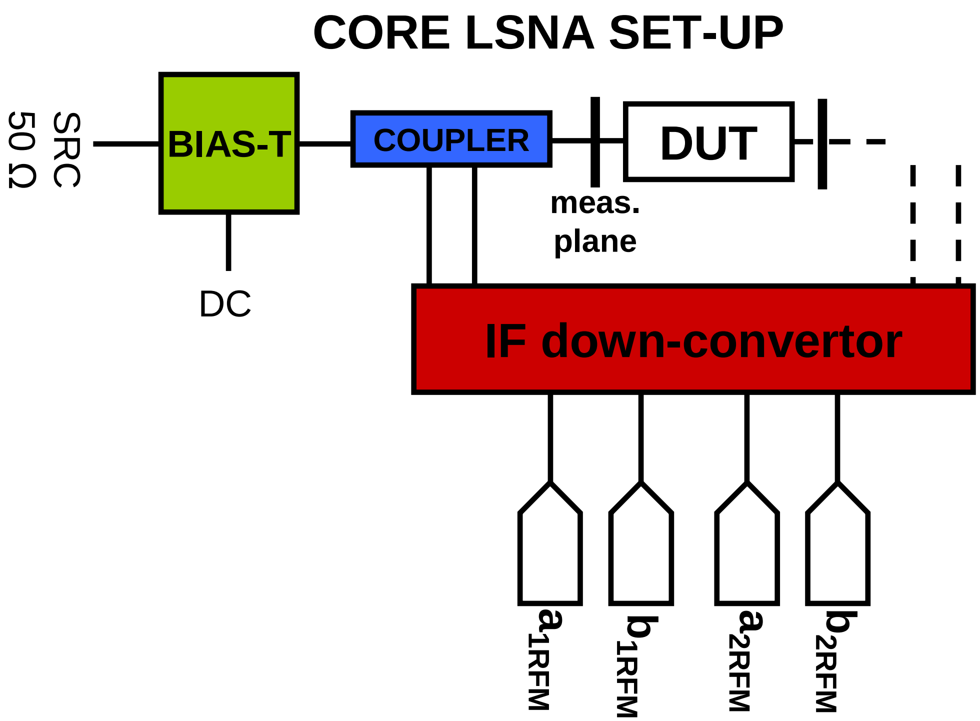


$s(t)=V\cos(\boldsymbol{\omega_1}t+\varphi_1)+V\cos(\boldsymbol{\omega_2}t+\varphi_2) \Rightarrow s(t)=2V\cos(\boldsymbol{\omega_m}t)\cos(\boldsymbol{\omega_c}t)$

$\boldsymbol{\omega_m}=(\omega_2-\omega_1)/2 \quad \boldsymbol{\omega_c}=(\omega_2+\omega_1)/2 \quad \varphi_1,\varphi_2=0$



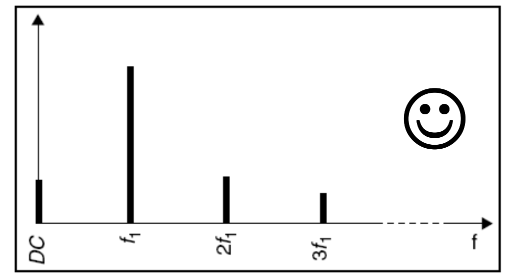
‘Dynamic Bias’: Why?



