CSE 593 - Introduction to VLSI Electronics with Professor Sridhar

As someone with a keen interest in using microcontrollers and embedded processors to solve problems, I was eager to learn more about the architecture of digital circuits. Although CSE 593 did not cover the design of a computer processor, it did cover the design of fundamental digital components and the layout of a custom chip.

We began the course with CMOS logic and learned how logic gates, registers, latches, and multiplexers are built on the transistor level. As the course progressed, we covered more complicated components, such as adders, multipliers, and DRAM. One focus of the course was on design for low power and high performance. We discussed ways to save power. Clock gating.

Lab exercises were a significant component of CSE 593. Using Cadence, I learned how to design the schematic for a digital circuit, then lay out the physical transistors for production on a silicon wafer. Learning to use the tools in Cadence to develop the layout was the most challenging part of the course for me, but by the end I came to really enjoy routing layers of metal and polysilicon around my chip. I learned how to ensure my circuit passed the design rule checks, which are checks that make sure that the layout meets certain physical specifications of the process, and layout vs. schematic checks, which check that the logic of the layout is the same as the layout of the schematic. Once complete, the circuits were simulated with transient inputs to check that the outputs were computed as expected.

For our final project, we worked in small groups to design a small computer chip with ? IO pins. My group chose to design a traffic light controller, which was modeled as a finite state machine. An open-ended project was more challenging than the class assignments. First, we discussed how our traffic light controller would operate and which cases it would handle. We decided it would work on a timer, but the timing would be affected based on whether cars were waiting at certain areas of the intersection. Due to this, our circuit required four inputs. We then mapped out the logic of the finite state machine and translated the logic into digital components. Next, we created schematics for each of the components in Cadence. After that, we created the layout for every component. Finally, we assembled all of our components onto a chip in Cadence and simulated the chip's response to various inputs. I completed a large part of the component layouts. The final assembly on the chip was especially difficult - the component that we were given was confusing to work with. Our group needed to discuss with the TA to make sure that everything was working as expected. At the linked page are screenshots of the process. [Link here to page with screenshots of schematic, layout, and chip layout.]

In the end, the final project required a good deal of team collaboration. It was difficult to coordinate everyone's schedules and to make sure that everyone's individual parts worked together. We set up regular team meetings and were flexible on the tasks assigned to each person. We presented our final project as a team, but we were able to emphasize our own individual contributions.

This was certainly a difficult course due to the need to learn how to use Cadence, a complicated piece of software, without much guidance. However, I do think it was an extremely valuable course. Despite being offered by the computer science department, I think it is a must for any electrical engineering student. Although my immediate career goals don't include the design of VLSI circuits, this was one of the most interesting classes I have taken. I feel that a deep understanding of digital logic and the principles involved in manufacturing digital chips have given me a better understanding of how microprocessors operate. Programming microprocessors also has the goal of low power use and high performance and understanding how the hardware works is essential to writing efficient software.

EE 567 - Power Electronics with Professor Yao

Professor Yao's course on power electronics gave me a very thorough introduction to the field and included many interesting applications to exciting fields like electric vehicle design. Going into this course, I wasn't even sure what power electronics were. Coming out of this course, I was very confident in understanding the topologies of different DC/DC converters, DC/AC inverters, and AC/DC rectifiers.

Professor Yao's lectures were clear and meticulous. I never felt like there was information I needed to memorize - instead, I felt like I was gaining a deep understanding in the design of various power electronics circuits, which made adapting the principles to different designs simple. I appreciated Professor Yao's down-to-earth way of conveying information. Although we certainly covered a great deal of theory, she made it clear how the theory related to applications that were common in real life. For example, when discussing transformers, I learned about the implications of the material choice, size, cost, and physical shape of inductors, rather than a mere abstraction. I also had an opportunity to become very familiar with reading data sheets and selecting the appropriate components, which is an essential part of any engineering job. I found Professor Yao's passion for engineering infectious.

We also covered some methods of control, like pulse width modulation. These methods are useful not only in power electronics but also in other applications where a motor must be controlled or the brightness of a light modulation. I believe that exposure to these methods of control will be useful in a career involving microcontrollers.

An essential component of this course was the use of MATLAB and Simulink to design and simulate power electronic circuits. This was my first exposure to Simulink, but I had the opportunity to practice a lot in the homework. Most homeworks involved the design of different power electronic circuits in Simulink. I needed to consult with the TA and official MATLAB documentation often to determine which components were appropriate to use in my simulations. I think that if I used Simulink regularly I would get used to this, but I found the variety of similar components to be confusing and I felt like building the simulation took much longer than doing the calculations. This experience made me suspect that I would prefer a job that doesn't use Simulink, which is good for me to know.

In the final project, I worked with a partner to design a traction drive for an electric vehicle. The traction drive consisted of a battery, a DC/DC boost converter, a DC/AC inverter, and a motor. We needed to determine parameters for the boost converter and inverter to operate under varying conditions. We also simulated the output of the inverter, which was controlled by PWM. A screenshot and overview of the simulation is described here: [Link to simulation schematic and parameter calculation.] We typeset a report of the process in LaTeX. This project involved working closely with just one other student, which I find easier than working in a larger team. I feel like we both had a very complete understanding of the entire process as opposed to specializing in different chunks, so we were able to communicate well and come to an agreement about the necessary parameters.

