Modeling, Simulation and Synthesis of Continuous-Time ΣΔ modulators

International Mobility Report

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1 Introduction

This report documents a mobility internship carried out in Seville, Spain, at the *Instituto de Microelectrónica de Sevilla* (IMSE). The motivation for undertaking an internship abroad was driven by a desire to gain international research experience, broaden my technical and cultural horizons, and work in a renowned microelectronics laboratory. As a graduate engineering student, I wanted to apply my academic knowledge in a real-world project while also improving my professional skills in a new environment. The opportunity to join IMSE for this internship came through a mobility program, and I was eager to learn from experts in the field of mixed-signal integrated circuit design.

Seville, the host city, offered a vibrant cultural and lifestyle experience that greatly enriched my stay. As the capital of Andalusia in southern Spain, Seville is known for its rich history, warm climate, and lively traditions. During my stay, I experienced the city's famously hot summer climate, which created a bright and energetic atmosphere. The local lifestyle in Seville is relaxed and family-oriented: people typically enjoy late-evening gatherings over tapas, lively flamenco music, and a friendly social scene. I found the Sevillian culture to be welcoming and festive, with events like summer ferias and weekly cultural activities that allowed me to immerse myself in Spanish traditions outside of work.

The internship took place at IMSE-CNM, a joint research center of the Spanish National Research Council (CSIC) and the University of Seville. IMSE is a medium-sized research institute (approximately one hundred members including scientists, engineers, PhD students, and technical staff) specializing in microelectronic circuit design and test. The institute's focus areas are analog and mixed-signal integrated circuits, data converters, RF and communications circuits, and emerging technologies. Within IMSE, research teams are organized into groups that collaborate on projects ranging from sigma-delta analog-to-digital converters (ADCs) to neuromorphic circuits. The team dynamics at IMSE struck me as very collaborative and academically stimulating: senior researchers guide projects alongside graduate students and interns, creating a learning environment where open discussion and knowledge sharing are encouraged.

My hosting lab at IMSE was the **Data Converters** group, which concentrates on the design of high-performance ADCs, particularly Sigma-Delta Modulators (SDMs). The working environment in this lab was both welcoming and technically rigorous. I was introduced to a structured workflow from the outset: I had a dedicated desk with the required computing resources and was given access to the Cadence design tools used by the team. The lab operates in such a cohesive and harmonic workflow; regular group meetings were held to discuss progress, challenges, and next steps for ongoing projects. I was assigned a mentor (a junior engineer) who supervised my work, helped me with several problems and integrated me into the team's activities. This supportive environment, combined with IMSE's state-of-the-art facilities, provided an ideal setting for me to learn and contribute during my internship.

2 Scientific Project Description

The core of my internship project was the **development of design automation flows for Sigma-Delta Modulators (SDMs)** using Python scripting alongside Cadence Spectre/OCEAN tools. Sigma-Delta modulators are a class of oversampling ADCs that achieve high resolution by trading off speed for accuracy; they are widely used in applications like audio ADCs and sensor interfaces. Designing such modulators involves careful selection of parameters and evaluation of performance metrics (such as Signal-to-Noise Ratio, linearity, etc.), which can be time-consuming if done manually. My project aimed to automate significant parts of this design and simulation process, thereby accelerating the evaluation of different modulator architectures and their non-idealities.

In practical terms, the project required me to bridge the gap between high-level design ideas and circuit-level verification by creating scripts and tools that run simulations automatically and process the results. The tasks I performed over the course of the internship included:

- **Behavioral modeling of SDMs in Cadence Spectre:** I built simplified schematic models of various Sigma-Delta modulator architectures (e.g., second-order and third-order loops in different topologies like CIFB/CIFF) using Cadence Spectre, an analog circuit simulator. These models included ideal functional blocks as well as controllable non-idealities (such as finite op-amp gain, bandwidth, thermal noise sources, etc.) to allow realistic performance evaluation at the system level.
- **Dataset verification via automated OCEAN simulations:** I developed OCEAN scripts (Cadence's scripting interface for simulations) to automate the process of sweeping through many design configurations. This involved writing a script to read a dataset of modulator design parameters (such as bias currents, capacitor values, and device settings), run a Spectre transient noise simulation for each set of parameters, and record the output performance metrics. The script leveraged loops and file I/O to systematically vary parameters and capture results like the output spectrum, SNR, and SNDR for each simulation. By automating this, I could verify large datasets of design points without manual intervention, ensuring consistency and saving a great deal of time.
- **Topology-aware simulation flows:** Because different modulator topologies or circuit implementations might require slight modifications in simulation setup (for example, a Gm-C integrator vs. an Active-RC integrator, or single-ended vs. fully differential circuits), I made the automation flow adaptable to these differences. I structured the simulation scripts and configuration files to be modular, so that key settings (such as which net to probe for output, or which noise injection files to include) could be adjusted based on the topology under test. This flexibility allowed the same overarching flow to be reused for various designs by simply changing a configuration or dataset file, making the automation "topology-aware."
- **Creation of a Python GUI for simulation sweeps:** To make the tools more user-friendly for the research team, I created a Graphical User Interface in Python that serves as a front-end to the OCEAN simulation scripts. Using Python (along with libraries such as PyQt or Tkinter for the interface), I built a simple application where a user can select a particular modulator design, set ranges or lists of values for certain design variables, and then launch the automated sweep of simulations with a button click. The GUI interacts with the underlying scripts (by generating the required input files or invoking the Cadence tools via command line), and it presents a summary of results once simulations are complete. This interface significantly simplifies configuring simulation runs, especially for team members who are less comfortable editing script files directly, thereby lowering the barrier to using the automated flow.