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

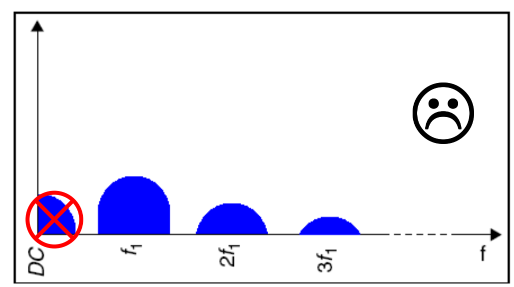
One-tone excitation

- Harmonic generation
- Self-biasing



Modulated excitation

- IMD



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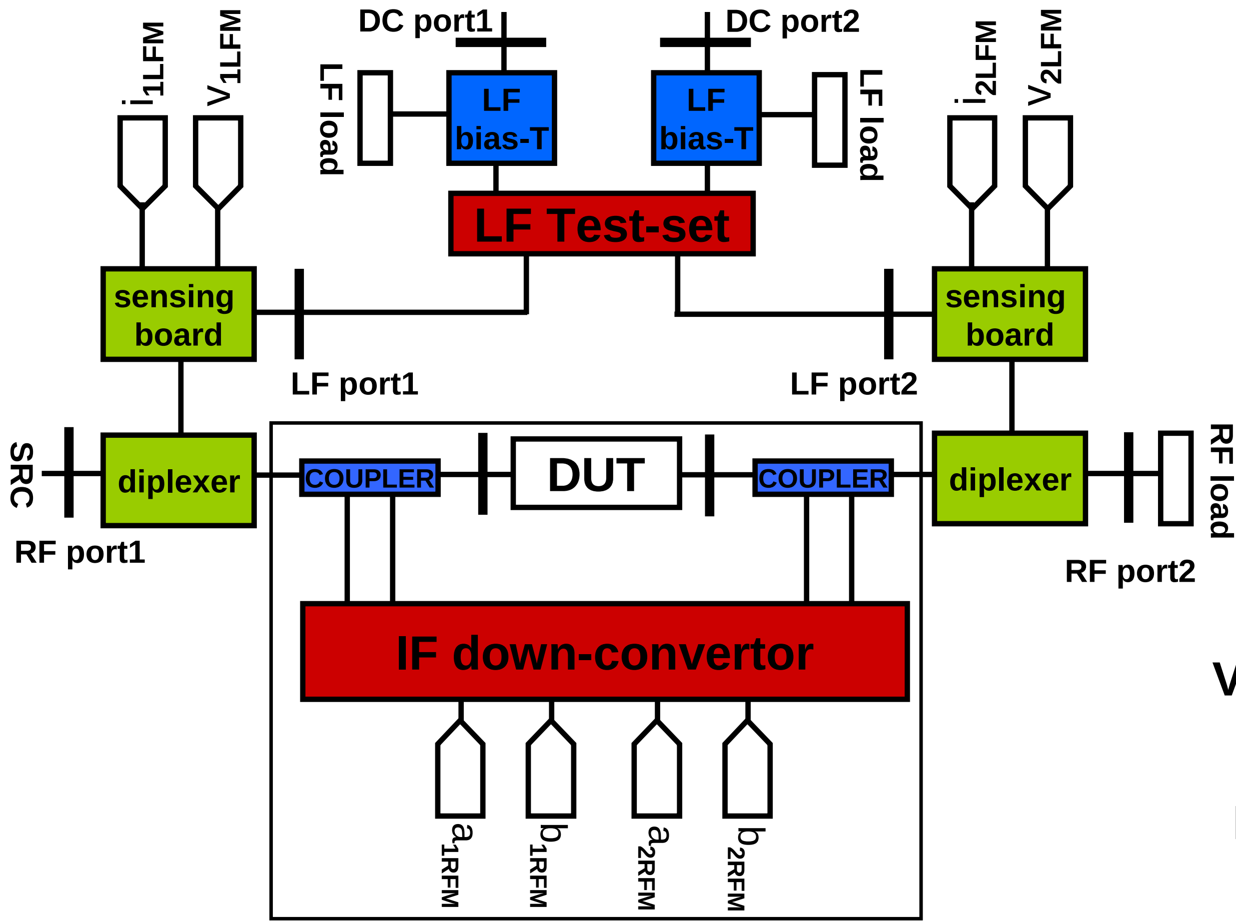
'Dynamic Bias' extension



Additional ADC channels

Additional modules

Additional bias-tees

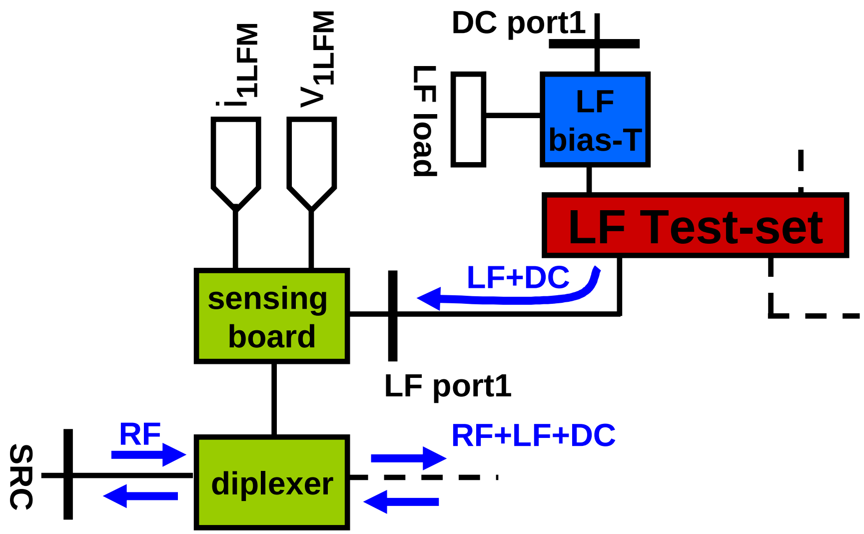
Additional software

VECTOR MEASUREMENTS

LF BW 10 kHz-24 MHz

RF BW 600 MHz-50 GHz

Hardware



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

Calibration

1)RF path (LRRM)

$$\begin{bmatrix} a_{1D} \\ b_{1D} \\ a_{2D} \\ b_{2D} \end{bmatrix} = Ke^{j\varphi} \begin{bmatrix} 1 & \beta_1 & 0 & 0 \\ \delta_1 & \gamma_1 & 0 & 0 \\ 0 & 0 & \alpha_2 & \beta_2 \\ 0 & 0 & \delta_2 & \gamma_2 \end{bmatrix} \begin{bmatrix} a_{1M} \\ b_{1M} \\ a_{2M} \\ b_{2M} \end{bmatrix}$$

$\alpha, \beta, \gamma, \delta \Rightarrow$ relative calibration

$K, \varphi \Rightarrow$ absolute calibration

2)LF path (SOLT)

$$\begin{bmatrix} v_{1D} \\ i_{1D} \\ v_{2D} \\ i_{2D} \end{bmatrix} = K_{LF} e^{j\varphi_{LF}} \begin{bmatrix} 1 & b_1 & 0 & 0 \\ c_1 & d_1 & 0 & 0 \\ 0 & 0 & a_2 & b_2 \\ 0 & 0 & c_2 & d_2 \end{bmatrix} \begin{bmatrix} v_{1M} \\ i_{1M} \\ v_{2M} \\ i_{2M} \end{bmatrix}$$

