RF & HYPER EUROPE 2005

POWER AMPLIFIER WORKSHOP

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Recent advances in RF measurements systems : How to choose the good characterization tools to help the power amplifiers designers

D. BARATAUD, J.P. TEYSSIER, T. REVEYRAND, G. NEVEUX, J.M. NEBUS

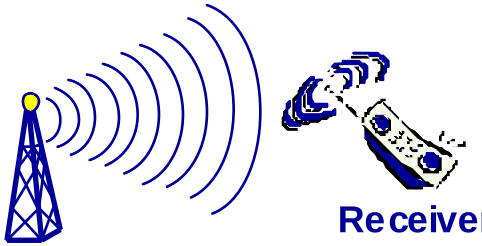
IRCOM - Faculté des sciences - UMR CNRS n°6615

123, Avenue Albert Thomas - 87060 LIMOGES Cédex
Phone : (033) 555-457753 - Fax : (033) 555-457666

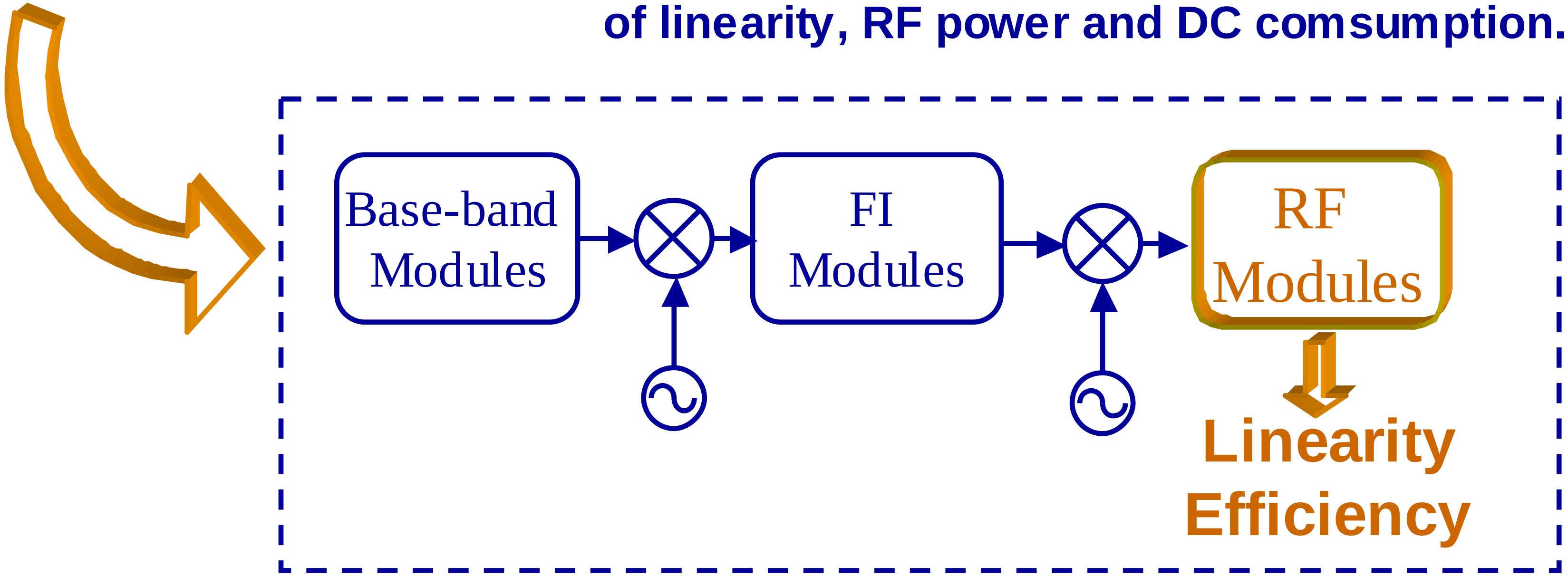
e-mail : barataud@ircom.unilim.fr
www : http://ircom.unilim.fr

1. Introduction – Classical Characterization Methods.
2. RF Time-domain characterization
3. Conclusion and future investigations

- **Telecommunication systems :**



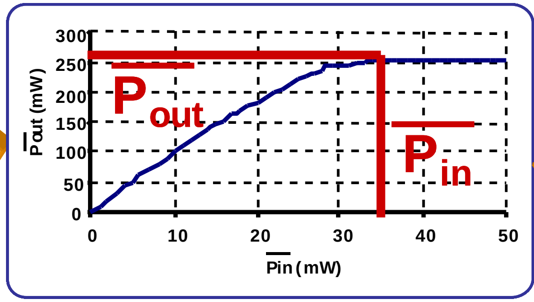
- **Use of Digital complex modulations**
- **Base-band modules based on DSP**
- **Critical specifications for RF modules in terms of linearity, RF power and DC comsumption.**



↳Linearity versus efficiency optimization of power amplifier

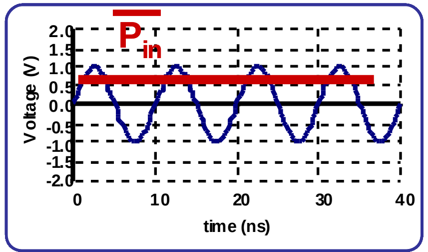
x(t) → **Non linear Device** → y(t)

x(t) : Single tone
↳Constant envelope

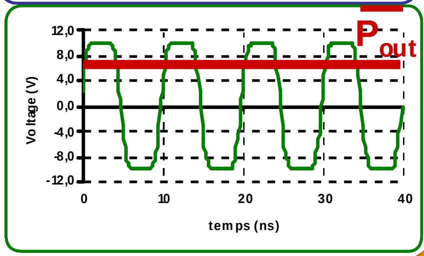


Time Domain approach

x(t)



y(t)



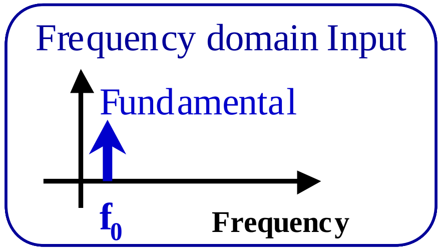
Non linear Device :

↳Average Power Characteristics

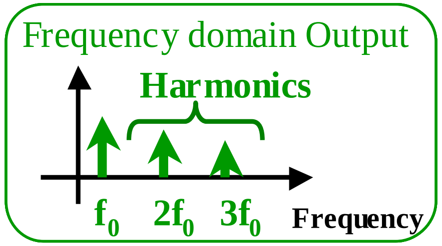
↳Gain Compression/expansion

Frequency Domain approach

X(f)



