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A new method to measure pulsed RF time domain waveforms with a sub-sampling system

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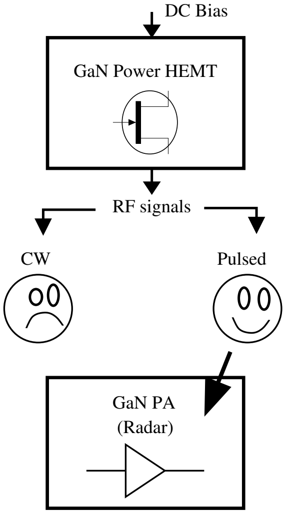
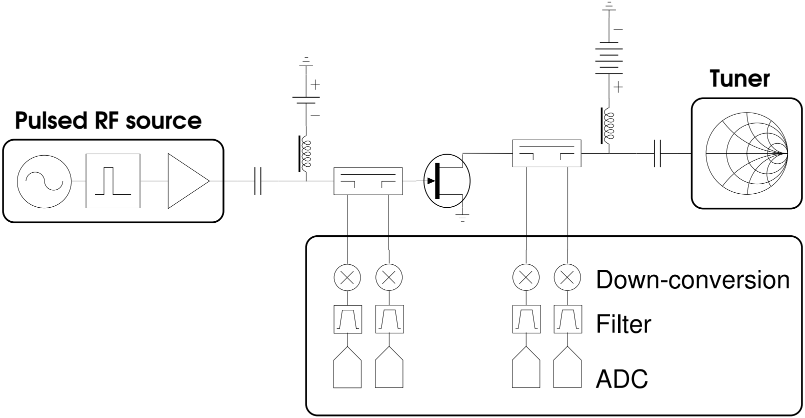
Introduction

Designing very high efficiency Power Amplifiers requires transistors level characterizations such as :

- Large-signal measurements ;
- RF time-domain measurements ;
- Pulsed mode for radar applications ;



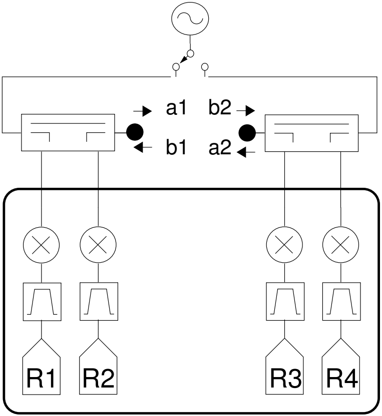
Large-Signal Measurement Setup



Calibration Procedure (CW)

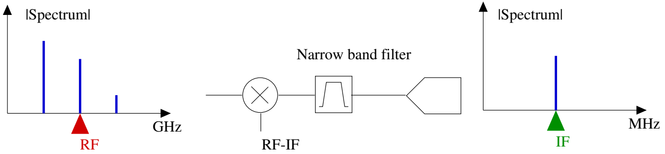
- SOLT
- Absolute Power
- Absolute Phase

$$\begin{pmatrix} a1 \\ b1 \\ a2 \\ b2 \end{pmatrix} = \|K\| . e^{j.\phi} . \begin{bmatrix} 1 & \beta_1 & 0 & 0 \\ \gamma_1 & \delta_1 & 0 & 0 \\ 0 & 0 & \alpha_2 & \beta_2 \\ 0 & 0 & \gamma_2 & \delta_2 \end{bmatrix} . \begin{pmatrix} R1 \\ R2 \\ R3 \\ R4 \end{pmatrix}$$