$a, b, c, d \Rightarrow$ relative calibration

$K_{LF}, \varphi_{LF} \Rightarrow$ absolute calibration

3)delay compensation

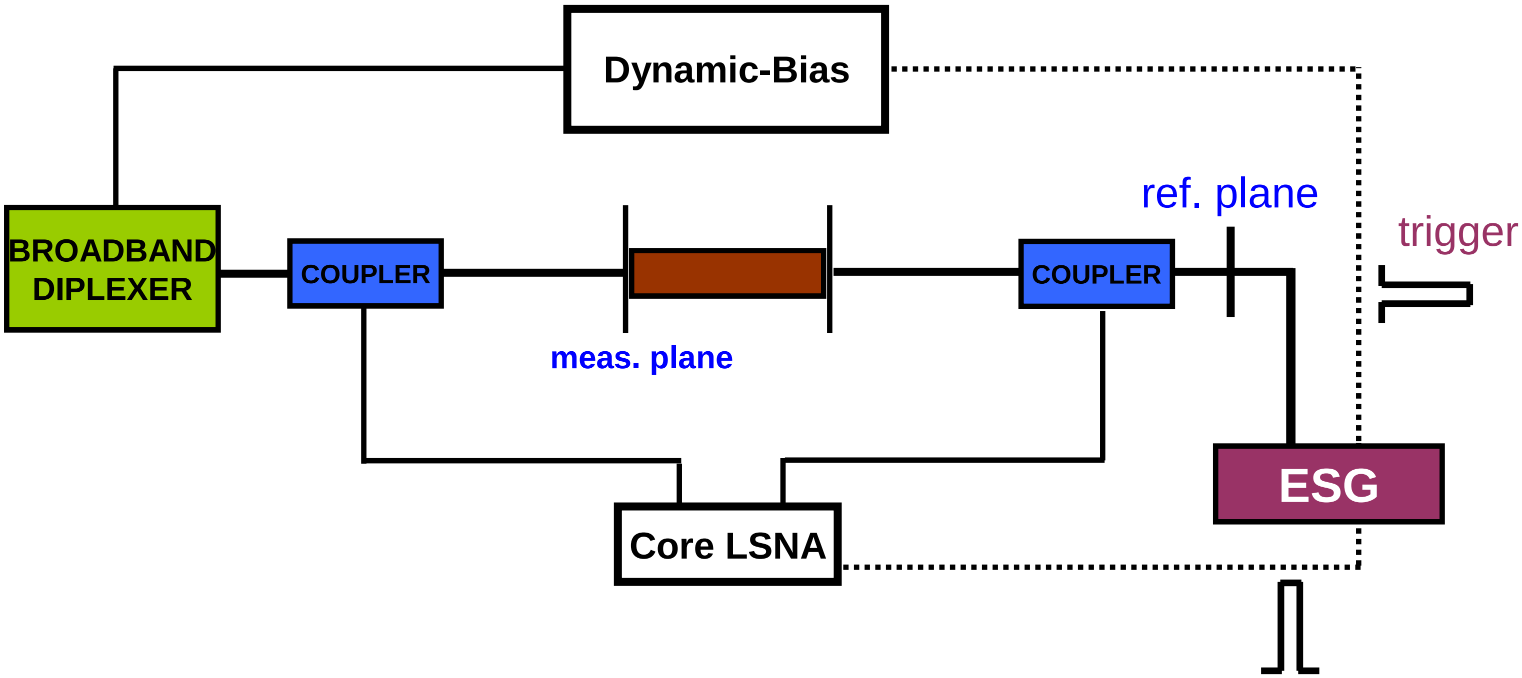
$$Ke^{j\varphi} e^{j(2\pi i * \tau_{RF})}$$

$$K_{LF} e^{j\varphi_{LF}} e^{j(2\pi i * \tau_{LF})}$$

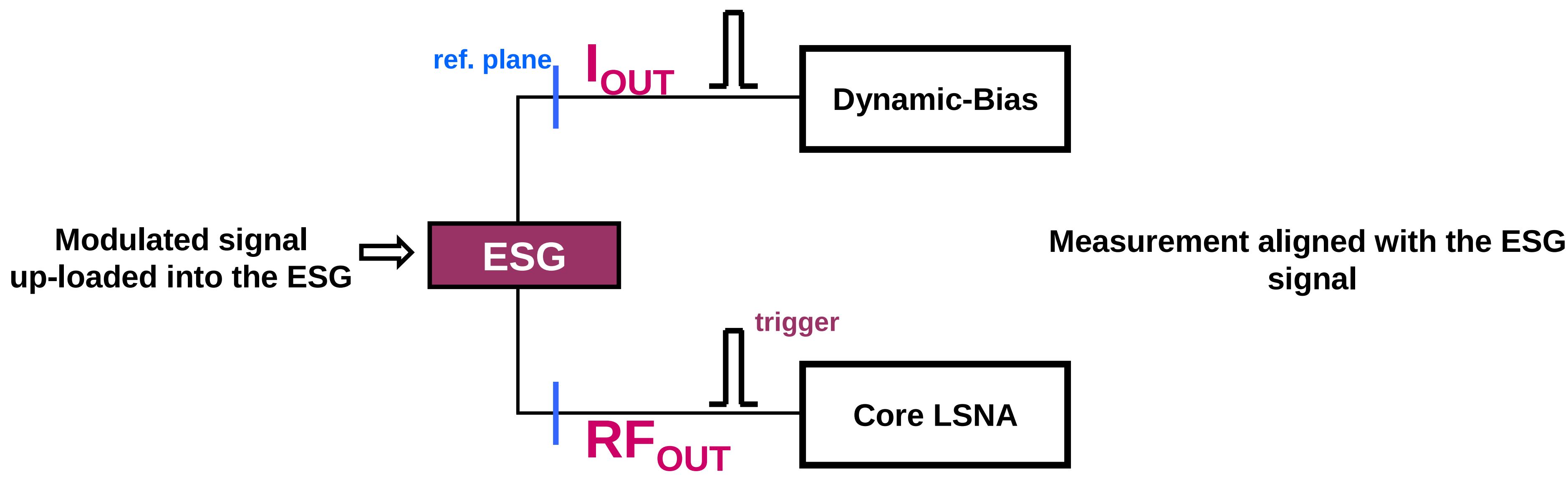
$\tau_{RF} - \tau_{LF} \Rightarrow$ alignment

