Feedback(*) on

The use of Large-Signal Network Analysis

NMDG Engineering
Leading beyond S-parameters

(*) The feedback has been provided by the different institutes with their explicit approval for publication

Institutes

In alphabetic order

- CNES and IRCOM
- KUL
- NIST
- VUB

LSNA Technology at IRCOM and CNES

Institut de Recherche
en Communications Optiques et Microondes
Unité mixte de Recherche CNRS
Université de Limoges

Jean Michel NEBUS – Denis BARATAUD
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IRCOM - Non Linear Electronic Circuits and Sub-Systems

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RF circuits and sub-systems characterization to give expertise on smart power solutions.

Radar Applications

Software radio Applications

Centre National d'Etudes Spatiales (French Space Agency)

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Microwave and Time-Frequency Department

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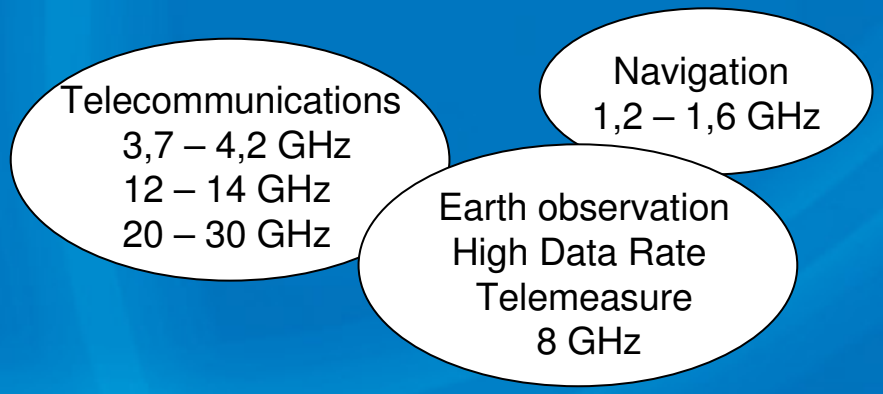
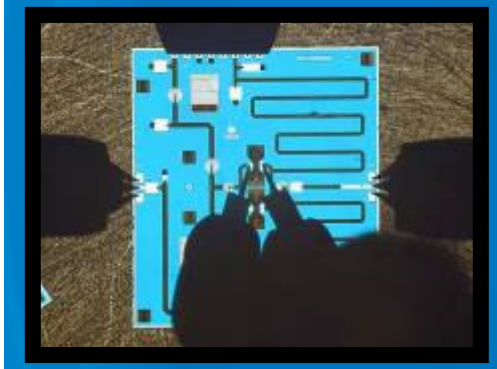
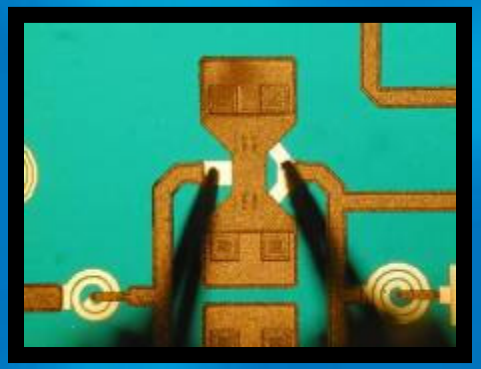
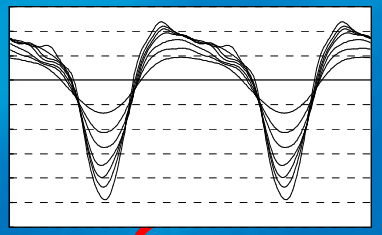
RF circuits and sub-systems characterization for space applications :

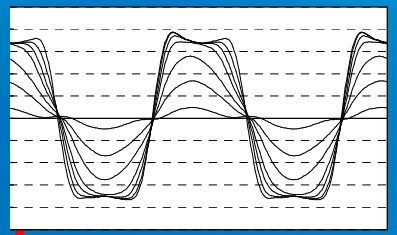


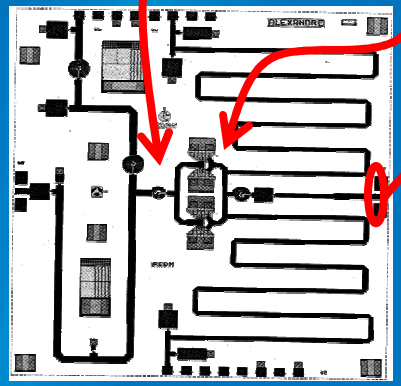
What did IRCOM-CNES realize with the LSNA?

