Analogue-Digital Simulation of Radio Frequency and Baseband Circuitry via Simulator Coupling

Steiger Martin[1], Brachtendorf Hans-Georg[1], and Bittner Kai[1]

University Of Applied Sciences Upper Austria, Hagenberg

Summary. This paper presents a methodology to perform both mixed-signal analogue-digital and radio frequency-baseband signal processing at the same time. To this end, the analogue circuit simulator LinzFrame has been coupled with MATLAB. The analogue circuitry both at radio frequency (RF), intermediate frequency (IF) and baseband is simulated by LinzFrame, whereas the digital baseband signal processing etc. by MATLAB, employing its full functionality of its toolboxes. Therefore this simulator coupling enables a mixed-mode analogue-digital simulation of radio frequency front-ends and the digital signal processing at the same time. Applications include non-linear distortion analysis, digital pre-distortion techniques, coexistence analysis of mobile communication standards etc.

1 Problem Statement

Common analogue circuit simulators like Spice [7] perform outstandingly well for low frequencies, but when it comes to high frequency applications, a vast number of problems occur. For example, Spice suffers from undesired oscillations which arise from too ideal component descriptions or numerical noise, which makes it difficult for the linear equation solver to converge to the expected accuracy. Moreover, transient analysis suffers from runtime efficiency at high frequencies due to the Nyquist-Shannon-Whittaker sampling theorem bottleneck. Therefore, new techniques have been developed such as multi-tone harmonic balance [3, 5, 9]. These techniques are, e.g., available in commercial circuit simulators such as SpectreRF, AWR Aplac, and Eldo RF. On the other hand, the digital counterparts like the SystemC derivatives [1] provide a wide variety of mixed-signal capabilities, also including digital signal processing methods, but are rather unsatisfying when it comes to digital system design. Different libraries are available, e.g. the SystemC AMS Building Block Library [2], to make those approaches more suitable for this task, but they are still depending on external toolboxes to design pulse shaping filters, special transmission channels or matched filters within the receivers. To perform a complete transmission system design, including the analogue radio frequency transmitter/receiver architecture and the digital signal processing blocks, a combination of multiple tools is necessary. In order to address these shortcomings, the already existing radio frequency circuit simulator LinzFrame has been extended with different types of digital signal sources. This integrates the signal processing blocks directly into the circuit as voltage or current sources operating in symbol cycles. Currently a vast number of signal sources is available ranging from simple binary phase shift keying sources (BPSK) with rectangular pulse shapers to advanced multicarrier OFDM (orthogonal frequency division multiplexing) [6] methods with RRC pulse shapers, which is the current state of the art for mobile radio applications. Coupled with the already existing functionality of LinzFrame, a powerful toolbox, has been developed to perform accurate and fast circuit simulations. However the actual core novelty of this extension is the included MATLAB interface, which leads towards a simplified modelling methodology. It is possible to implement and reconfigure all kinds of digital components through a dedicated interface. One application is the analysis of coexistence and interference analysis in the presence of non-linear distortion caused by the analogue parts. Traditional techniques employ behavioural modelling of the analogue components by so-called X-parameters [8]. However, this modelling technique is error prone. This tool enables the simulation on transistor level without the limitations of behavioural modelling.

2 Structural Design

The essential structure of the toolbox consists of four different parts which operate independently. LinzFrame handles and manages the communication between other components of the toolbox and provides interfaces for a various amount of class libraries and subcomponents [4]. In order to solve the linear and non-linear systems of equations, which arise during the analysis of digital and analogue circuits, different numerical solvers are addressable through the LinzFrame interfaces. To conclude, the actual innovation of this work refers to the last two components, namely MATLAB or its open source pendant GNU Octave, which are referred to as M/O in this paper and the corresponding interface to LinzFrame. The main goal is to extend the various functions of M/O to the field specialized in LinzFrame, namely the analysis of analogue circuits. In addition, various digital signal sources can be controlled and configured more easily in M/O, because it provides additional DSP toolboxes. To clarify the structural communication flow between LinzFrame

