# Overview on System Level Simulation Environment for Characterization, Modeling and Simulation of RF and Microwave devices

T. Reveyrand, D. Barataud, G. Neveux, J-M. Nebus, E. Ngoya, J-P. Teyssier, and R. Quéré

XLIM - UMR CNRS 6172
123 Avenue Albert Thomas
87060 Limoges Cedex, France

*Abstract* — **This paper presents an overview of research activities on system level design characterization and analysis for RF and microwave devices. The strategy consists on the use of a development platform for both simulation and instrumentation. The kernel of this platform was developed under Scilab/Scicos environment. This open-source development tool drives both instrumentation and simulation algorithms. The measurement setup, interfaced within Scilab and dedicated to the system level analysis will be described. Some measurement based models, extracted from this characterization setup, and recent advanced in system level simulation with Scicos will be also presented. The use of Scilab/Scicos for both characterization and simulation enables an "hardware in the loop" in system level simulations in order to allow an high flexibility for device characterization and modeling processes.**

*Index Terms* — **Microwave measurements, modeling, nonlinear circuits, non-linear systems, power amplifier measurements.**

## I. INTRODUCTION

Accurate RF and microwave designs at system level require different formalisms and tools to complete the three main steps which are the characterization, the modeling and the use of the models in a system level simulator. Interactions between those steps make the common tools unsuitable to obtain a good design and accurate results. Therefore, we began the integration of tools in Scilab/Scicos for characterization, modelisation and simulation in order to develop an open research tool which allow to make the various softwares to communicate together.

Scilab/Scicos is a free and open-source scientific environment similar to Matlab/Simulink[TM]. Scilab/Scicos includes a great number of mathematical functions, a high level programming language, the possibility to link interactively programs from various languages, a system simulator (Scicos) and a TCL/TK kernel for GUIs.

## II. SCILAB CHARACTERIZATION TOOL : A TIME DOMAIN ENVELOPE VECTORIAL NETWORK ANALYSER

One improvement in the use of Scilab has been the development of the Scilab GPIB toolbox which enables communication between instrumentation and Scilab via the VISA layer from Agilent or National Instrument.
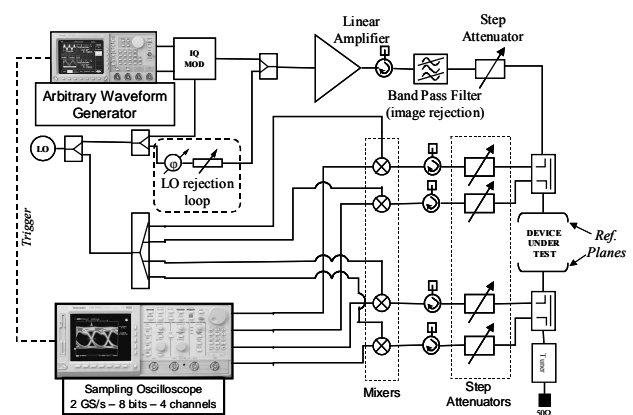


Fig. 1.   Schematic of the time domain envelope VNA

A characterization tool, automated with Scilab, for system level modeling and simulation was presented in [2] at L and S band. This setup can be extended to K band by adding an other translating stage like in [3]. This bench consists of a four channels receiver part and an emitter part.

The emitter part includes an AWG to generates a FI modulated signal, an IQ modulator to transpose this FI signal at RF frequencies, an OL rejection loop and a filter to avoid spurious frequencies at the reference plane. The receiver part measures simultaneously the IF image of the 4 waves (a1, b1, a2 and b2) located at the reference plane. The frequency translation is done with four mixers. The use of four step attenuators optimizes the linearity of the mixers.

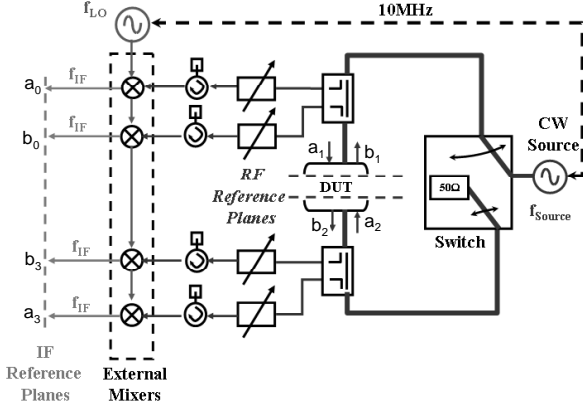## A. Calibration of the receiver part



Fig. 2.    Relative calibration procedure

Because of the four waves are measured simultaneously, we apply a eight terms error model to calibrated the receiver part [4].