Y(f)



↳Waveform Distortions

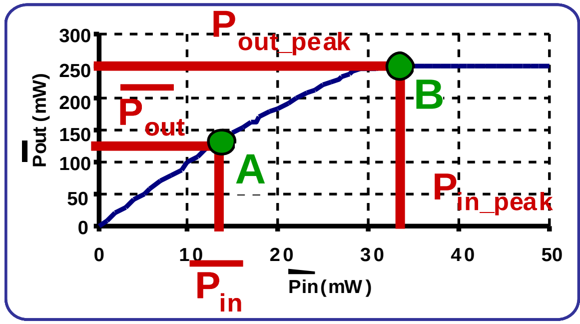
Basic correspondences to kept in mind

↳Generation of harmonics

Two tones characterization

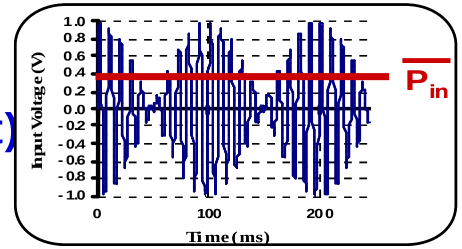
x(t) : Two-tones

↳ Non Constant envelope

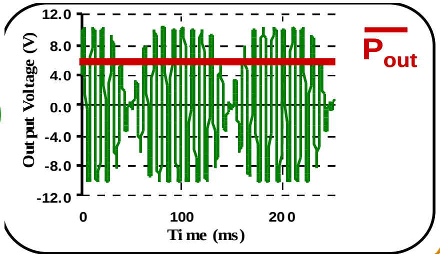


Time Domain approach

x(t)



y(t)



↳ Carrier and envelope Distortions

Non linear Device :

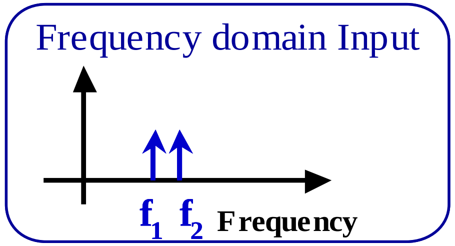
↳ Average Power Characteristics

↳ Gain Compression/expansion

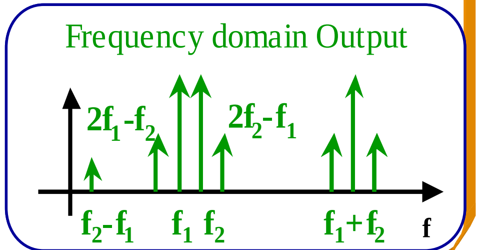
↳ **Time variable instantaneous gain**

Frequency Domain approach

X(f)

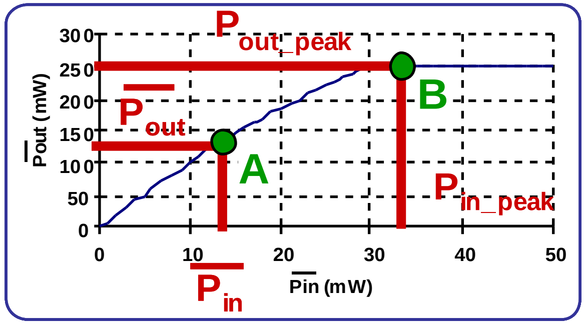


Y(f)



↳ IMD Products

Basic correspondences to kept in mind



Non linear Device :

- Average Power Characteristics
- Gain Compression/expansion

Dynamic behavior

Linearity specifications :

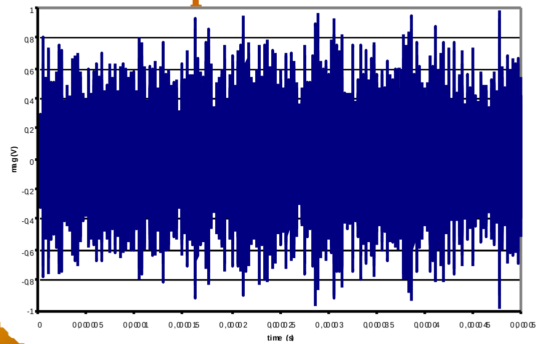
⇩

strongly depend on the application

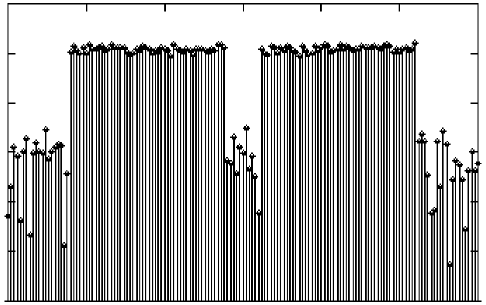
x(t) : Complex modulated signals

Non Constant envelope

Time Domain Representation



Frequency Domain Representation



Both Domain Visualization :

Average of the nonlinear phenomena difficult to distinguish and analyze.

↗ Complexity test signals

⇕

↗ difficulty of comprehension of the fundamental phenomena

➢ Classical approach :

- Input Power Back-off ⇨ over-sized Pas (poor efficiency performances)
- External linearisation (Feedforward, Cartesian Feedback, ...) ⇨ Complex sub-system Designs

↳ **A Posteriori Curative solutions**

➢ New trends :

From optimized transistor process :

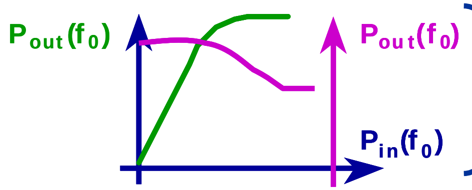
- Optimization of Operating conditions of transistors (RF impedances, biasing circuit topology)
- « SMART POWER » Design Solutions (dynamic biasing, CALLUM, adaptative pre-distortions)

↳ Characterization methods and tools are necessary to aid in :