Phase alignment

- Delay compensation requires a common plane for RF and LF



Phase alignment: procedure



Triggered measurements connecting ESG at a reference plane

(a through is placed at probe tips)

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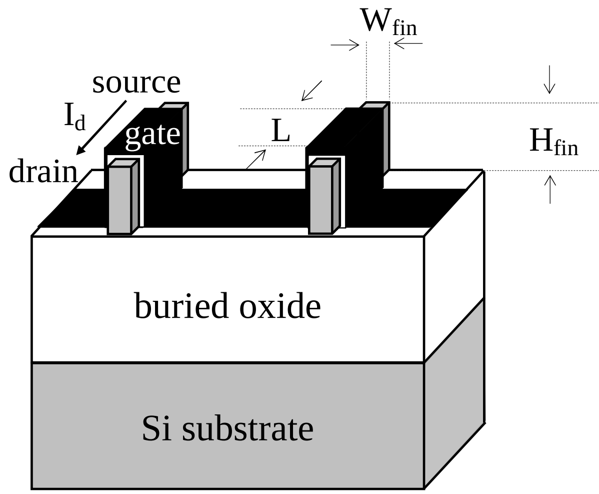
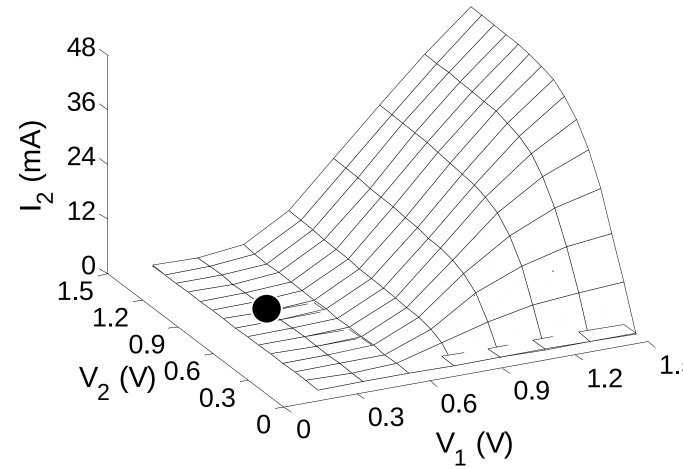
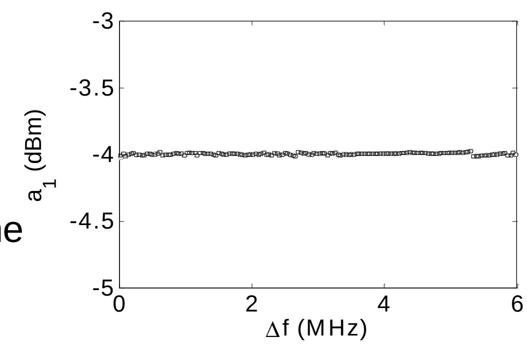
Measurement