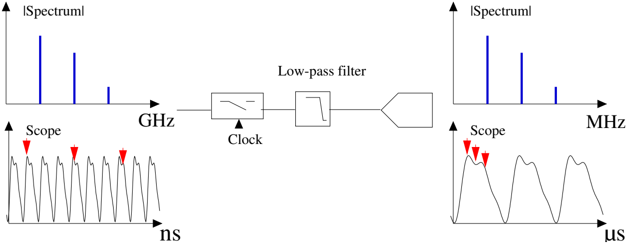


Receivers for CW measurements

- NVNA approach : frequency domain

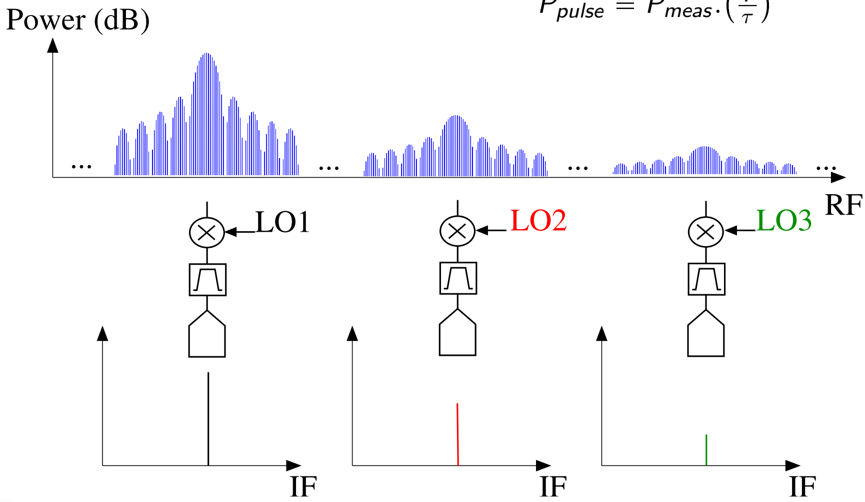


- LSNA approach : subsampling



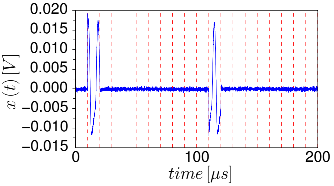
Mixer based pulsed measurements (NVNA)

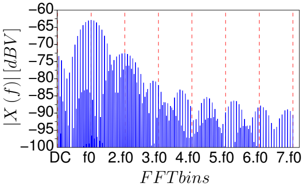
$$P_{pulse} = P_{meas} \cdot \left(\frac{T}{\tau}\right)^2$$

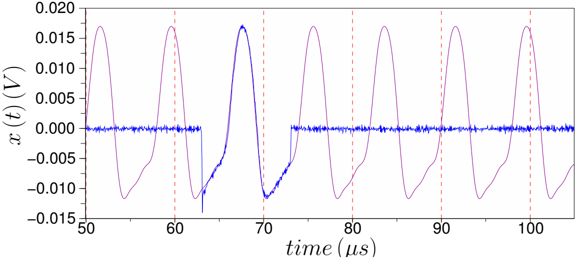


Sampler based pulsed measurements (LSNA)

$f_{RF} = 1.5 GHz$ $\tau_{pulse} = 10\mu s$ $T_{IF} = 8\mu s$







About inner-products

According to a dictionary

$$\mathcal{D} = \{\psi_k\}_{k\in\Gamma}$$

$x(t)$ can be represented by its inner-products coefficients

$$\langle x, \psi_k \rangle = \int_{-\infty}^{+\infty} x(t) \, . \overline{\psi}_k(t) \, . dt$$

If $x(t)$ is sparse in $\mathcal{D}$ then

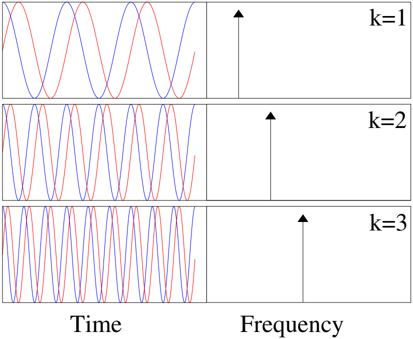
$$x(t) \approx \sum_{k\in\Lambda\subset\Gamma} \langle x, \psi_k \rangle \, . \psi_k$$

What is a Fourier Transform ?

- $\mathcal{D} = \left\{\psi_f(t) = e^{j.2.\pi.f.t}\right\}$
- $X(f) = \langle x, \psi_f \rangle$
- $x(t) = \int_{-\infty}^{+\infty} X(f)\, e^{j.2.\pi.f.t} df$
- $X(f) = \int_{-\infty}^{+\infty} x(t)\, e^{-j.2.\pi.f.t} dt$
- $x(t) \approx \sum_k X(k.f_0)\, e^{j.2.\pi.k.f_0.t}$

Standard LSNA uses boxcar window

Projection basis :

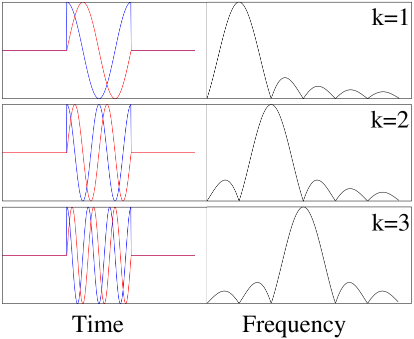


The Short Time Fourier Transform

Rectangular STFT is well suited for harmonic analysis

Projection basis :