- ➢ defining DESIGN CRETERIA
- ➢ implementing PRACTICAL and EFFICIENT solutions

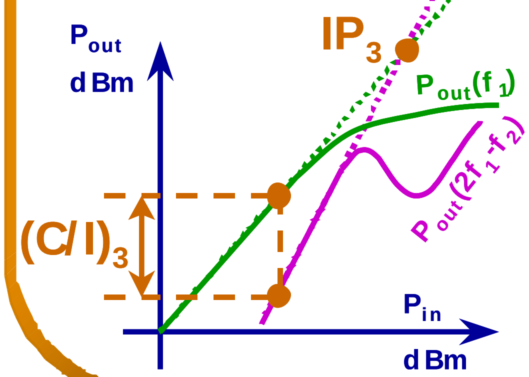
Simple test signal

☞ **CW test signal :**



AM/AM
AM/PM
Characteristics

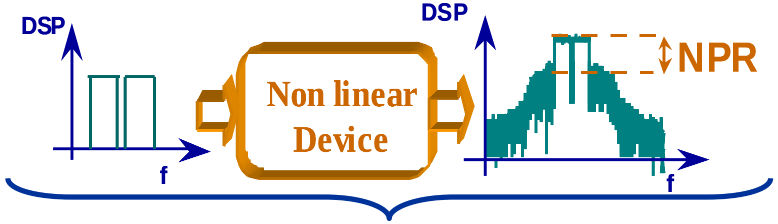
☞ **Two-tones test signal**



- IMD
- $(C/I)_3$ @ P_{out}
- IP_3

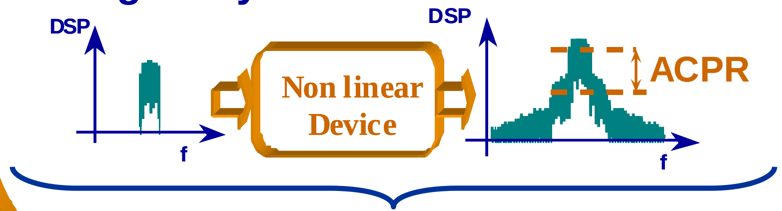
More complex test signals

☞ **Band-limited noise :**



Intermodulation noise

☞ **Digitally modulated carrier :**



Spectral regrowth

- **Simple test signals :** ➪Design methodology and criterion identification
- **Complex test signals :** ➪validation step

↳ Needs of specific characterization tools making enable :

- **Average Power measurements :**
  - ✓ Power Meter
  - ✓ Scalar Analyzer
  - ✓ Spectrum Analyzer
- **Frequency Domain Measurements**
  - ✓ Vector Network Analyzer
- **Time Domain measurements.**
  - ✓ sampling Oscilloscopes
  - ✓ MTA
  - ✓ LSNA
  - ✓ DC current and voltage probes

The simplest and easiest to implement

The most conventional

The most informative BUT More complex to implement

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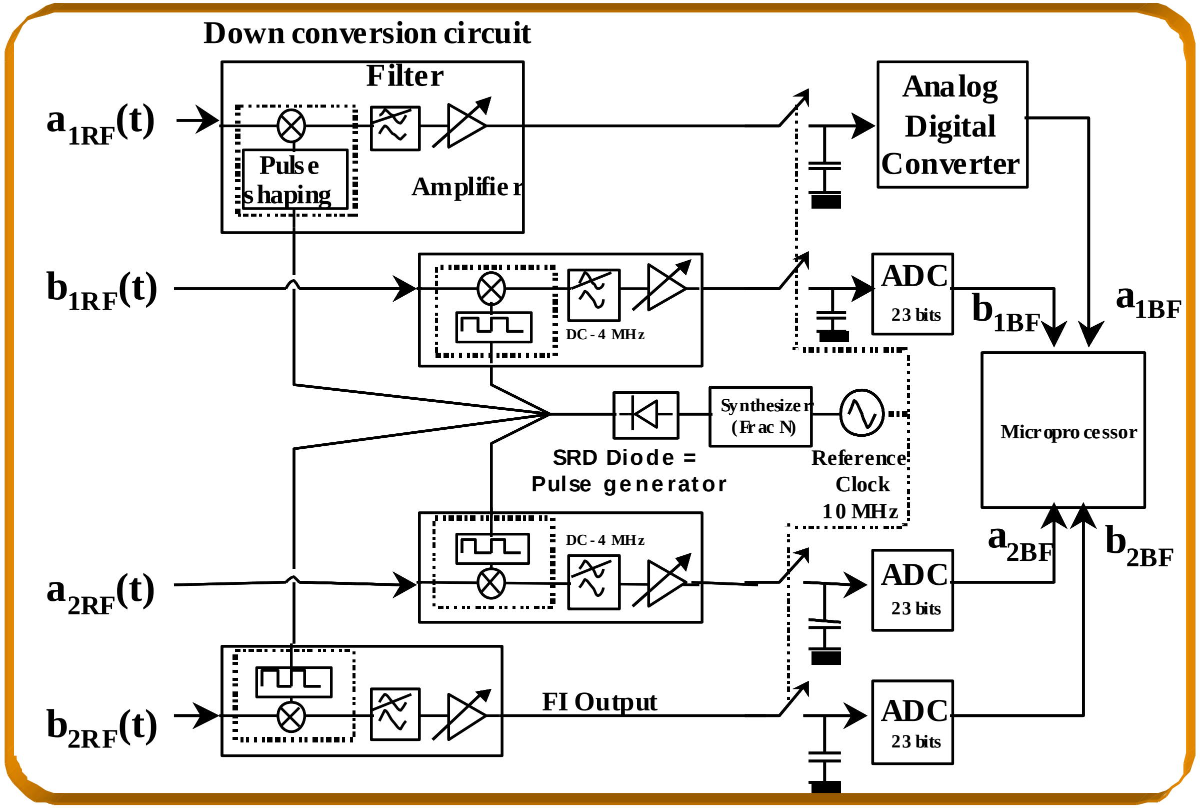
➢ **Measurement Instrument :** ☞ Large Signal Network Analyzer (LSNA)