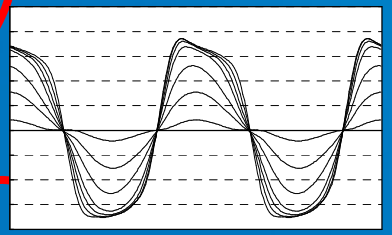










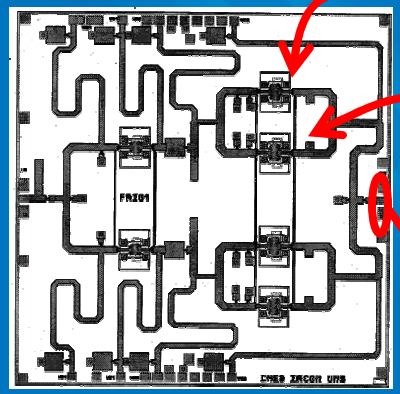


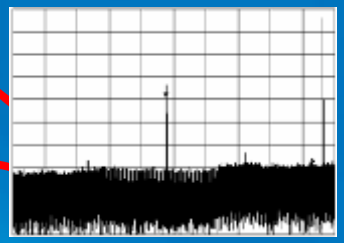
Class F design validation

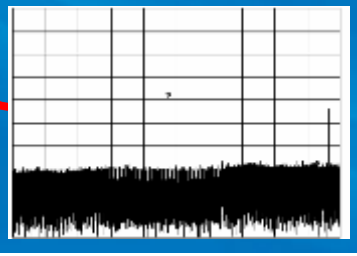
Square voltage wave at the output of HBTs (f=2 GHz)

Enhanced tool for reliability too

LSNA + High Impedance Probes
Calibrated internal node voltage waveforms







Parametric Stability

HIP enables oscillation detection
LSNA enables phases measurements

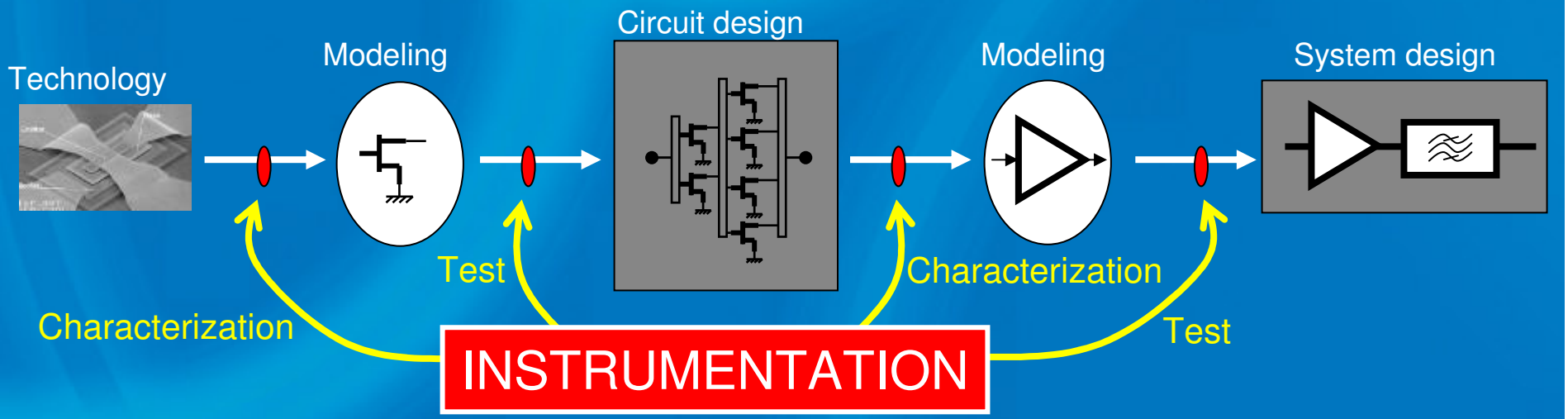
Even / Odd oscillation mode measurement setup

Dynamic Load-line

Check transistor behavior in a load-pull environment
Only powered by LSNA technology

Future work of IRCOM-CNES with the LSNA?

Design method requires accurate modeling,
Non Linear simulation and characterization



Visualization of
Dynamics nonlinear phenomena and behaviors

Time domain analysis and instrumentation

Accurate measurements at circuit and system levels considering harmonic components up to 40GHz

Time-domain voltage Waveform measurements for failure analysis

Modulated signals measurement capability

LSNA Technology at K.U.Leuven, div ESAT-TELEMIC

- **K.U.Leuven**
  Dept. Electrical Engineering (ESAT),
  Div. ESAT-TELEMIC
  - **University founded in 1425**
  - **LSNA user since 1995**
- **The circuits and devices group of ESAT-TELEMIC is continuously working towards excellence in measurement, modeling and design of microwave devices and circuits.**
- **LSNA is the key measurement instrument for non-linear circuits and devices:**
  - **Device-model validation (for compact models, equivalent circuit models and table-based models derived from ANA-measurements)**
  - **Device-model construction through multi-tone measurements**
  - **Circuit performance measurements (compression, harmonic distortion,…)**
  - **Circuit modeling based on measurements**
- **Contact**

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What did TELEMIC realize with the LSNA?

