

Development of Educational Software for Mixed Signal Design in Electronic Engineering

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Abstract

In engineering education, an understanding of the operation and design of an Analog to Digital Converter (ADC) will equip students with essential knowledge, particularly in electronics. ADC circuit is a type of analog and mixed signal (AMS) circuit, where in this paper, the Sigma Delta ADC is chosen as a study case. Instructional software is an education tool that could enhance students' learning process, and can be used to highlight the key areas of mixed signal design. Additional detailed information will be created through the use of simulation and verification tools with specific examples of mixed-signal design. These include problems in mixed signal design methodologies and flows, modeling and verification. The goal is to provide real world examples and hands on experience for students who will have access to the educational material through software modules and be able to customize their learning experience to meet specific needs.

Keywords: engineering education; mixed signal design; software module

1. Introduction

From the point-of-view of education, an understanding of the operation and design of an ADC will equip students with much essential knowledge, particularly in electronics.

Propagation of ADC performance characteristic when documented and presented carefully to students (in medium to advanced level of tertiary education) can be used as instructional software that is an education tool that could enhance students learning process [1,2]. Also, the documentation of the experience of a full-custom integrated circuit (IC) design, from system-level specification to transistor-level implementation, and from layout to the final measurement of a fabricated ADC, shall be a valuable method of knowledge transfer to students.

Computer-aided software provides an effective way to improve the quality of understanding in education. The procedures involved in the development of instructional software including design approach and simulation. The courseware links the theory and the concepts thus helping the students not to only visualize but also to retain key concepts and solution procedures.

There is practical application based multimedia developed by the CAEME Center for education [3]. Application is used as a concrete means of demonstrating the material being taught. Several

video clips involving various simulations are used as a mean to illustrate the flow of the process involved.

In [4], animated instructional software is used to teach a subject that involved components of three dimensional (3D) objects. This subject is generally taught through static two dimensional illustrations in classroom. Using computer based instruction offers new capabilities that can enhance the student's understanding. With 3D modeling and rendering software, it is possible to create photo realistic images of various components. From this project, students reported that using the software helped them to feel more confident and become interested in the course.

Some results based from [5], suggest that undergraduates are capable of learning appropriately selected topics in mixed signal IC design is a reasonable approach. Mixed signal design requires a command of analog and digital IC design which has made teaching this topic to undergraduate students a challenge. The technique used to help students feel more comfortable with this complex material is multiple hands on experiences in classroom and laboratory.

This paper presents the details of the hands on experiences in developing instructional software.

2. Literature review

2.1 ADC Design Architecture

Distinguish by sampling rate, ADC can be classified in to Nyquist rate converters and oversampled converters. For this paper, the ADC design architecture chosen is oversampled converter, Sigma Delta which is the most commonly used ADC.

The sigma-delta architecture takes a fundamentally different approach from those outlined above. In its most basic form, a sigma-delta converter consists of an integrator, a comparator, and a single-bit DAC, as shown in Figure 1. Main components in ADC are amplifier, integrator and comparator.

The operational amplifier that the integrator uses must have high gain to effectively carry out a smooth integration, as well as a large enough bandwidth to support the high frequency square waves it will be integrating. The performance of many circuit is influenced by the operational amplifier performance operational amplifiers have sufficiently high voltage gain so that when the negative feedback is applied, the closed-loop transfer function can be made practically independent of the gain of the op-amp. The comparator plays an important role in analog to digital converter. It will be the major factor determining how accurately and how quickly analog signal processing can be accomplished.

A Sigma Delta ADC oversamples the desired signal by a large factor and filters the desired signal band. Sigma Delta ADC has the capability of trading off speed for resolution [6].

In term of advantages, Sigma Delta ADC offer improvement for circuitry imperfections, noise shaping and high frequency operation features.

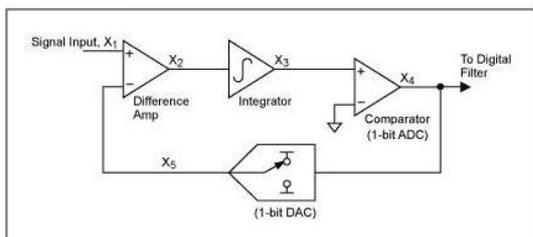


Figure 1 Block Diagram of Sigma Delta ADC [7]

3. Design approach

3.1 Top down approach

Top down approach is a design methodology that is useful when designing large complex systems [8]. The basic concept is to design and

verify the system at block diagram level before starting with the detailed specification. With top - down design, the individual block performance needed to meet the overall system performance requirement is carefully studied and understood before the blocks are developed. This avoid the over design problem of the individual blocks. But, the risk is if the required performance is unachieved, need to redesign the blocks.