➢ **4 fully synchronized Channels of acquisition**

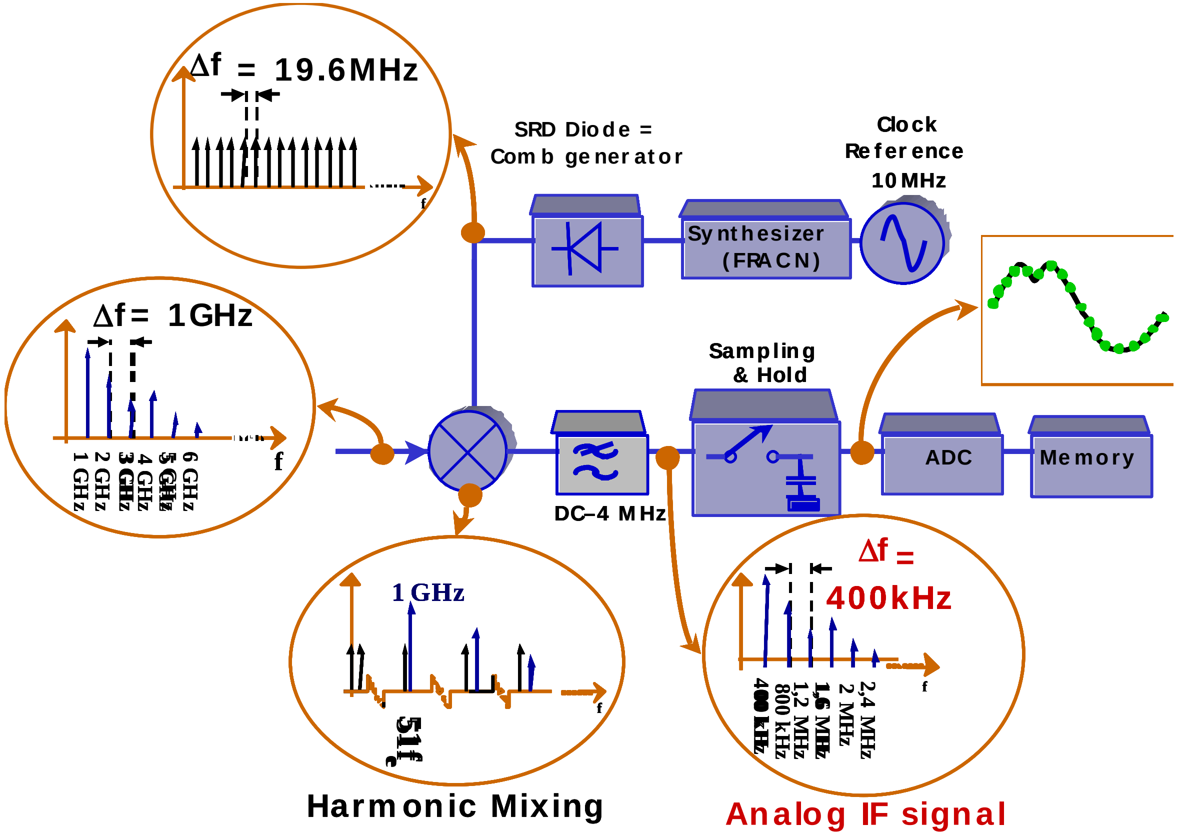
➢ **Use of harmonic repetitive Sampling Principle**

➢ **Bandwidth limitation : low pass Filter**

➢ **Measurement Instrument :** ☞ Large Signal Network Analyzer (LSNA)

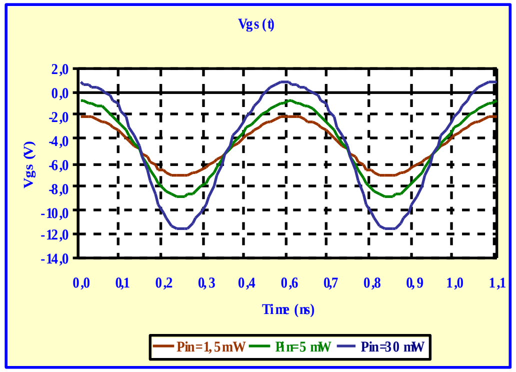
➢ **Analog IF signal is an equivalent image of the analog RF signal**

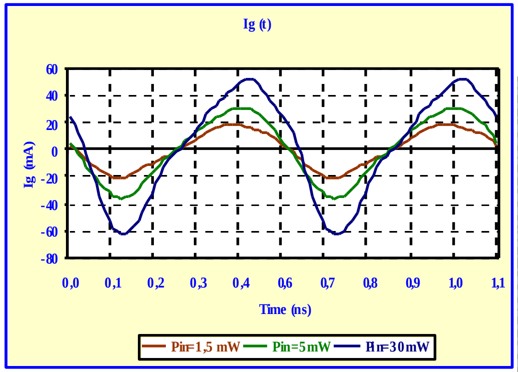
↳ **frequency translation and compression**

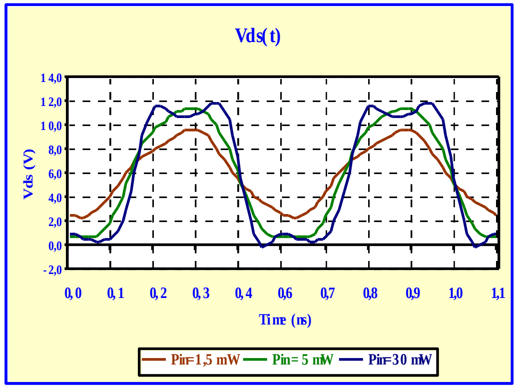


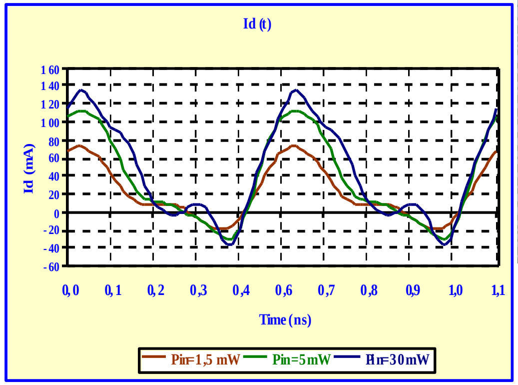
Measurement of a 8x75 µm FET

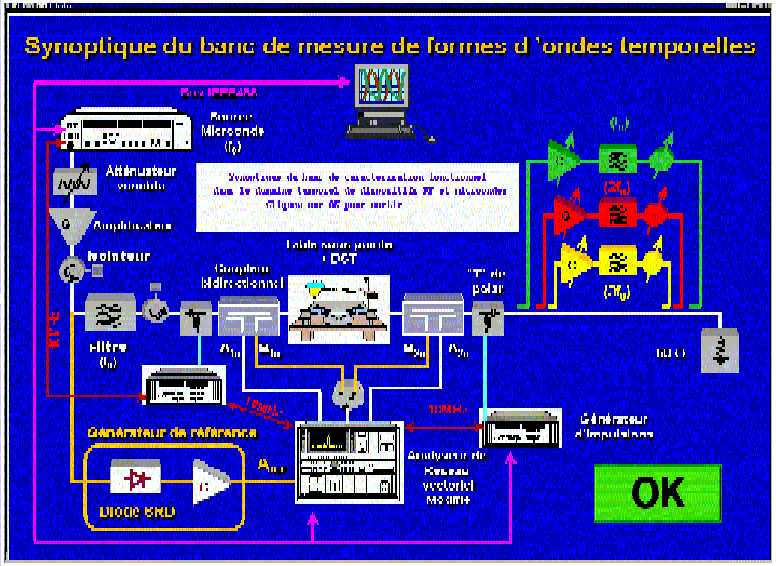
V_{gs0}=-4,5 V - V_{ds0}=6 V I_{g0}=0 mA - I_{d0}=5 mA f_0=1,8 GHz





