Mixed-mode Simulation of RF Communication Link

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Abstract – **Paper describes techniques and example of mixed level mixed mode simulation of complete communication link. Proposed approach uses co-simulation to compute overall link merits, allowing to simulate digital parts of link using existing commercial digital simulator(s) and RF parts using Modulation Harmonic Balance simulator. Simulation example is presented.**

Design of RF link entails significant amount of simulation at different levels. System-level simulation allows estimating design solutions and making first-order estimation of link merits. Basing on system-level design, specifications on constituting blocks are established and those blocks are designed. This outlines top-down "waterfall" design flow. But, most often, such design flow is insufficient, as it does not take into account block interaction and block non-idealities, which may take influence onto complete link merits (like bit or symbol error level, unnecessary RF radiation, etc.). To be sure about system properties, system verification have to be performed, which very often brings to new design iterations. To alleviate that burden, more information about system have to be provided at each design stage. One of possible solutions is to perform simulation at different levels simultaneously – at system level and circuit level.

Complex envelope technique is a most widely used for communication system simulation. According to it, information signal along the system is represented in a form of two orthogonal components – I and Q. After sampling, reaction of nonlinear block to input may be defined as:

$$y_n = m(x_n, x_{n-1}, ..., x_{n-i}, ..)\qquad(1)$$

where l – linear block response, m – nonlinear block function, i – sample number. If blocks constitute directed graph without loops with incidence matrix A, then resulting system response may be written as:

$$Y_n = A \cdot \begin{bmatrix} m_j(y_n, y_{n-1}, ..., y_{n-i}, ..) \\ w_j(n) \end{bmatrix}\qquad(2)$$

where $w_j(n)$ - excitation components at n-th time sample and $m_j()$ - response components, j - component index in a vector.

At circuit level for RF and MW circuits modulation (envelope) harmonic balance (MHB) is looks like most suitable. MHB equations are formulated:

$$F_k(X_l(t)) \equiv$$

$$I_k(X_l(t)) + \Omega Q_k(X_l(t)) + \frac{d}{dt}\, Q_k(X_l(t)) + \qquad(3)$$

$$+ LX_k(t) + M\{\Omega X + \frac{d}{dt}\, X_k(t)\} + U_k(t) = 0$$

Here $X_k(t)$ – k-th harmonic component of unknowns X as function of time t , $I()$ – vector-function of nonlinear responses, $Q()$ – vector-function of reactive nonlinear responses, L and M – matrices of linear components of circuit response: resistive and reactive, Ω - frequencies matrix, $U_k(t)$ – free excitation term, k - harmonic number.

MHB Eq. (3) can be sampled in discrete moments of time of Eq. (2). That will allow substituting terms of Eq. (3) in Eq. (2) composing equations into one system.

Two ready-made components were chosen to build co-simulation system: Matlab/Simulink [10] and Rincon [11]. Simulink - Rincon interaction is built such way, that Rincon is considered as one of the discrete Simulink blocks with fixed signal sampling frequency. Simulink also is used to perform results visualization, as any circuit variable inside Rincon is available in Simulink.

To demonstrate the abilities of implemented co-simulation system, model of communication link with QPSK modulation (Fig. 1) has been simulated. Power amplifier, being represented at circuit level, has been co-simulated with the whole system. Schematic of power amplifier is presented at Fig. 2.

Simulation results are presented at the following figures. Spectrum at input and output of amplifier is presented at Fig. 3 to show regrowth due to amplifier nonlinearities. Signal trajectories before and after amplifier are shown at Fig. 4 and eye diagrams are shown at Fig. 5.