The use of behavioural models helps in achieving the target. Behavioural simulators work much faster than the transistor level counterparts thus permitting to explore all the regions of operation. Moreover, designer can use the electrical design features such as the gain, the bandwidth, the offset, and the parasitic elements as parameters of the behavioural model.

Therefore, the behavioural simulation allows the designer to estimate the effect of basic blocks limitations on the ADC performances. Also, the specifications of the data converter permit to extract the electrical specifications of the building blocks.

For mixed-signal problems or ADC specifically, there are several languages or tools available to construct behavioural models, such as Very high speed integrated circuit Hardware Description Language Analog Mixed Signal (VHDL - AMS), MATLAB, Synopsys Design Compiler and Mentor Graphic.

3.2 Bottom up approach

Bottom up approach means the designer design the ADC from circuit level or the structure of the original circuit is preserved. Using bottom up approach, designer needs to fully design the individual circuit that build the system.

Bottom up approach mostly did in over designed characteristics [9] to ensure enough margin if unexpected problem happen. If the system specification not achievable after the design, the circuit needs to redesign. For transistor level modelling, there was simulation software that able to simulate the design such as LTSPICE, PSPICE, and etc.

4. Simulation of Sigma Delta ADC

In this section, Sigma Delta ADC is simulated from transistor level to layout. The simulation tools that being used are MATLAB, LTSPICE and Mentor Graphics. In Section 4.1, MATLAB simulation 2nd order Sigma Delta ADC and its nonidealities is simulated using model based by S. Brigati [10]. In 4.2, operational amplifier and comparator in 2nd order Sigma Delta ADC is simulated using LTSPICE. While in 4.3, for layout simulation, 1st order Sigma Delta ADC simulated using Mentor Graphics. Sigma Delta ADC is

designed in standard TSMC 0.25 process technology.

4.1 MATLAB Simulation

As one of the key components in signal processing system, ADC device plays a fundamental role in interfacing the processing core with the analog world. High speed and resolution applications require ultrahigh linearity, but ADC linearity often degrades due to nonlinear errors. If ADC nonlinear behavior could be accurately modeled, several ADC nonlinear error correction methods could be adopted to compensate them in order to increase the converter dynamic range. Therefore, many efforts are devoted to the ADC modeling, capturing the nonlinearities.

In this project, the case study of second order sigma delta ADC were simulated in system level by using Matlab & Simulink to analyze the performance of ADC. Sigma delta ADC is well suited for low bandwidth, high-resolution and acquisition. High resolution ADC provides higher accuracy of data that convert analog signal to digital signal. In sigma delta ADC, the performance will be evaluated in SNR, SQNR, ENOB, NTF, STF, INL and DNL.

To validate the models proposed of the various non-idealities affecting the operation of a sigma delta modulator, we performed several simulations with SIMULINK on the 2nd order modulator shown in Figure 2, where only the non idealities of the first integrator were considered, since their effects are not attenuated by the noise shaping.

Figure 2 showed the nonlinearities model based on SIMULINK that introduced by S. Brigati [10]. This model allow us to perform exhaustive behavioral simulations of any Sigma Delta ADC taking into account most of the non idealities.

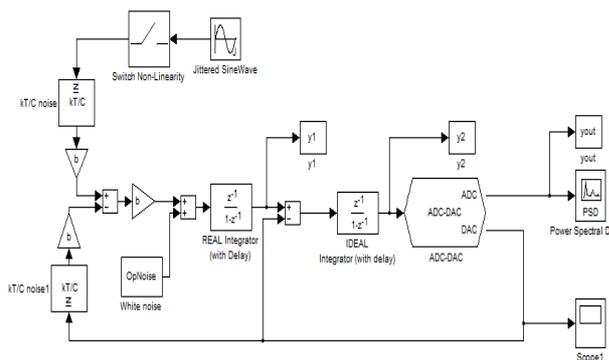


Figure 2 Nonidealities model in SIMULINK

Figure 3 showed the simulation result of nonlinearities including sampling jitter, kT/C noise and opamp noise. The graph is represent in power spectral density which is PSD (decibels) versus frequency (Hertz).