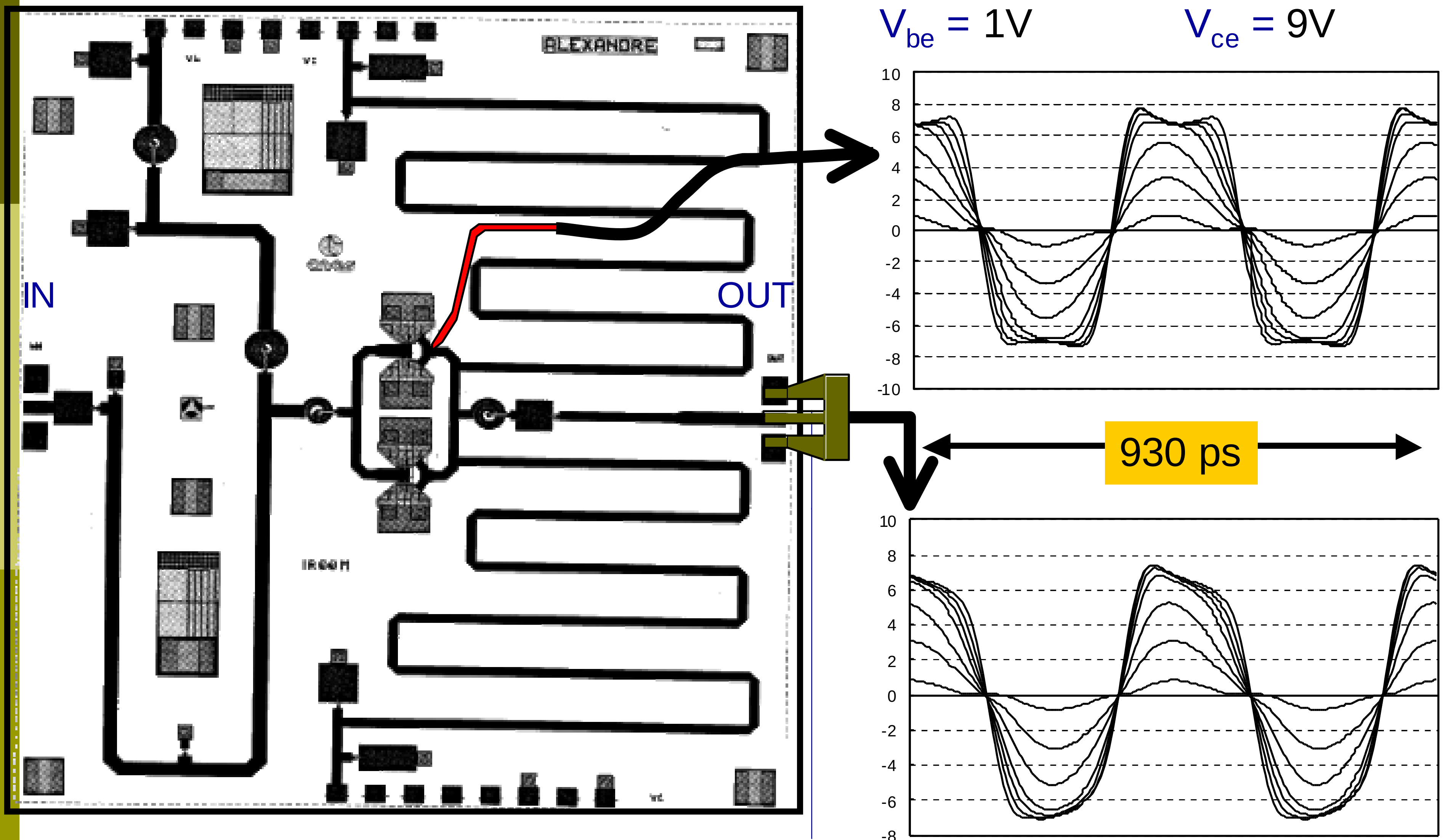




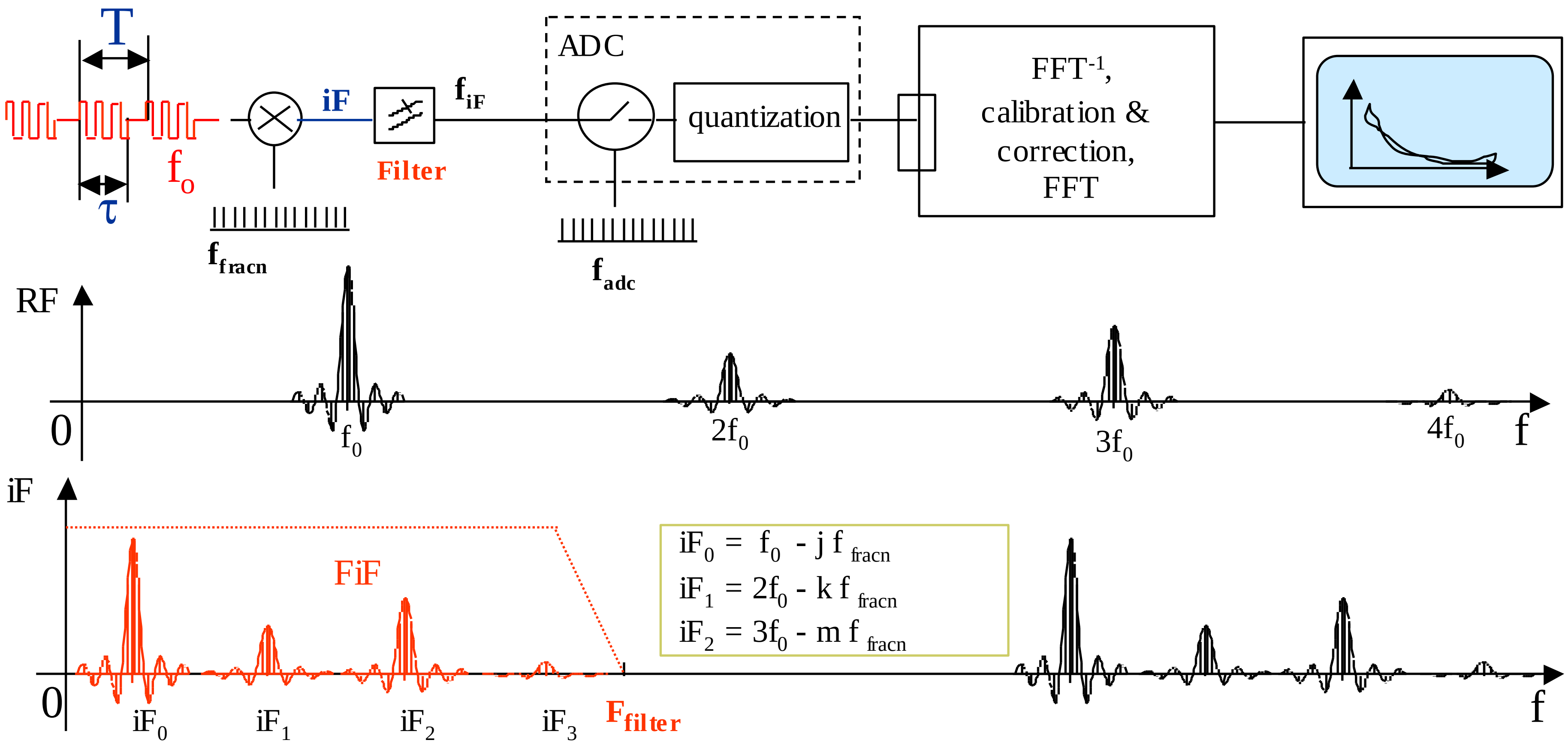


➢ **Accurate validation of non linear models of transistors**

➢ Experimental results on a non linear class F operation mode amplifier :