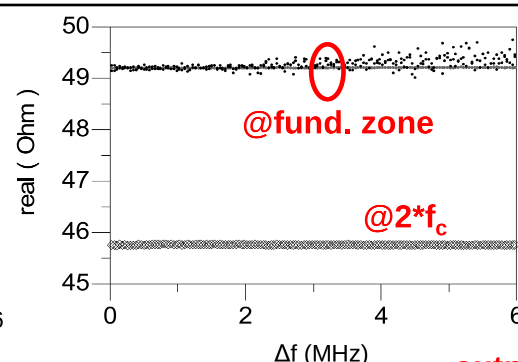
- FinFET L=0.13um
- V_G=0.3 V, V_D=0.9V

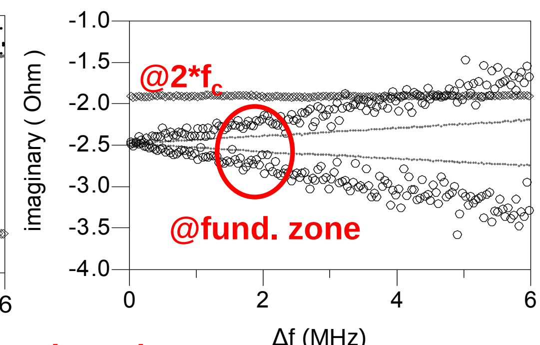




- f_c = 4 GHz
- Pin= -4 dBm for each input tone

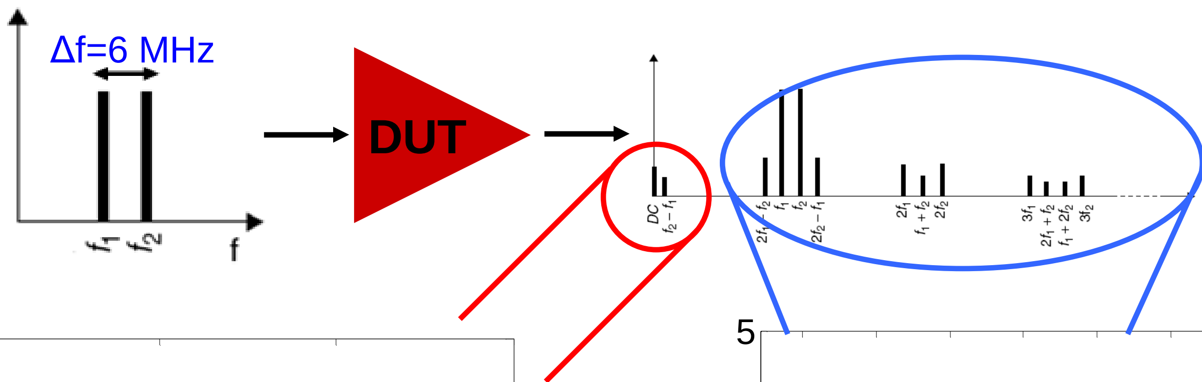


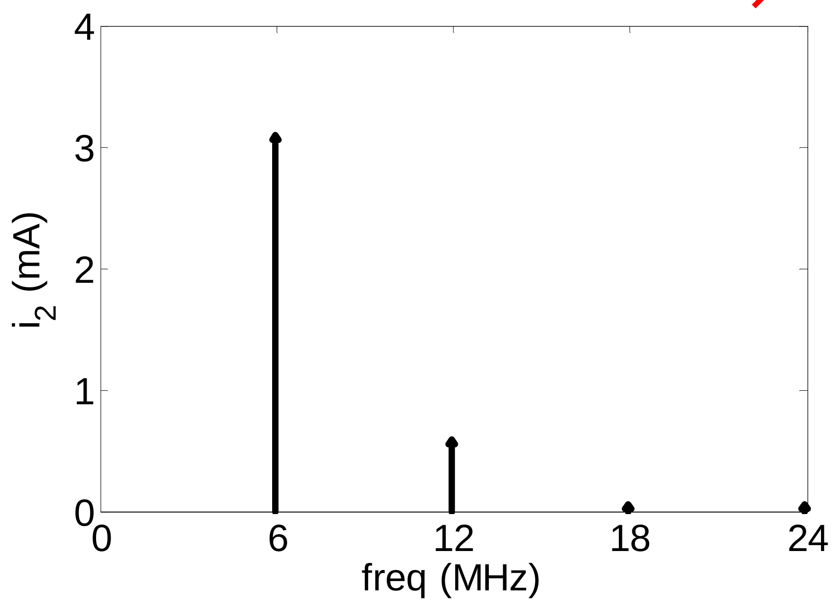


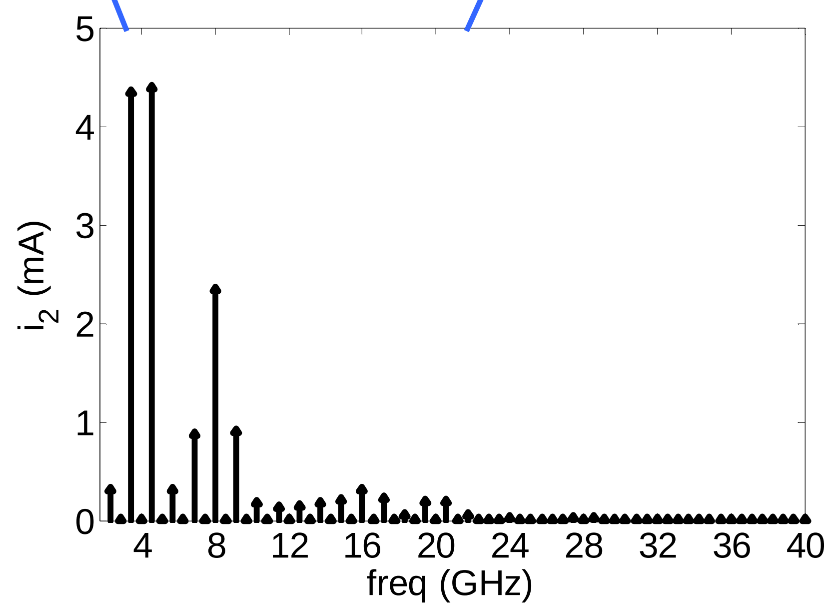