The power spectral densities (PSD) at the output of the modulator, when two of the most significant

non-idealities in the first integrator are taken into account, with the PSD of the ideal modulator. The spectra put in evidence how the kT/C noise increases the in-band noise floor, while the slew-rate produces harmonic distortion. It must be noted from the results that the non-ideal effects resulting from practical circuit limitations add up and contribute to increase the in-band noise-plus-distortion and, therefore, can become a severe limitation to the performance achievable from a given architecture. The models using in this paper is allowed to carefully predict, at the behavioral level, the performance of the real modulator.

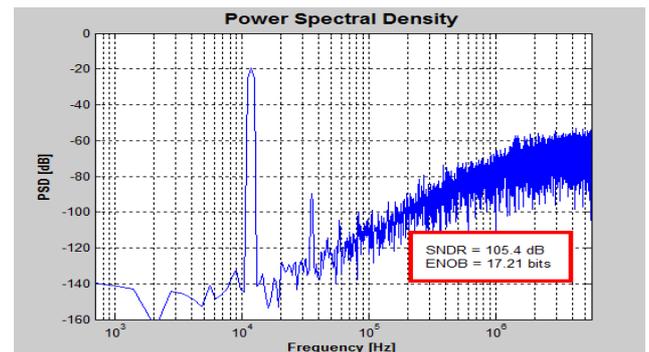


Figure 3 Simulation results of nonidealities

4.2 SPICE Simulation

In this section operational amplifier and comparator of 2nd order Sigma Delta ADC is simulated using LTSPICE.

4.2.1 Operational amplifier in LT Spice simulator

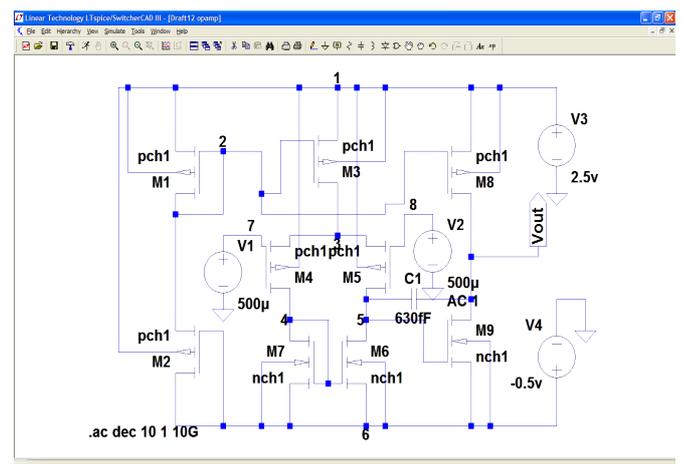


Figure 4 Schematic of 2 stage Operational amplifier in LT Spice

4.2.2 Comparator in LT Spice

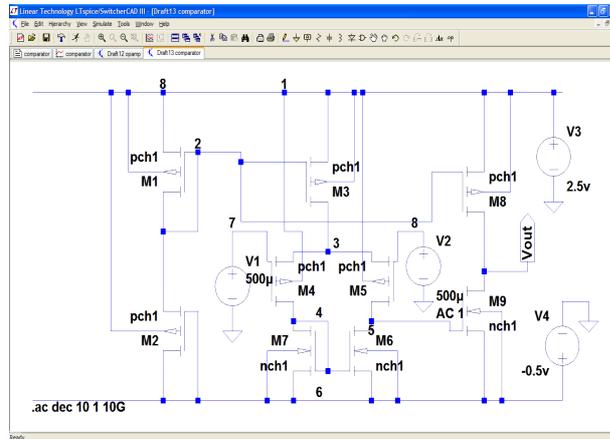


Figure 5 Schematic of 2 stage Comparator in LT Spice

The analysis in LT Spice used to determine the saturation mode, generate the AC gain, and generate the unity gain bandwidth. For analysis of circuit design, 2 type of analysis had been set up which include open loop gain, gain bandwidth (GB), phase margin (PM) and slew rate.

The choice of amplifier topology plays a critical role in a low-voltage, low-power integrator design. The desired main characteristics include maximum output swing, minimum number of current legs from a power-dissipation perspective, high gain for the linearity, enough bandwidth with high slew-rate and a minimum number of devices that contribute significant thermal noise.

4.3 Layout

In this section operational amplifier and comparator of 2nd order Sigma Delta ADC is simulated using Mentor Graphics. Figure 6 shows the layout of Operational Amplifier. The labels of M1 to M9 transistors refer to schematic of Operational Amplifier in figure 4. Figure 7 shows the layout of Comparator. The labels of M1 to M9 transistors refer to schematic of Comparator in figure 5.