LSNA with Pulsed f_0, $2f_0$, $3f_0$, …, nf_0 signal



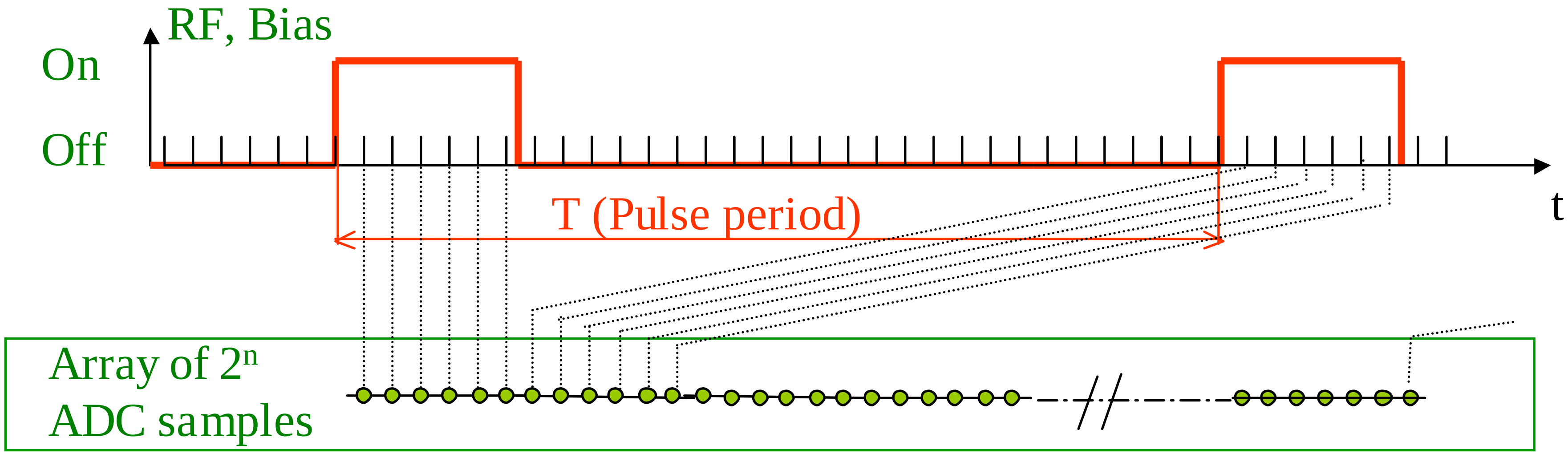
- Only the center frequency iF_i of each sinc envelope is to be considered.
- One must check that lateral (sinc) frequencies do not overlap iF_i frequencies.