Seven terms are obtain from a SOLT relative calibration.

Assuming the 7 error-terms matrix (equation 1) and considering the knowledge of 6 standards (two 'Open', 'Short' and 'Load') we solve the linear system of equations with a least square method.

$$\begin{pmatrix} a_1 \\ b_1 \\ a_2 \\ b_2 \end{pmatrix} = \begin{bmatrix} 1 & \beta_1 & 0 & 0 \\ \gamma_1 & \delta_1 & 0 & 0 \\ 0 & 0 & \alpha_2 & \beta_2 \\ 0 & 0 & \gamma_2 & \delta_2 \end{bmatrix} \begin{pmatrix} a_0 \\ b_0 \\ a_3 \\ b_3 \end{pmatrix} \qquad (1)$$

The linear system may be written $[A].(X)=(B)$ where $(X)$ is the 7 error terms vector as :



Fig. 3.    SOLT-8 Linear system

Here comes $(X) = [[A]'.[A]]^{-1}.[A]'.(B)$ with $[A]'$, the conjugate transpose of $[A]$.

The eighth term, a scalling factor of the matrix (1), is deduced from a power calibration.

Concerning the phase calibration, one assumes that the group delay of one precharacterized mixer (the phase reference one) remains constant in the modulated signal bandwidth.

## B. Calibration of the emitter part

The emitter part is calibrated as a four error terms model : one considers the entire emitter part as a single IQ modulator. Thus, we have to extract a complex gain for each RF way. We assume that the emitter part is linear nevertheless we consider the phase and magnitude unbalance.

The emitter part calibration uses 3 differents multisine signals generated with the AWG. Those multisine have a specific phase draw in order to minimize the crest factor [5] to optimize the AWG dynamic range. The 3 calibrations steps are illustrated in figure 5.
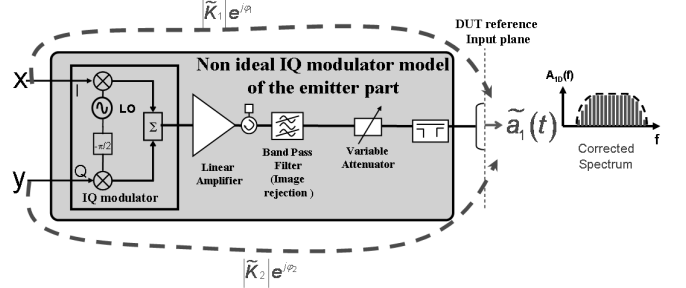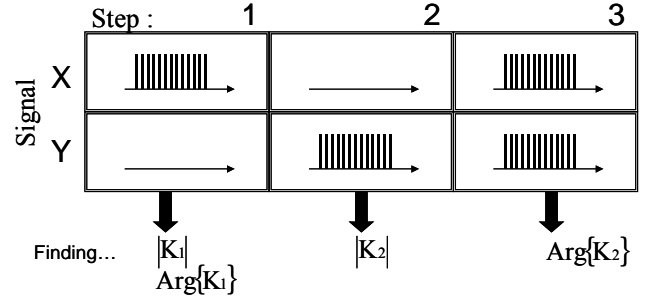


Fig. 4 Emitter part error terms



Fig. 5 Finding emitter part error terms. Signals are illustrated in the frequency domain

This calibration allows us to generate a predistorted IF signal for the AWG in order to drive the device with the exact expected stimulus at the RF reference plane (wave a1). This second calibration becomes of prime importance if we want to use the bench inside a system simulator.

## III.    FROM CHARACTERIZATION TO MEASUREMENT BASED MODELS

The measurement setup allow us a great number of characterizations useful at system level analysis because harmonics are not considerered : [S] parameters for linear systems ; pulsed RF, IM3, CCPR or NPR measurement for non-linear systems are realizable [3]. Most time domain complex envelope modulation may be used with this bench : 16QAM, QPSK, ... .

## A. Fifty ohms system level models

For classical system level simulating process, assuming that each block is 50 ohms matched, one considers only a1 and b2 waves and the measurement setup doesn't require a tuner at the output. Several measurement based behavioral models have been developed in this way among which : a dynamic complex gain, identified with the final application modulation and fitted with a neural network [6] ; a nonlinear impulse response extracted with a Heaviside function [7] ; one Volterra kernel identified with a power and frequency swept CW [8] or a two Volterra kernel identified with two tones (one in large signal, the other in small one) [9].