4.3.1 Design and simulation of the schematic of Operational Amplifier and Comparator in Mentor Graphics

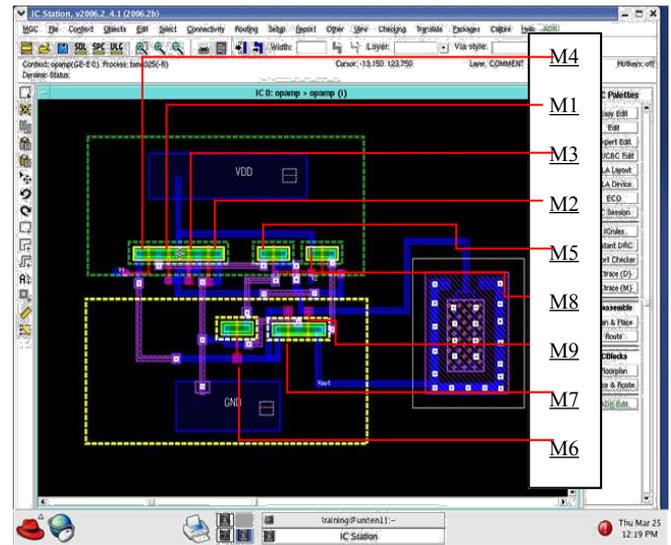


Figure 6 Layout of Operational Amplifier

Figure 6 shows the layout of Operational Amplifier. The labels of M1 to M9 transistors refer to schematic of Operational Amplifier in figure 4.

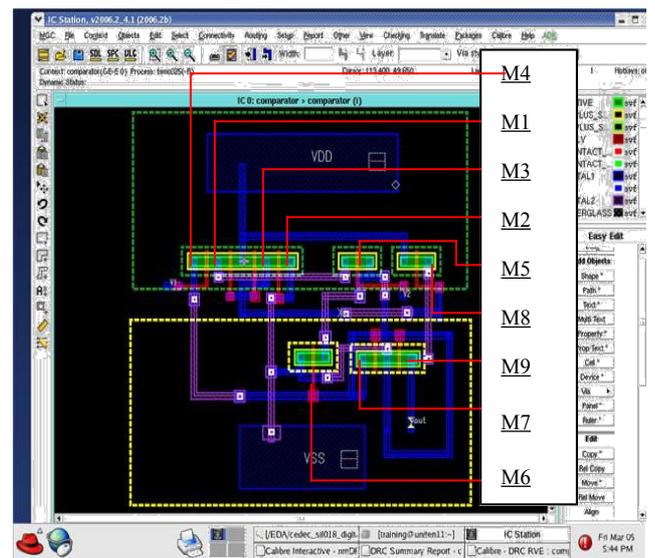


Figure 7 Layout of Comparator

The only difference in operational amplifier and comparator is that comparator doesn't require the compensation capacitor which is required by the operational amplifier.

4.3.2 Preparation for layout of first order modulator

Figure 8 shows the overall layout diagram of first order modulator with the no error DRC (Design Rule Check). The overall area for the layout is 0.739mm x 0.745mm.