- **Limitation of the bandwith :** F_{filter}

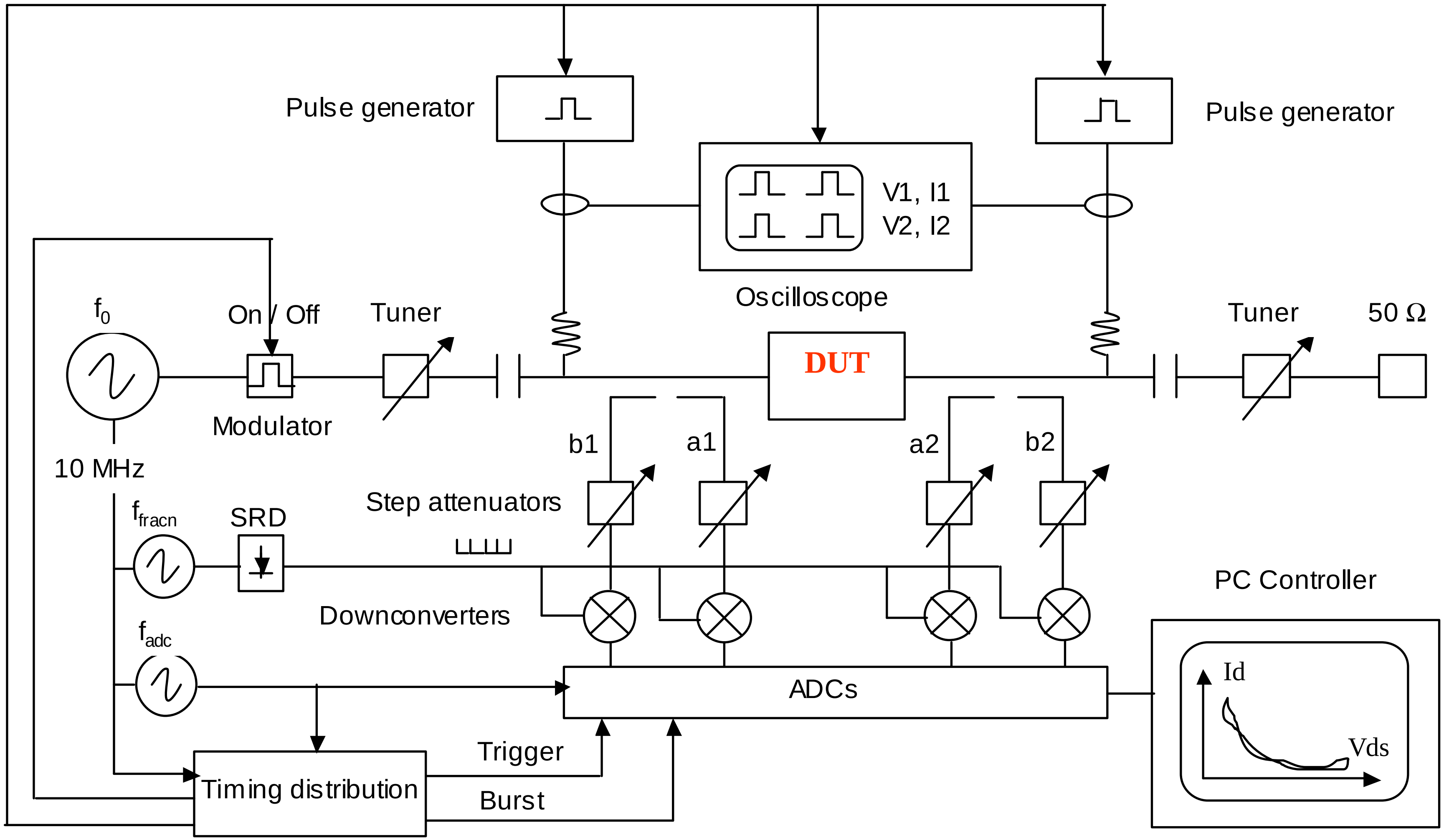
➢ **Time Domain representation :** ☞ Large Signal Network Analyzer (LSNA)

4 frequencies/periods are to be considered: f_o, f_{fracn}, f_{adc}, T (Pulse Period)

The idea : $T = q \times$ common period of $(fo, f_{fracn}, f_{adc}) + \varepsilon$



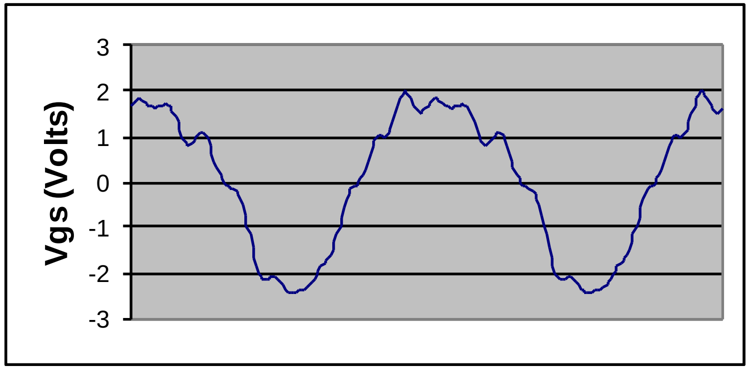
ε looks like the very slow phase drift of a stroboscope.

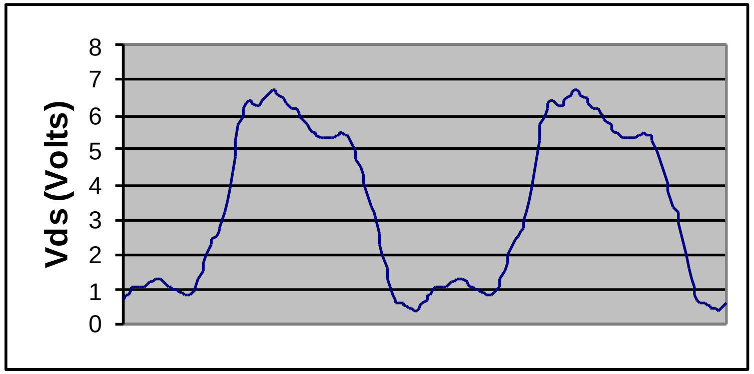


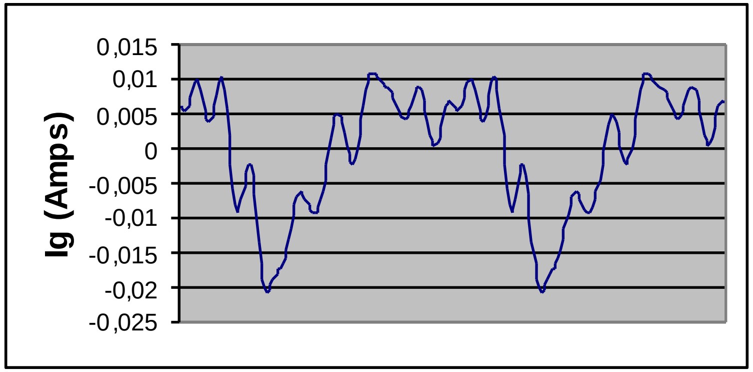
➢ All frequencies/clocks derive from the RF synthesizer high precision reference

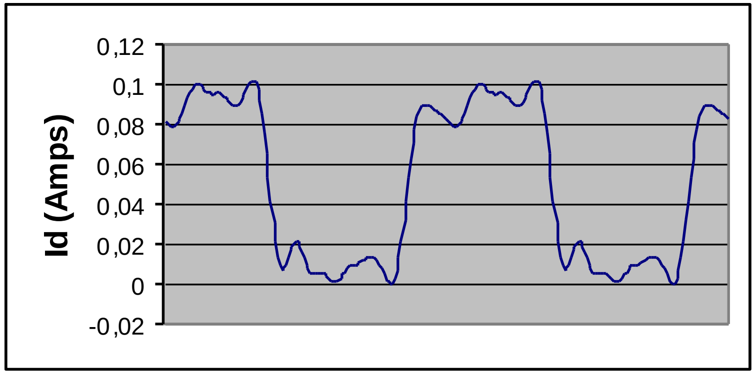
Measurement of a 6x40 µm P-HEMT 0,15 µm - f_0 =1GHz