By completing these tasks, I effectively developed a small "design automation framework" for Sigma-Delta modulator analysis. Over the internship period, we applied this framework to existing modulator designs in the lab's library to validate its effectiveness. For example, I was able to automatically sweep an entire dataset of a second-order $\Sigma\Delta$ modulator design, varying parameters like the op-amp gain and bias current, and observe the impact on SNR and stability for each case. The automated runs produced logs and result files (CSV data and plotted FFT spectra) that we then examined to draw conclusions about design trade-offs. This not only saved the team countless hours of manual simulation effort but also provided insights into how certain parameters influence performance in a systematic way.

Throughout the project, I gained significant technical knowledge and skills. I became proficient with Cadence Spectre for analog simulations and learned to write effective OCEAN scripts in SKILL language to control those simulations programmatically. I also improved my Python programming abilities, particularly in the context of EDA (Electronic Design Automation) tool integration and GUI development. More broadly, this project deepened my understanding of signal processing and data converter theory: for instance, I learned how oversampling ratio and loop filter architecture in an SDM affect the noise shaping and, ultimately, the converter's resolution. I also learned best practices in testbench scripting and data management, ensuring that simulation conditions were consistent, results were logged clearly, and that the framework could handle exceptions or simulation errors robustly. In summary, the scientific project allowed me to apply both circuit design knowledge and software development skills, reinforcing the importance of automation and careful verification in modern analog/mixed-signal design flows.

3 Personal Reflection

Beyond the technical accomplishments, this internship was a formative personal and professional experience. One key skill I acquired was rigorous **documentation habits**. Given that my work would be used by other team members, I maintained a detailed log of my procedures and wrote clear user guides for the scripts and tools I developed. I learned to document not only the "how" of using a tool, but also the design decisions and assumptions behind it. This habit improved my ability to communicate complex information clearly and will be invaluable in my future projects.

I also greatly improved my ability to **automate workflows** and handle complex engineering tasks systematically. Before this internship, I tended to perform many design tasks manually; by the end, I was much more comfortable writing scripts or programs to automate repetitive tasks. I realized the value of investing time upfront to create automation, as it pays off with faster iterations and fewer human errors. In particular, coupling a front-end interface (the Python GUI) with a back-end simulator taught me how to connect different components of a workflow into a cohesive tool. This front-end/back-end coupling experience is something I consider a highlight of my new skill set – it taught me how to make engineering tools more accessible and user-friendly without sacrificing functionality.

Working in a new research environment also honed my **teamwork and collaboration skills**. Initially, adapting to the IMSE lab meant understanding new protocols and software tools, as well as integrating into an existing research team. I made a conscious effort to communicate regularly with my supervisor and colleagues, updating them on progress and asking for feedback or advice when I encountered challenges. Through this process, I became more open to constructive criticism and learned how to iteratively improve my work based on team input. I also had the chance to assist a fellow student with using my Python GUI tool, which was a rewarding experience in mentorship and reinforced my understanding through teaching. The collaborative atmosphere at IMSE – from informal brainstorming sessions to formal project meetings – taught me how effective teamwork can accelerate problem-solving and innovation.

Adapting to life and work in Seville, away from my familiar home environment, was a valuable personal growth experience. I had to step out of my comfort zone – for example, navigating daily life in Spanish and adjusting to different work routines. Over time I became more confident in my ability to operate independently in a foreign setting. I found that being proactive in socializing not only enriched my cultural understanding but also created a support network that made the adaptation smoother. This internship reaffirmed the importance of cultural adaptability when working in an international context. I learned to appreciate different perspectives and ways of doing things, which is crucial in today's global engineering field.

In conclusion, this mobility internship at IMSE in Seville had a profound impact on my development as an aspiring engineer. Technically, it strengthened my expertise in mixed circuit simulation and automation, giving me practical experience in bridging hardware design with software tools. Personally, it broadened my horizons: I not only explored a new city and culture, but I also gained confidence in my ability to collaborate and contribute in a professional research team. The experience has shaped my view of engineering practice: I now understand how important continuous learning and adaptability are in solving those challenges. Furthermore, the internship has inspired me to pursue future opportunities that combine **research and development** across disciplines (electronics and software). Overall, the internship was a rewarding journey of growth, and it has prepared me for the next steps in my engineering career with a more mature perspective and bolstered professional skill set.