- Verification of transistor models
  - Applied to diodes, HEMTs, MOSFETs, HBTs, …
  - Applied to empirical, compact, and table-based models
- Construction of models from LSNA measurements
  - Devices: equivalent circuit based and behavioral models
  - Circuits: behavioral models
- Enhanced characterization methods
  - e.g., reliability studies

⇒ resulted in > 100 publications
http://www.esat.kuleuven.ac.be/telemic/publications/

⇒ cooperation with > 15 (inter)national research groups

Future work of TELEMIC with the LSNA?

- From devices to circuits and building blocks
  - LSNA to be used to a much larger extent than today for measurements of circuits and system building blocks, both for performance validation as for construction of models
  - Specific power devices and power amplifier circuits
- From simple stimuli to modulated excitations
  - Apart from single tone or multi-tone measurements, we will use modulated excitations in order to better cover the instantaneous signal space
- From basic to complex performance measures
  - Apart from simple harmonics and related performance indices we will add modulated and wide-band signals and the related quality measures such as ACPR, spectral regrowth,…

LSNA Technology at NIST

- Contact Information

  1. Nonlinear Device Characterization Project - RF Electronics Group 818.01

     http://www.boulder.nist.gov/nonlinear

     Project Leader: Don DeGroot, *degroot@boulder.nist.gov*

  2. Measurements for Wireless Systems - RF Electronics Group 818.01

     Project Leader: Kate Remley, *remley@boulder.nist.gov*

1. "NIST's Nonlinear Device Characterization Project (NDC) is directly supporting the development of radio-frequency, large-signal network analysis and nonlinear circuit design with several targeted research activities. We are developing basic measurement science to quantify the accuracy and uncertainty in data acquired with commercial and custom large signal network analyzers (LSNAs), we have developed a nonlinear verification wafer and are conducting an interlaboratory measurement comparison for LSNA users, and we are developing various behavioral modeling techniques to capture nonlinear device responses suitable for computer-aided design. In addition, we provide support for passive intermodulation measurements and network analysis using time-domain instruments."

   (http://www.boulder.nist.gov/nonlinear, June 2004)

2. In Wireless System metrology, we use large-signal network analysis to measure magnitude and phase relationships of two-port, bandpass systems that include nonlinearities. These measurements are used for: characterization of system distortion, development of appropriate test and calibration signals, assessment of common system-level figures of merit. We have been using large-signal network analysis is also used to measure the reflection coefficient of microwave sources. Maintaining the phase relationships between measured wave variables is key.

What did NIST realize with the LSNA?

1. With a new vector nonlinear network analyzer, NDC team members are making large-signal measurements of canonical circuits. These generalized measurements of input-output relationships include both magnitude and phase information for the frequency components of stimulus and response signals. These data allow us to compare predictions made by state-of-the-art CAD simulators and new behavioral models to reference measurements, and may form the basis of new RF circuit design methodologies.

   (http://www.boulder.nist.gov/nonlinear, June 2004)

2. Recent Wireless System Research Utilizing the LSNA:
   - Measurement of reflection coefficient of microwave source under large-signal operating conditions. J. Verspecht, D. F. Williams, D. M. M.-P. Schreurs, K. A. Remley, and M. D. McKinley, "Linearizing large-signal scattering functions," in review.
   - Characterization of ACPR for multisine signals having various phase relationships between the frequency components. K. A. Remley, "Multisine excitation for ACPR measurements," *IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 2141-2144, June 2003.
   - Identification of memory effects in nonlinear systems using two-tone methods and an extended measurement bandwidth.K. A. Remley, D. M. M.-P. Schreurs, D. F. Williams, and J. Wood, "Extended NVNA bandwidth for long-term memory measurement," *IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 1739-1742, June, 2004.

Future work of NIST with the LSNA?

1. The NDC project acquired a new large-signal measurement facility for nonlinear network analysis. The system provides the most general approach to stimulus-response measurements at RF and microwave frequencies (to 50 GHz). The network analyzer supplies periodic signals, then acquires broadband incident and reflection waveforms at the device under test. The NIST facility will be used as a reference system in measurement and model comparisons. The project team is developing accurate calibration and measurement techniques, including validation of the Nose-to-Nose calibration technique, the only practical method of measuring the phase relations of components in signals with 50 GHz bandwidths. The project team is now refining the statement of measurement uncertainty in the Nose-to-Nose method and will apply it to the nonlinear network measurement system.