Pulse period : 5,3125 µs, Pulse duration 400ns, pulsed bias and pulsed RF









Measurement of a 6x40 µm P-HEMT 0,15 µm - f_0 =1GHz

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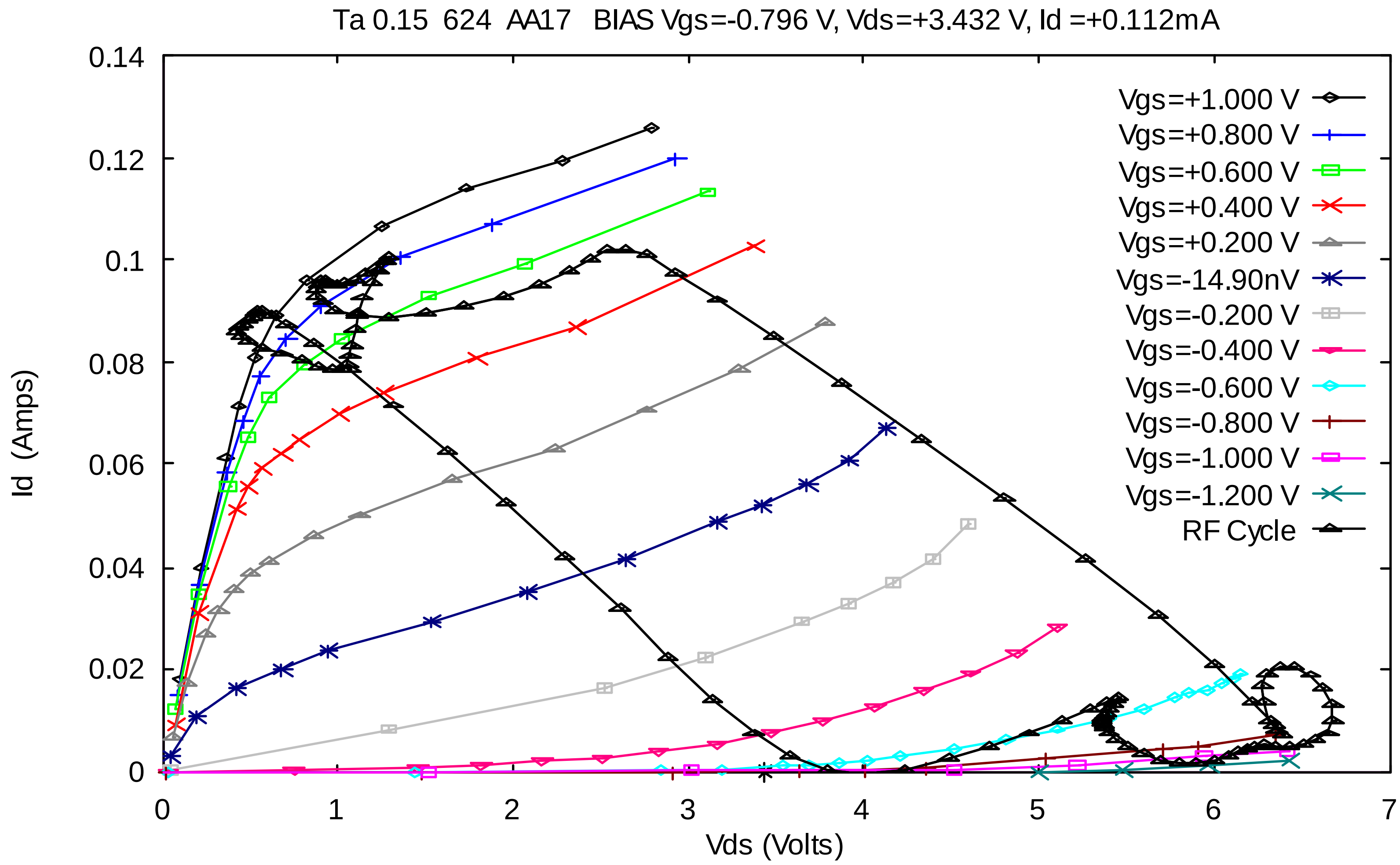

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Analysis…
Identification…
Understanding…

of

DYNAMICS
NONLINEAR
PHENOMENA

SIMULATIONS | MEASUREMENTS

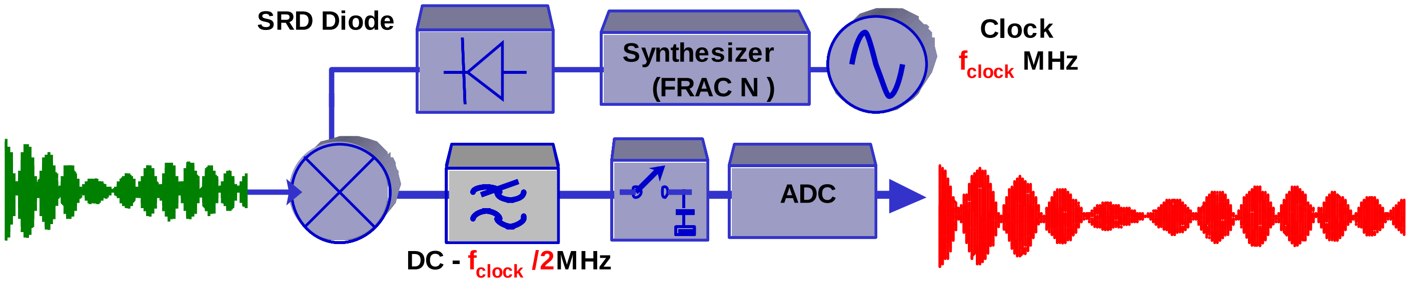
- ~~Time Domain Integration~~ ⟷ Time domain consistency ⟷ ~~Time Domain Characterization~~
- **Harmonic Balance + Envelope Transient** ⟷ Time & space domains consistency ⟷ LSNA + HIP

↓

Optimized designs of MMICs

➢ New large Signal characterization with modulated signals

✓ **Evolution of the LSNA to the characterization of RF complex signals**



Challenges:

➢ Definition of a new calibration procedure

➢ Definition of a new phase reference standards for modulated signals (multicarrier signals)