Principles of implementation of multilevel mixed-mode co-simulation environment for communication link simulation are discussed. Viable methods are considered for different levels of representation and ways of their interaction are presented. New implementation based onto proposed approach for co-simulation is described, which allows usage models of different levels. Results are illustrated with mixed-level mixed-mode simulation example, which includes power amplifier operated under complex modulated signals in QPSK RF communication link. Example allows visualizing signal impairments caused by amplifier nonlinearities.
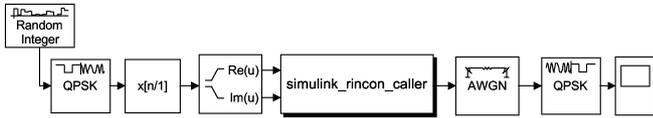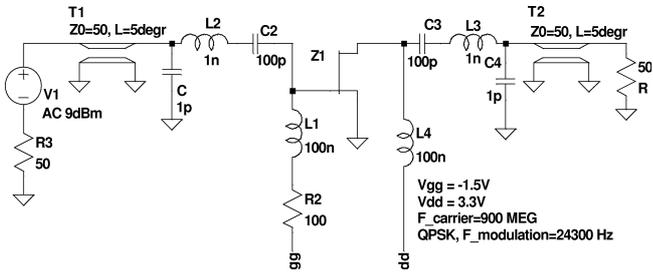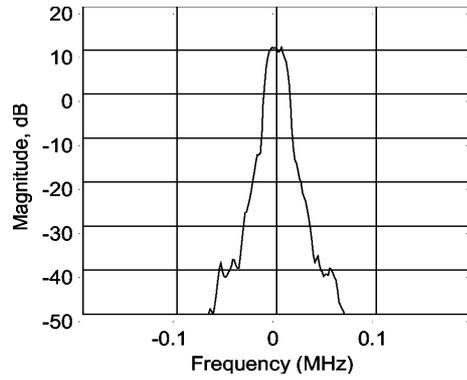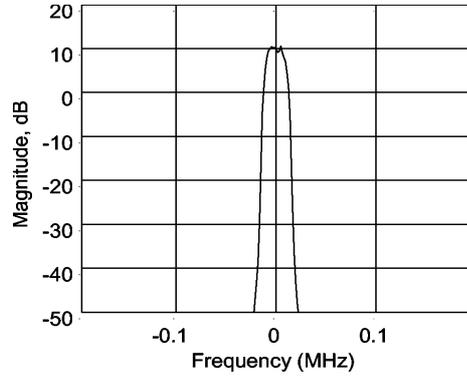
Fig. 2. QPSK Link
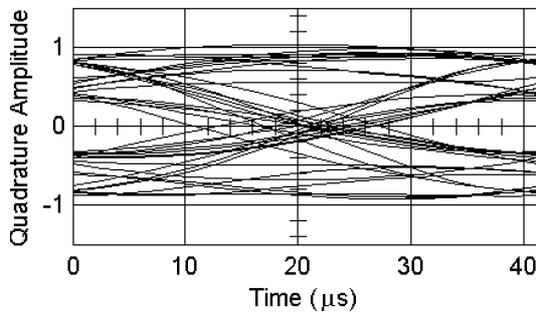

Fig. 2. Amplifier schematic
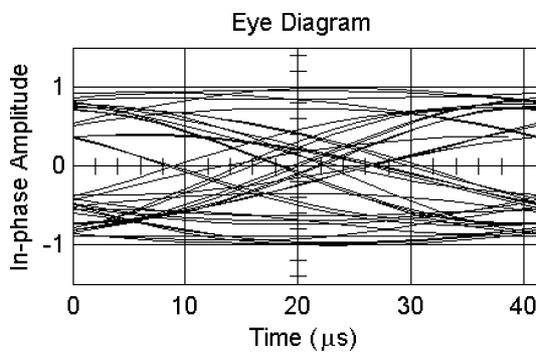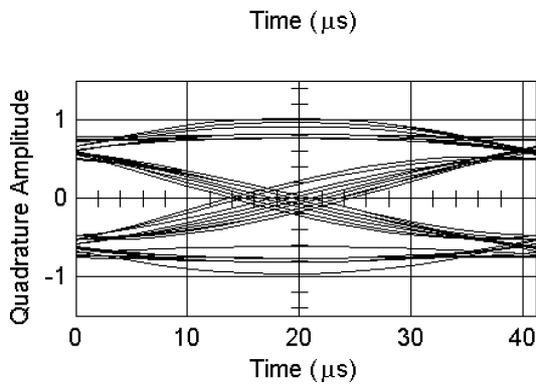

Fig. 3. Input and output amplifier spectra.

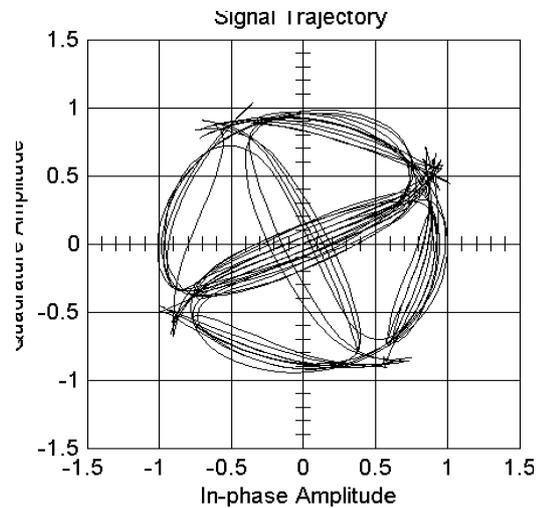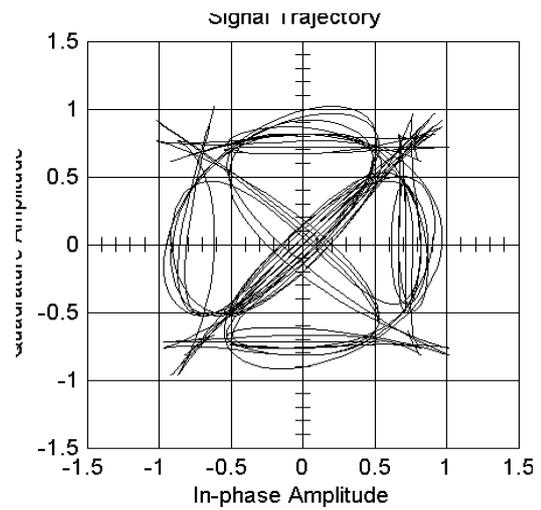Fig. 5. Eye diagrams after filter and after amplifier.

Fig. 4. Signal trajectories after filter and after amplifier.