   (http://www.boulder.nist.gov/nonlinear, June 2004)

2. Comparison of instrumentation capable of measuring bandpass nonlinearities: LSNAs, vector signal analyzers, oscilloscopes, NIST wideband sampling voltmeter. *In process*.

LSNA Technology at Department ELEC/VUB

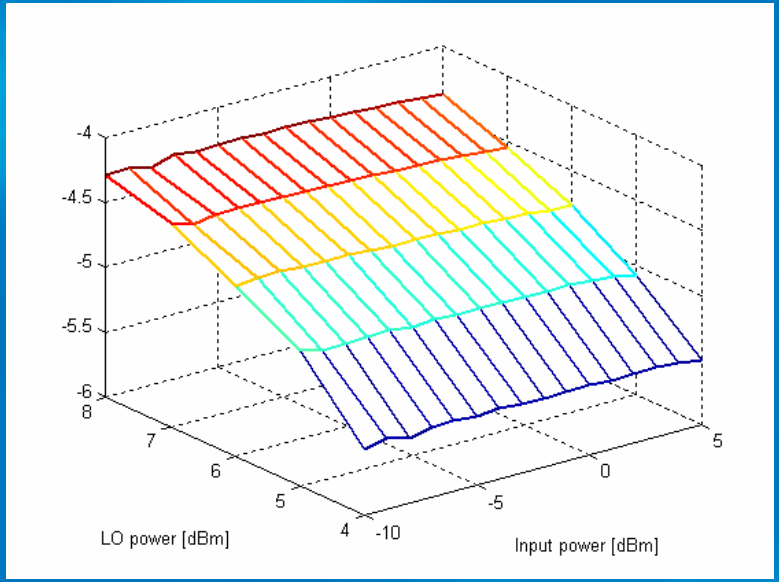
- **Vrije Universiteit Brussel - Department ELEC**
  Pleinlaan 2, Building K, 6th floor
  B-1050 Brussels, Belgium
  Contact: Prof. Alain Barel (+32.2.629.29.49 / abarel@vub.ac.be)
  http://wwwtw.vub.ac.be/elec/

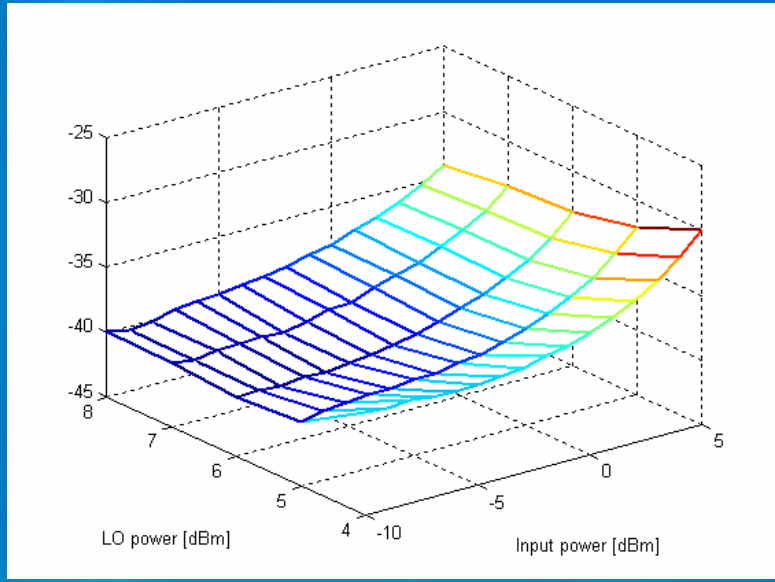
- "The main research activity of the department is the development of new measurement techniques using advanced signal processing methods, embedded in an identification framework. A very wide scope of application fields is dealt with: systems covering the frequency range from a few mHz up to 50 GHz, linear systems and nonlinear systems, lumped systems and distributed systems"

- "For nonlinear RF devices or components it is of vital importance that the excitation conditions of the devices in test and operation conditions match as closely as possible. Highly **flexible instrumentation** setups, like the **LSNA**, are therefore required. The device combines the advantages of reconfigurability and ease of use and provides an efficient and easy to use data handling capability"

What did ELEC realize with the LSNA?

- ***2-port device measurement and modelling under realistic excitation signals***: CW and modulated measurements, deep saturation, nonlinear behaviour, spectral regrowth,...
- ***3-port device measurements under realistic excitation signals***: Conversion loss of a mixer in amplitude and phase





Future work of ELEC with the LSNA?

- ***3-port device modelling under realistic excitations***
- ***Full nonlinear measurement and modelling of differential devices***