output impedance

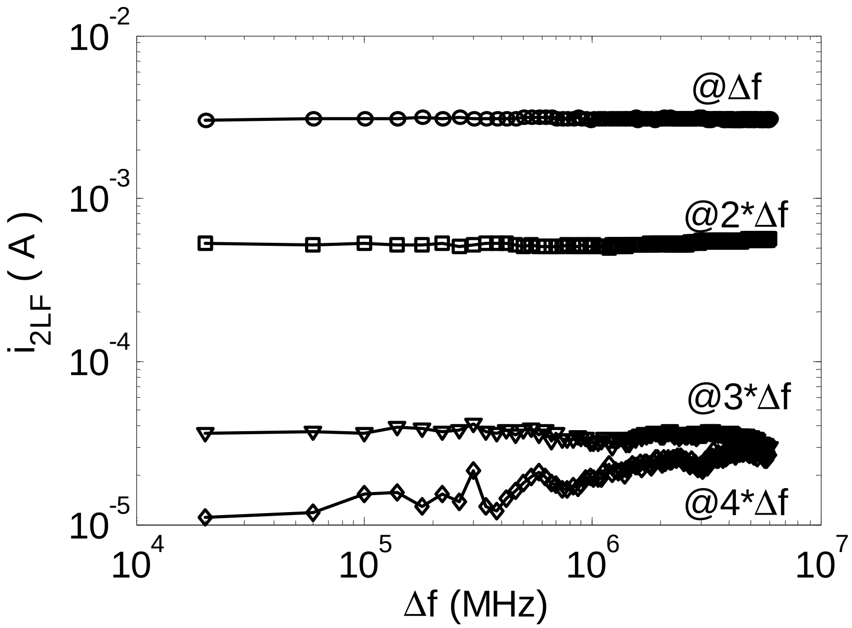
Measured response



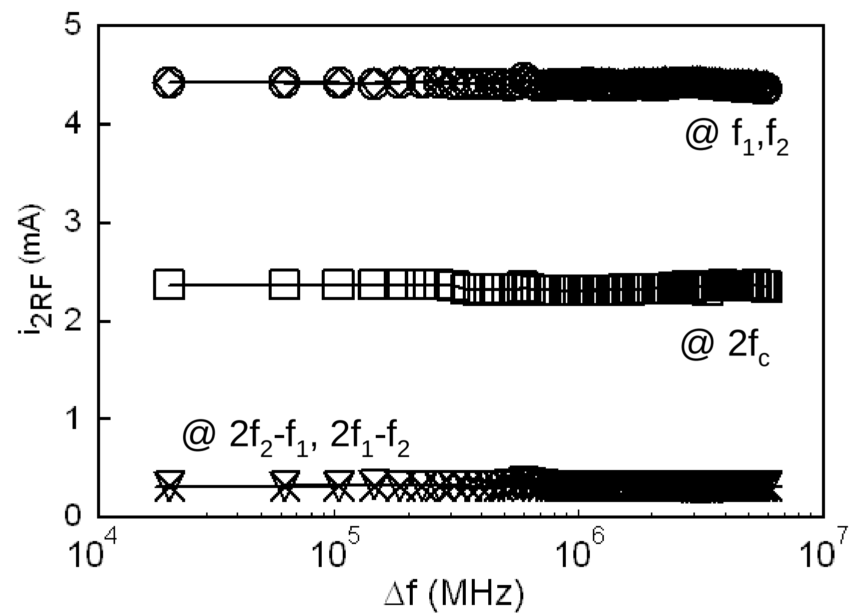




Δf sweep

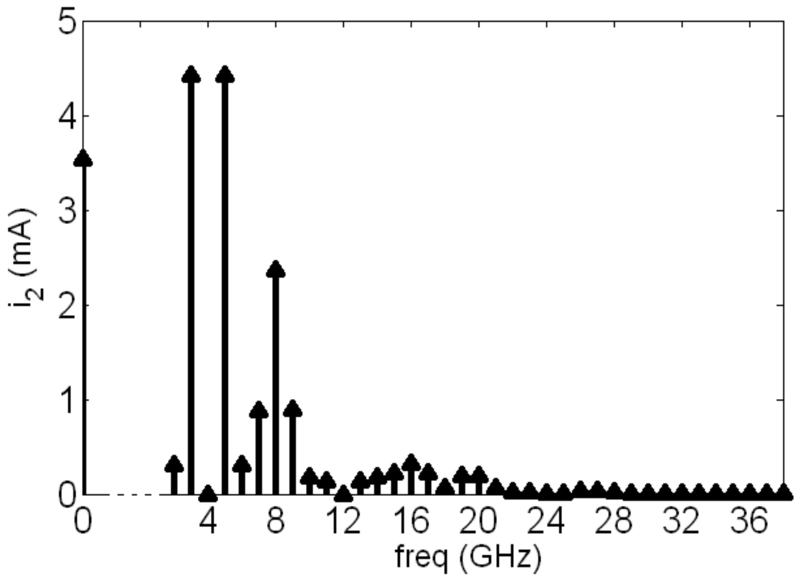


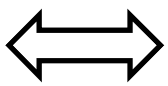
LF response

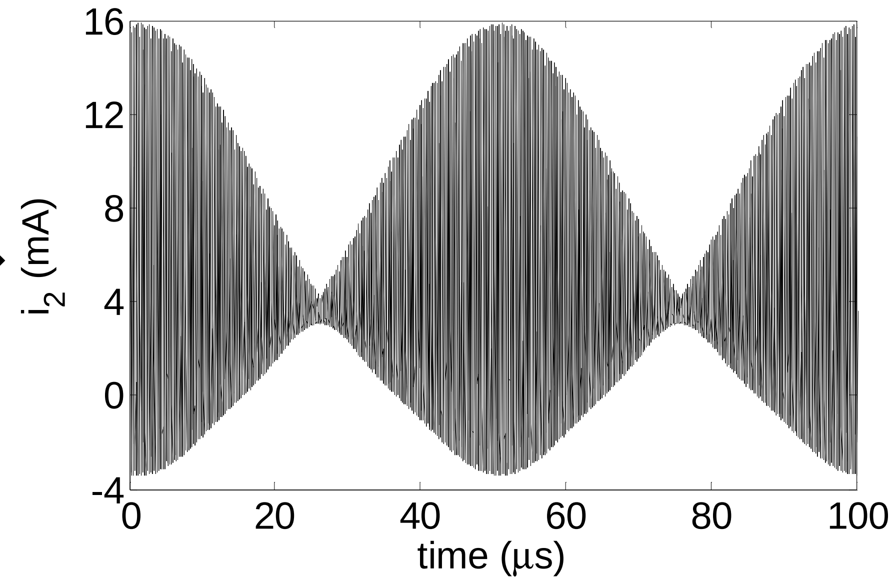


RF response

Time domain: RF response