I feel like I ended the course with a thorough understanding of power electronics and an appreciation for their ubiquity in modern devices.

EE 574 - RF/Microwave Circuits II with Professor Singisetti

This class was the second in a series. It followed RF/Microwave Circuits I, which introduced transmission lines, reflection coefficients, impedance matching, and reading Smith charts. In lab, we used a vector network analyzer to analyze the scattering parameters of circuits that we assembled. I chose to continue the series with the second course. This was partially because I wanted to learn more about advanced circuit design and partially because I heard that the second course was very difficult and I wanted to prove to myself that I could handle the challenge. RF II emphasized active RF devices like diodes, MOSFETS, and BJTs, and delved into their use in detectors, mixers, power amplifiers, and oscillators.

This was a lab-heavy course, where the theory discussed in class needed to be applied to our own circuit designs. I worked with a partner to complete a design of an RF circuit, such as an amplifier, before each lab session. We created our schematics in Advanced Design System, a CAD tool, and brought simulations of our circuit to our lab session to prove that our design would meet the requirements. Then, in the lab, we selected components and assembled our design. This lab was my first exposure to surface-mount soldering, and at first it was very difficult to get a handle on the correct soldering technique. The components seemed microscopic and my hands felt like they shook uncontrollably. Luckily, the lab period was long enough to accommodate a lot of trial and error, and eventually it became easier. This experience was valuable because I needed to solder frequently during my summer internship, and I was able to do so confidently. After our components were assembled, we used the vector network analyzer to see how our circuit operated and to confirm that it met the design specifications. An example of a design that we fabricated in the lab is linked here: [Link to power amplifier schematic, photo of circuit, and simulated vs. actual Smith charts]. Our designs never seemed to operate as predicted by our simulations, and discussion with other lab groups revealed that they often encountered the same problem. The errors might have been due to my poor soldering skills or maybe even accidentally swapping similar-looking components. Unfortunately, there was never enough time in the lab sessions to really get to the bottom of what was going wrong in the circuit. If a little extra solder to a loose-looking capacitor didn't fix the problem, we had to move on. I think having more time scheduled to allow for modifying the design or re-soldering components would have been useful and given me an opportunity to improve my hardware debugging skills. Even one larger lab-based final project would have accomplished this. Even so, I do think that the lab period helped me learn the steps involved in bringing a design to life.

To me, the part of the course that covered mixers and their use in radio transmitters and receivers was the most interesting because it is something that is found in every radio. Unfortunately, this was not incorporated into any lab project, but I hope that I'll be able to incorporate it into a personal project at some point.

This course was one of my favorites because it covered many useful applications of Rf circuits. I also think that its approach to teaching us how to design circuits was very useful. Even if I do not work with Rf/microwave frequencies, I think that a detailed knowledge of oscillator and amplifier design is important for any hardware designer.

EE 620 - MIMO Wireless Communications with Professor Su

This course was a continuation of a typical communications class. Instead of single-input, single-output (SISO) transmission, we focused exclusively on multiple-input, multiple-output (MIMO). The syllabus for this course was intimidating. Professor Su told us that many of his graduate students were initially frightened by the topic because the math looked too complicated! He also said that this appearance of complexity was the reason why MIMO systems had come into wide use only recently. However, he assured us the course would break the topic down into manageable parts and we would see that it wasn't that complicated after all.

The reason why modeling MIMO systems seems so difficult is that describing transmission between multiple inputs and multiple outputs requires a lot of equations. Luckily, almost all of these equations can be handled using ordinary linear algebra. We analyzed the performance of MIMO systems and learned what their advantages are over SISO systems (improved bandwidth and lower bit error rate). We also discussed methods of space-time coding, which exploits the multiple transmitting antennas to improve reliability, and modulation schemes.

During class, Professor Su continually emphasized that the theorems he presented had real-world consequences. He introduced little exercises in class to make sure that we weren't getting lost in theory and were able to see the applications to mobile or WiFi networks. These exercises often involved calculating the signal range, the bit error rate, or the data rate of MIMO systems so we could see the advantages of different schemes. Professor Su also made sure to highlight how MIMO techniques appear in the current IEEE standards and how they have developed over the past few decades. The final project for the course was not a technical project, but an essay analyzing how MIMO systems were incorporated into the current IEEE standards for 5g and WiFi.

The homework assignments in this course relied heavily on MATLAB. Although I had used MATLAB a little bit in the past, I needed to improve my skills a lot in order to succeed in this course. The strength of MATLAB is in matrix manipulations, but I had never used it for matrix computations before. However, MIMO systems, due to their nature, are represented by matrices, so MATLAB is suited well to handle these kinds of simulations. The first homework assignment, for example, required simulating a Rayleigh fading channel. I spent a long time reading documentation online in order to figure out how to write the simulation. Ultimately, the homework assignments contributed not only to my understanding of MIMO systems, but also to my understanding of MATLAB. [Link to code snippet] I was able to apply this understanding to a later project in EE 516 (Introduction to Digital Signal Processing).

Although I will probably not pursue a career in telecommunications, this course did interest me in the topic. As wirelessly-connected devices become ubiquitous, a good understanding of exactly how standards like WiFi, Bluetooth, and 5g actually operate is useful. As I plan to work on embedded devices, some of which may have wireless connectivity, I feel that this course was valuable. If I did want to work in telecommunications, this course would be absolutely essential.