- $\mathcal{D} = \{\psi_{k,\tau}(t)\}$
- $\psi_{k,\tau}(t) = P_k.\psi_k(t-\tau)$
- $\psi_k(t) = \Pi(f_0.t)\, e^{j.2.\pi.k.f_0.t}$
- $P_k = f_0.e^{j.2.\pi.k.f_0.\tau}$
- $X(k.f_0,\tau) = \overline{P}_k.x(t) * \overline{\psi}_k(t)$



$$\boxed{X(k.f_0,\tau) = \overline{P}_k.\mathcal{F}^{-1}\left\{X(f).\overline{\Psi}_k(f)\right\}}$$

LSNA software modifications

Standard procedure

Raw Data

↓

FFT
Coefficient Extraction (K)

↓

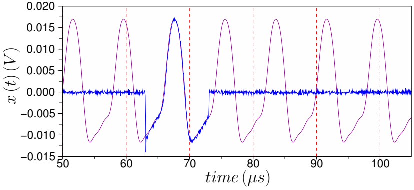
V/I Calculation

↓

Phase Normalization

↓

Results



New procedure

Raw Data

↓

K times

FFT
IFFT

→ Threshold → Gate Mask → ⊗

↓

Average → Coefficient Extraction (1)

Transcient → ...

↓

V/I Calculation

↓

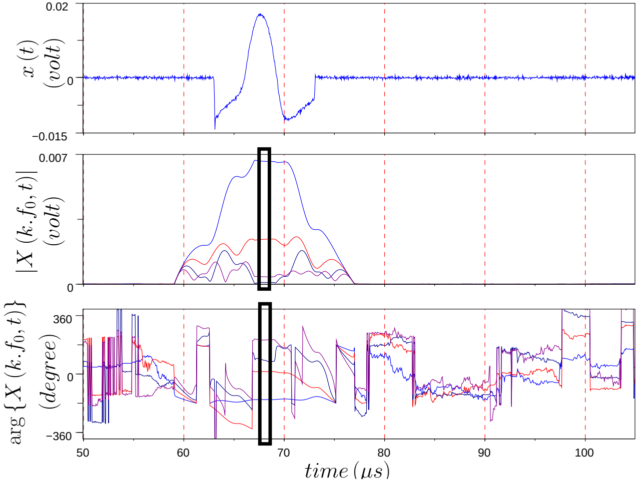
Phase Normalization

↓

Results

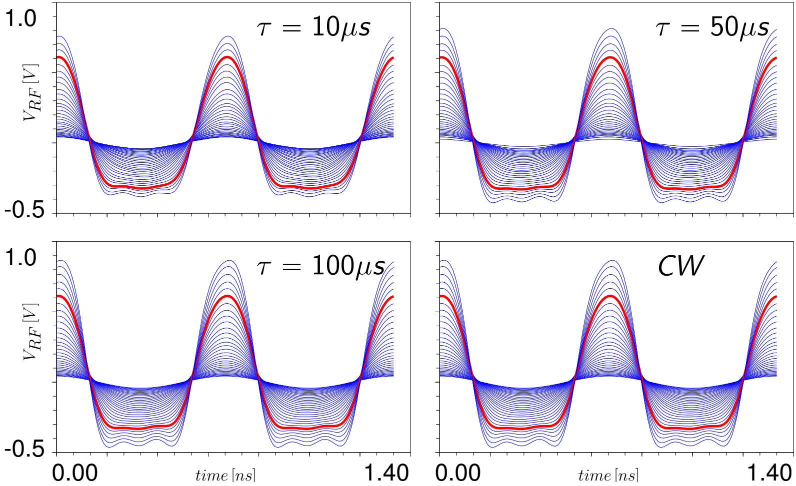
Experimental view of the algorithm

$f_{RF} = 1.5GHz \qquad \tau_{pulse} = 10\mu s \qquad T_{\psi} = 8\mu s \qquad k \in \{1, 2, 3, 4\}$



LSNA pulsed measurements on a PA ($T = 100\mu s$)

$f_{RF} = 1.5 GHz$ $T_{\psi} = 8\mu s$ $k \in \{1, 2, 3, 4\}$



Conclusion

- Standard LSNA harware can measure pulsed RF
- Minimal software modification (FFT procedure)
- Compatible with CW and pulsed signals
- Adaptive method
  - No trigger
  - Pulse's width and period (τ, T) not required
- Both 'Average' and 'Envelope Transcient' modes availables

Future work :

- Narrow pulses (double aliasing)
- Other types of modulation