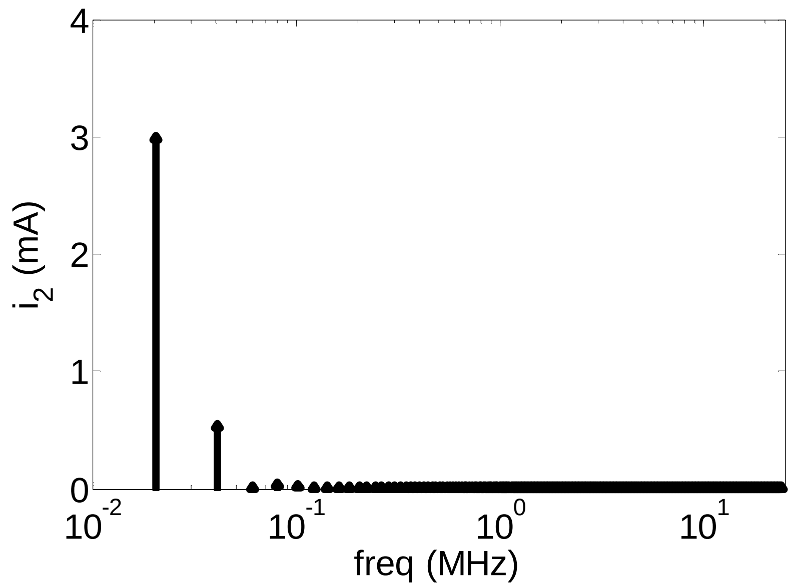




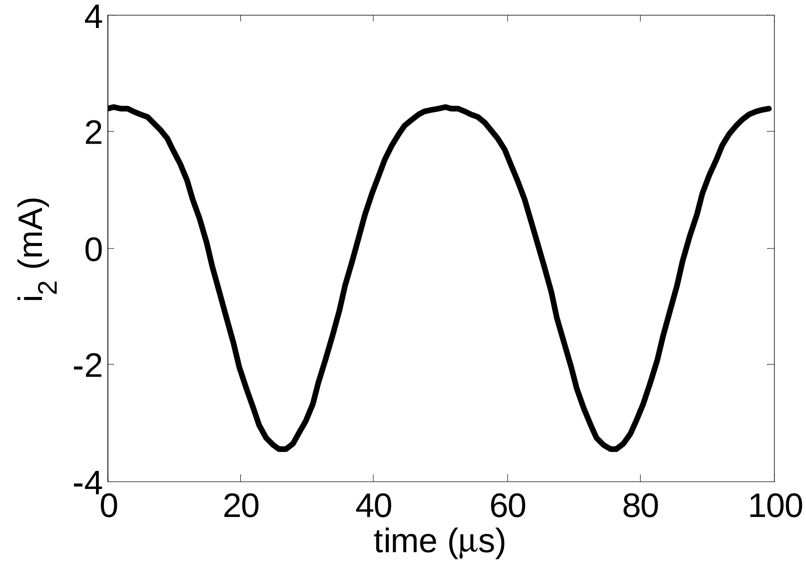
Only IMDs in the RF BW

Current does not clip

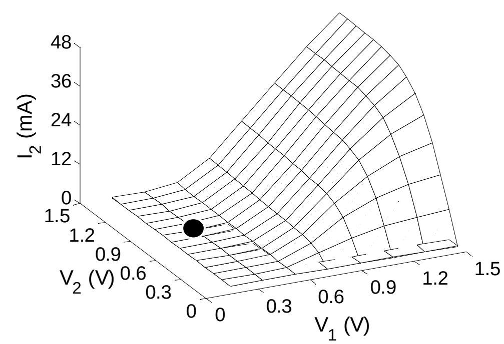
Time domain: LF response



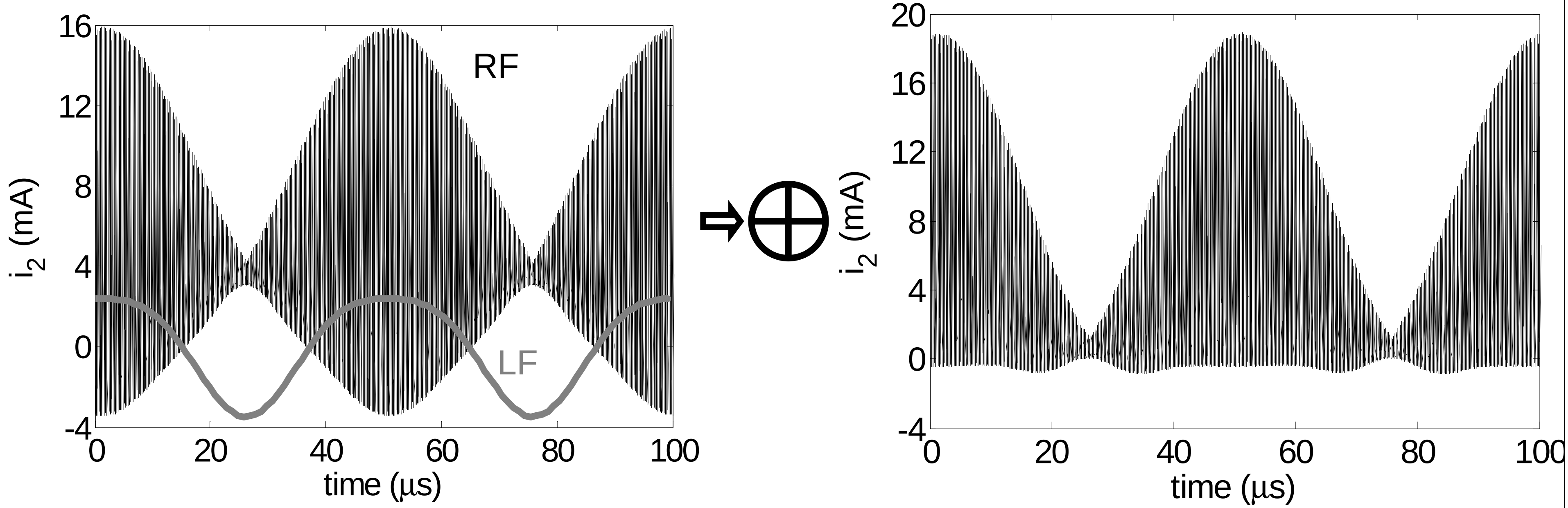
FFT



Significant self-biasing