Those models are based on a relationship between the output voltage (according to a fifty ohms load impedance) and the input voltage. Figure 6 presents the relation for different models. The main issue in the behavioral modelling is to take into account memory effect. Basically, memory effects are functions of both high frequencies (where the signal is located) and low frequencies (implied by RF modulations).

| | |
|---|---|
| $\tilde{x} \rightarrow \boxed{f(|\tilde{x}|)} \rightarrow \tilde{y}$ | AM/AM – AM/PM |
| $\tilde{x} \rightarrow \boxed{f(|\tilde{x}|,\Omega_{RF})} \rightarrow \tilde{y}$ | 1 Volterra Kernel |
| $\tilde{x} \rightarrow \boxed{f\left(|\tilde{x}|,\dfrac{\partial|\tilde{x}|}{\partial t},\dfrac{\partial\angle\tilde{x}}{\partial t}\right)} \rightarrow \tilde{y}$ | Dynamic Complex Gain |
| $\tilde{x} \rightarrow \boxed{f(|\tilde{x}|,t_{BF})} \rightarrow \tilde{y}$ | NL Impulse Response |
| $\tilde{x} \rightarrow \boxed{f(|\tilde{x}|,\Omega_{RF},t_{BF})} \rightarrow \tilde{y}$ | 2 Volterra Kernels |

Fig. 6 Fifty ohms power amplifiers behavioral models for system level simulators

## B. System level models taking into account impedance mismatches

Taking into account the loading impedance of the amplifier under test is necessary to improve measurements in real conditions signal modulations for different SWR mismatches at the output. This is particularly useful when the power amplifier under test is intended to be placed before an antenna whose SWR may strongly change. Some measurement based behavioral models, taking into account input and output voltages but also $\Gamma_{out}$ and eventually $\Gamma_{in}$ have been developed [10]. This model uses the the large signal [S] parameters formalism for the amplifier under test. The relation between scaterring waves is :

$$
\begin{pmatrix} b_1(\Omega) \\ b_2(\Omega) \end{pmatrix} = \begin{bmatrix} S_{11}(\Omega,|a_1|) & S_{12}(\Omega,|a_1|) \\ S_{21}(\Omega,|a_1|) & S_{22}(\Omega,|a_1|) \end{bmatrix} \cdot \begin{pmatrix} a_1(\Omega) \\ a_2(\Omega) \end{pmatrix}
$$
$$
+ e^{j.2\varphi(a_1)} \cdot \begin{bmatrix} 0 & S_{12}^{\Delta}(\Omega,|a_1|) \\ 0 & S_{22}^{\Delta}(\Omega,|a_1|) \end{bmatrix} \cdot \begin{pmatrix} a_1^*(-\Omega) \\ a_2^*(-\Omega) \end{pmatrix} \quad (2)
$$

The six terms can be extracted from measurements. For that purpose, we have to consider either a second signal injected at the output of the device under test [11] or 3 different loading impedance with a passive tuner.

Figures 7, 8 and 9 present measurements results obtained on the HFET SSPA for different frequencies (40MHz around 1.6 GHz) with the second method.
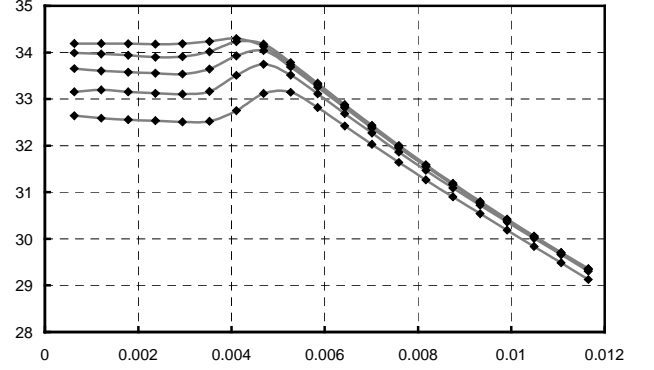

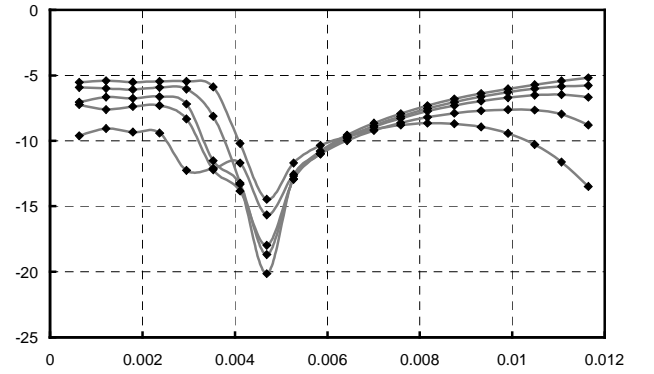
Fig. 7 $S_{21}$ Magnitude (dB) versus the magnitude of a1