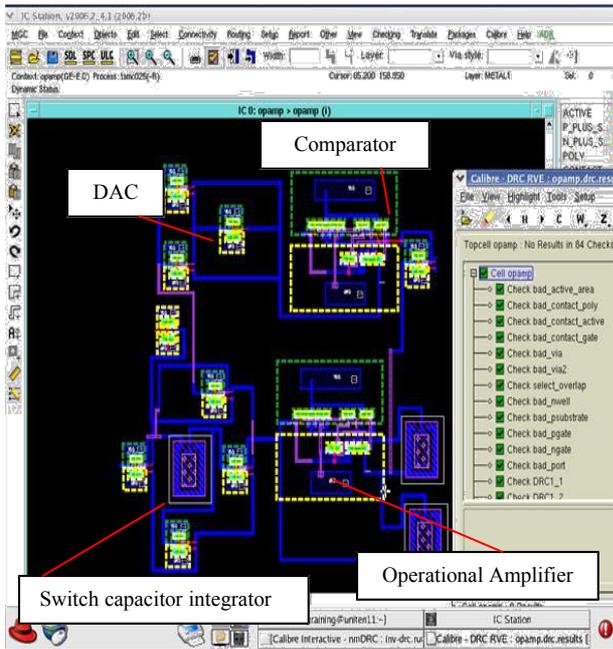


Figure 8 Full layout diagram of first order modulator in Mentor Graphics

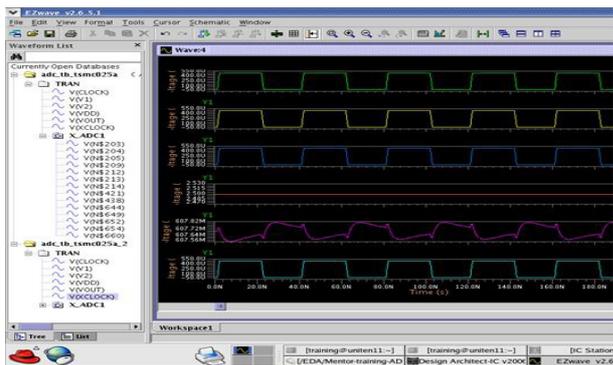


Figure 9 Pre-simulation result for first order modulator in Mentor Graphics

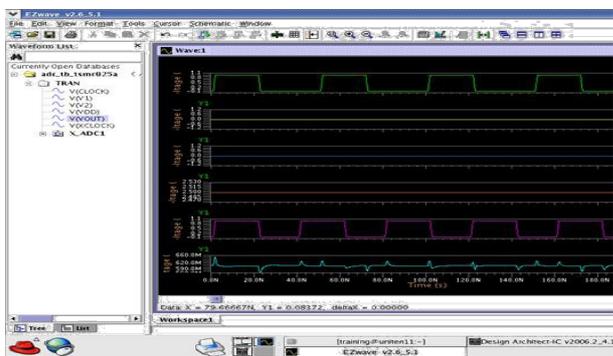


Figure 10 Post simulation result for first order modulator in Mentor Graphics

By doing comparison of output voltage waveform of pre-simulation result in figure 9 and the output voltage waveform of post simulation in figure 10, the waveform of pre-simulation is better

than the output waveform of the post simulation. The pre-simulation result is obtained direct from the schematic of the first order modulator, while the post simulation is obtained from the layout of first order modulator. The post simulation result is expected worst than the pre-simulation, because the result from post simulation is affected by the design of the layout. The output waveform result in post simulation can be improved by a better design of layout, and the output voltage waveform of pre-simulation can be improved by using the second order modulator or higher order modulator to improve the stability of the sinusoidal waveform.

5. Instructional software

In order to cover the major topics outlined in previous sections, a set of instructional software will be generated to highlight the key areas of mixed signal design. Additional detailed information will be created through the used of simulation tools and examples of mixed signal architecture. An outline of the material covered [11]:

- 1: Familiarity with workstations, introduction of the circuit example, the hardware description language, introduction to the simulation system.
- 2: Construction of the layout system
- 3: Completion of the circuit layout including pads, extraction and simulation
- 4: Introduction to schematic capture, repetition of the design example using schematic capture

The design specifications have to be chosen very carefully to produce a target which is realistic from both the functional and the teaching points of view. The targets of this educational exercise are:

- (i) To give students some practical experience of IC design
- (ii) To introduce students to a practical CAD system of IC design
- (iii) To expose students to the constraints and difficulties of carrying out a design
- (iv) To allow students the satisfaction of completing a realistic and potentially useful logic IC design

The courseware design has to be as simple as possible. User can easily choose which simulation to play from the courseware. Once the user chooses, the courseware will play the selected project title. The order of each design flow is shown in figure 11.

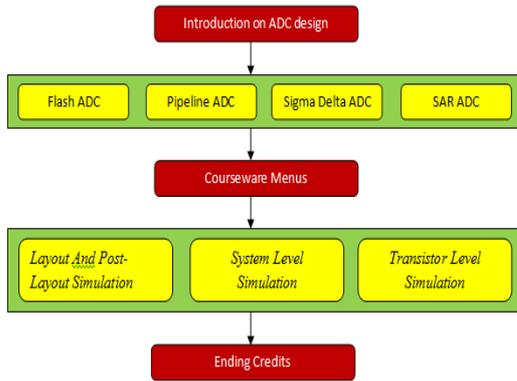


Figure 11 Courseware content

6. Conclusion

Instructional software is being developed in the area of mixed signal design. The material covered is fundamental in electronic design. The goal is to provide real world example and hands on experience for students who will have access to the educational material and be able to customize their learning experience to meet specific needs.

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