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

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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

Pulsed RF source

Down-conversion

Filter

ADC

Tuner

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Calibration Procedure (CW)

- SOLT
- Absolute Power
- Absolute Phase

\[
\begin{pmatrix}
  a_1 \\
  b_1 \\
  a_2 \\
  b_2
\end{pmatrix} = \| K \| . e^{j \phi} \cdot \begin{bmatrix}
  1 & \beta_1 & 0 & 0 \\
  \gamma_1 & \delta_1 & 0 & 0 \\
  0 & 0 & \alpha_2 & \beta_2 \\
  0 & 0 & \gamma_2 & \delta_2
\end{bmatrix} \cdot \begin{pmatrix}
  R_1 \\
  R_2 \\
  R_3 \\
  R_4
\end{pmatrix}
\]
Receivers for CW measurements

- **NVNA approach**: frequency domain

  - Narrow band filter

- **LSNA approach**: subsampling

  - Low-pass filter
Mixer based pulsed measurements (NVNA)

\[ P_{pulse} = P_{meas} \cdot \left(\frac{T}{\tau}\right)^2 \]
Sampler based pulsed measurements (LSNA)

\[ f_{RF} = 1.5 \text{GHz} \quad \tau_{pulse} = 10\mu s \quad T_{IF} = 8\mu s \]
About inner-products

According to a dictionary

\[ D = \{ \psi_k \}_{k \in \Gamma} \]

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

\[
\langle x, \psi_k \rangle = \int_{-\infty}^{+\infty} x(t) \cdot \overline{\psi_k(t)} \cdot dt
\]

If \( x(t) \) is sparse in \( D \) then

\[
x(t) \approx \sum_{k \in \Lambda \subset \Gamma} \langle x, \psi_k \rangle \cdot \psi_k
\]
What is a Fourier Transform?

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

Standard LSNA uses boxcar window
The Short Time Fourier Transform

Rectangular STFT is well suited for harmonic analysis

Projection basis:

- \( D = \{ \psi_{k, \tau} (t) \} \)
- \( \psi_{k, \tau} (t) = P_k \cdot \psi_k (t - \tau) \)
- \( \psi_k (t) = \prod (f_0 \cdot t) e^{i \cdot 2 \cdot \pi \cdot k \cdot f_0 \cdot t} \)
- \( P_k = f_0 \cdot e^{i \cdot 2 \cdot \pi \cdot k \cdot f_0 \cdot \tau} \)
- \( X (k \cdot f_0, \tau) = \overline{P_k} \cdot X (t) \ast \overline{\psi_k} (t) \)

\[
X (k \cdot f_0, \tau) = \overline{P_k} \cdot \mathcal{F}^{-1} \{ X (f) \cdot \overline{\Psi_k} (f) \}
\]
LSNA software modifications

Standard procedure

New procedure

- Raw Data
- FFT
  - Coefficient Extraction (K)
- V/I Calculation
- Phase Normalization
- Results

- Raw Data
  - K times
  - FFT
  - IFFT
  - Threshold
  - Gate Mask
  - Average
  - Transcient
  - Coefficient Extraction (1)
  - V/I Calculation
  - Phase Normalization
  - Results
Experimental view of the algorithm

\[ f_{RF} = 1.5 \text{GHz} \quad \tau_{\text{pulse}} = 10 \mu s \quad T_\psi = 8 \mu s \quad k \in \{1, 2, 3, 4\} \]
LSNA pulsed measurements on a PA \( (T = 100\mu s) \)

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

\[
\tau = 10\mu s
\]

\[
\tau = 50\mu s
\]

\[
\tau = 100\mu s
\]

\[
CW
\]
Conclusion

- Standard LSNA hardware can measure pulsed RF
- Minimal software modification (FFT procedure)
- Compatible with CW and pulsed signals
- Adaptive method
  - No trigger
  - Pulse’s width and period ($\tau, T$) not required
- Both ’Average’ and ’Envelope Transient’ modes availables

Future work:
- Narrow pulses (double aliasing)
- Other types of modulation