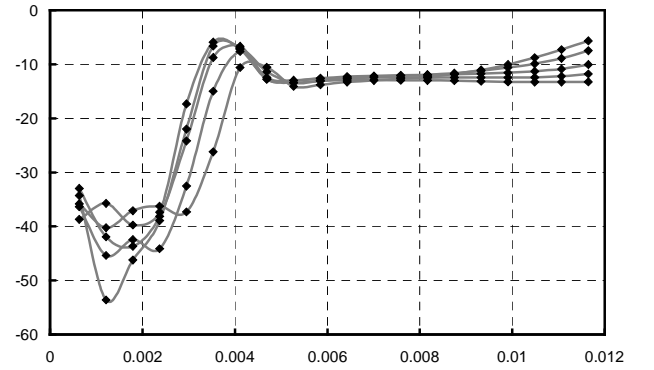Fig. 8 $S_{22}$ Magnitude (dB) versus the magnitude of a1



Fig. 9 $S_{22}^{\Delta}$ Magnitude (dB) versus the magnitude of a1

## IV. A COMPLETE CHAIN SIMULATION WITH SCICOS

A system level simulation tool for RF and microwave devices has been implemented in the Scilab connected object simulator (Scicos) [1]. This toolbox includes many low pass discrete time representation elements as filters, modulators, demodulators, signal and noise generators, samplers but also some analyzers like spectrum analyzers, constellation and eye diagram scopes, or BER calculators [12]. This toolbox is well suited for digital communications system level simulations. Power amplifiers may be included in the chain from their associated models described in the previous paragraph.
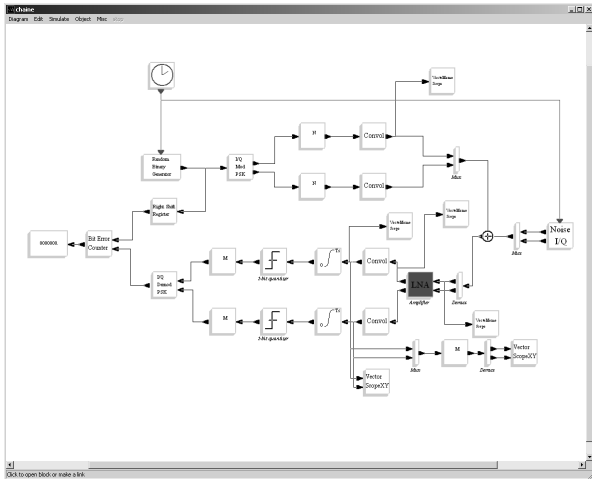


Fig. 10   A transmission chain diagram under Scicos [12]. The amplifier block (red) may be a a system level behavioral model, a circuit level co-simulation principle [8] or a link throught measurements.

If modeling become to complex for a device, one can use either a co-simulation process which enables a link between Scicos and a circuit level simulator [8] or a link in quasi real-time between Scicos and the time domain instrumentation : the "hardware in the loop" process. In this last case, the signal located at the input of the amplifier under simulation is applied to the amplifier under test. This signal is pre-distorted according to the calibration of the emitter part of the bench and sent to the AWG. The calibrated response of the amplifier under test is feed backed to Scicos. Then, the simulation process carry on under the system simulator.  This method provides a friendly environment in order to compare easily and simultaneously a device under test and its associated model with a modulated signal excitation.

## V. CONCLUSION

This paper has presented an overview of the current software development and strategy at XLIM laboratory in order to federate different tools within a system level hierarchic design framework. Scilab/Scicos may be considered as a very efficient tool. Therefore, some Scilab/Scicos toolboxes were presented. Those toolboxes are open source and freely usable and distributable [1].
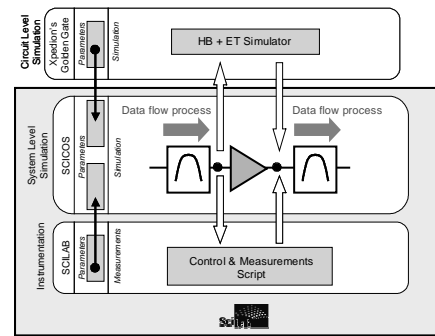


Fig. 11.   Dynamic links between simulation tools and instrumentation

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