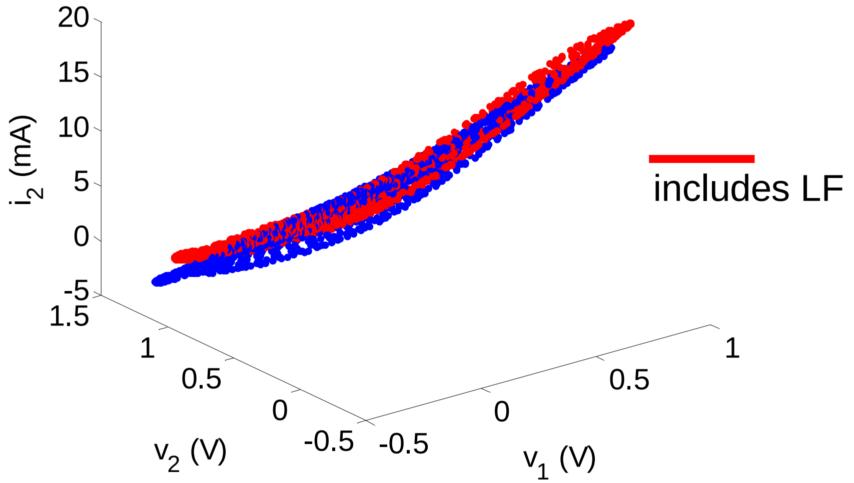


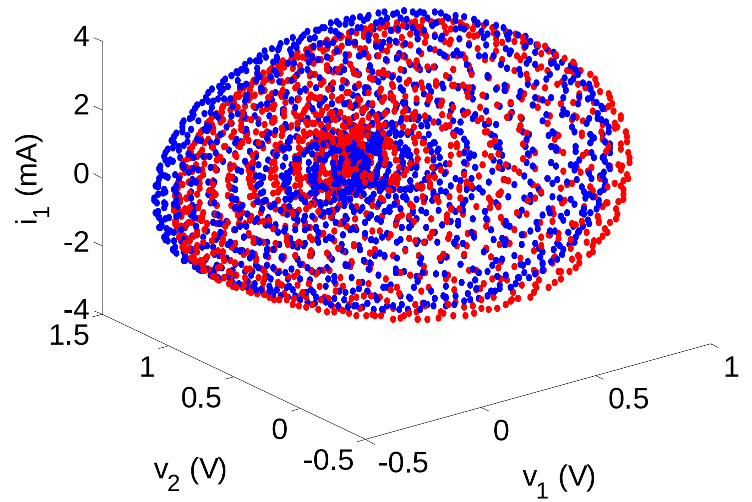
The missing information



LF information is fundamental in this case

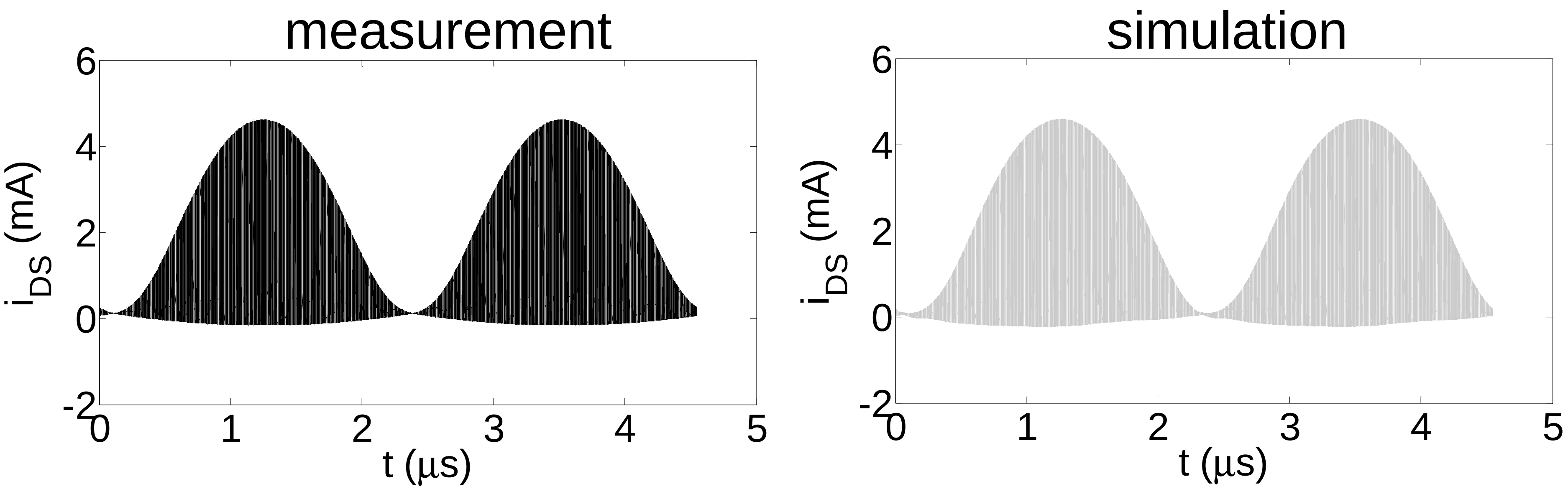
i-v trajectories





(v_1,v_2) coverage plane shifted by LF components

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 !