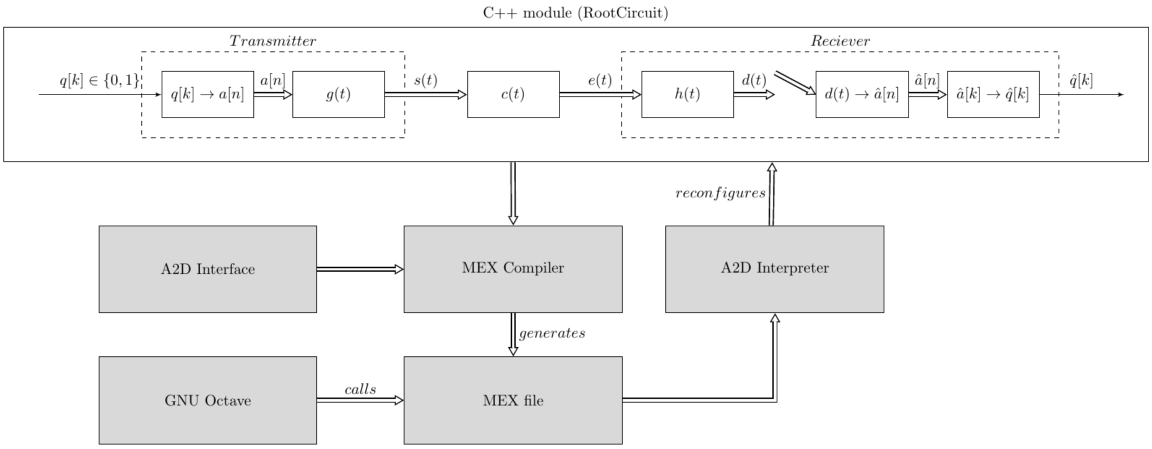

Fig. 1. Internal structure of the A2D interface

and M/O, it is reduced to several simple tasks, which are described in Section 3.

3 Analogue-To-Digital Interface

LinzFrame is essentially based on an extensive collection of C++ classes. In combination with the internal circuit parser, this classes enable a vast circuit analysis. The majority of these configurable classes are based on *ParMap*, which enables the user to include any number of named parameters. In the classes derived from ParMap, functionality of the corresponding parameters are defined. The novelty of the presented toolbox lies in the communication between the C++ components and the A2D-compatible classes and MATLAB or GNU Octave. Both tools provide the mex file format, which allows the integration of external C++ code into the tool environments. In brief, a so-called analogue-to-digital (A2D) interpreter was integrated in LinzFrame for both tools, which manages and processes the communication between the classes from LinzFrame and the tool environments. This interpreter can execute various commands based on the respective transfer parameters from M/O, such as changing circuit parameters, time step configurations for the subsequent analogue simulation or utility specific functions. M/O serves as master which initiates communication in this structure. The communication flow is also displayed in Figure 1. Due to the unique naming convention introduced in *ParMap*, all circuit devices can be accessed using the interpreter independently from their rank within the call hierarchy. After the analogue simulation in LinzFrame has finished, there are different options how to proceed. The generated logfiles to access the generated results in M/O and the A2D interpreter provide appropriate values, which may be processed within M/O. With the information obtained, the A2D-compatible blocks can now be reconfigured as required. Depending on the circuit, basic properties such as the digital transmission modulation scheme used or the sampling frequency can also change.

Acknowledgement. This project InterOP ATCZ175 has been co-financed by the European Union using financial means of the European Regional Development Fund (INTERREG) for sustainable cross boarder cooperation. Further information on INTERREG Austria-Czech Republic is available at `https://www.at-cz.eu/at`.

References

1. IEEE standard for standard SystemC language reference manual. *IEEE Std 1666-2011 (Revision of IEEE Std 1666-2005)*, pages 1–638, Jan 2012.
2. Standard SystemC AMS extensions 2.0 Language Reference Manual. *Accellera Systems Initiative*, pages 1–212, 2016.
3. P. Feldmann and J. Roychowdhury. Computation of circuit waveform envelopes using an efficient, matrix-decomposed harmonic balance algorithm. In *Proc. ICCAD-96*, 1996.
4. H. G. Brachtendorf K. Bittner and W. Schoenmaker. Linzframe - a modular mixed-level simulator with emphasis on radio frequency circuits. pages 1–2.
5. K. S. Kundert, J. K. White, and A. Sangiovanni-Vincentelli. *Steady-State Methods for Simulating Analog and Microwave Circuits*. Kluwer Academic, Boston, 1990.
6. P. Massoud Salehi and J. Proakis. *Digital Communications*. McGraw-Hill Education, 2007.
7. L. W. Nagel. *SPICE2: A simulation program with integrated circuit emphasis*. PhD thesis, May 1975.
8. J.C. Pedro, D.E. Root, J. Xu, and L.C. Nunes. *Nonlinear Circuit Simulation and Modeling: Fundamentals for Microwave Design*. The Cambridge RF and Microwave Engineering Series. Cambridge University Press, 2018.
9. V. Rizzoli, D. Masotti, F. Mastri, and E. Montanari. System-oriented harmonic-balance algorithms for circuit-level simulation. *Computer-Aided Design of Integrated Circuits and Systems, IEEE Transactions on*, 30(2):256 –269, feb. 2011.