Why learn design of integrated circuits?

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***Abstract*—I explain what you'll learn in Design of Integrated Circuits, why integrated circuits are used, why I work on them, and how we'll teach you about integrated circuits.**

I. Introduction

The manufacture of integrated circuits is complicated, and only a handful of companies – TSMC, Samsung, Globalfoundries, and maybe a few others – have the the capital and capability push the cutting edge. Most of us in the IC industry work in companies called fabless design houses. We design ICs but we don't manufacture them.

Integrated circuits are everywhere, in every cell phone, almost every toy, computer, washing machine, fridge, and electric scooter. A modern car has hundreds. Someone has to know how to make these integrated circuits. Today, that is me, and my colleagues. Tomorrow, it will be some of you. You're at a disadvantage though. The circuits are more complex and complicated than 60 years ago, and you may need to invent new methods to deal. I can help you learn what you need to know to make today's integrated circuits, but I can't teach you what you need to invent the integrated circuits of tomorrow.

I can promise you, however, that what I'll help you learn is not wasted. In this course we deal with physics and the fundamental components of ICs. Although the details might change, the physical properties of transistors have remained the same for more than 70 years, since Brittain, Bardeen and Shockley discovered the first [1].

II. Why

Why make integrated circuits, and why learn them? For me, it's this. I use my computer to design a piece of an integrated circuit. Maybe it takes me 6 months. The pieces are combined into a IC. Then, it might take a year or two until it goes into volume production. Why so long? The bane of ICs is variability, no transistor, resistor, capacitor, diode, inductor are the same. We have to make sure that each IC works by test over temperature, voltage, humidity, impact, age, electrostatic discharge. Google 'jedec esd', 'jedec htol', or 'jedec hast' and you'll see what I mean. Testing takes time.

When an IC is in volume production our customers can design them into their products. That takes time. But, after 5 years there can be hundreds of customers selling end products back to me, using the integrated circuit I worked on. The work I've done, the new circuit I've made, the tools I put into the hands of my customers, may have made the world better. Maybe by pushing people to get off the couch (step counters and heart rate monitors), improving everyday life of diabetics (smart insulin pump), or reducing energy consumption (smart lights, and smart buildings). I find that rewarding, especially when I think of the billions of copies of my work that is out there.

I believe, that integrated circuits, is one of the few industries where you can make something in Trondheim, and affect the fate of the whole world.

III. How

Imagine the computer mouse you bought, inside the mouse is a printed circuit board (PCB), and on that printed circuit board are multiple integrated circuits. One for universal serial bus (USB), one for charging a battery, one for laser sensor, one for communication. In addition, capacitors, crystals, inductors, resistors, diodes, electrostatic discharge protection, ground planes, antennas, and so much more.

The IC in figure 1 is a micro-controller with a Bluetooth Low Energy radio, which in a mouse is used for communication with a PC. The pins in black are digital inputs/outputs, the green are analog, the red are power, and blue is the ground connection. The digital input/outputs are controlled via the micro-controller, or peripherals – SPI, I2C, UART. The analog pins need external circuits like, crystal (XC1, XC2), inductor and capacitor (DCC), matching network and antenna (ANT). The power supply can come from a battery (VDD), while the DEC pins are the outputs of internal voltage regulators.

You may ask – will I learn everything on the inside in this course – and the answer is no. How can I help you learn about the millions of digital gates, and thousand schematic pages in this integrated circuit when you may not have understood the transistor yet? We must start with the basics, the technology, devices, and fundamental blocks. I can promise though, that if you choose take courses like analog CMOS, digital design, digital communication, digital signal processing, and advanced integrated circuits (my course), you will start to understand. Fair warning, very few people master all areas of integrated circuit design, I choose to focus on analog, others choose digital, or signal processing. Most of you will have too choose. A few of you may have the hubris to think that you can learn everything. I like hubris.

I need you to trust me that I will help you learn the fundamentals. A foundation to build on for future years.

IV. Purpose

All integrated circuits are made for a purpose. An integrated circuit is like an advanced tool. Maybe your customer want to control a sensor, charge a battery, turn on a light, or connect to the internet. An IC help them do that. Remember this. If you don't know the purpose of the circuit that you're making, then you need to figure out what the purpose is. There is always a purpose.

V. Skills

The integrated circuit in figure 1 is split into multiple levels of hierarchy.

- Infrastructure - Power management, reset, bias, clocks
- Domains - CPUs, peripherals, memories, bus systems
- Sub-systems - Radio's, analog-to-digital converters, comparators
- Blocks - Analog Radio, Digital radio baseband
- Modules - Transmitter, receiver, de-modulator, timing recovery
- Designs - Opamps, current-mirrors, adders, inverters, random access memory blocks, standard cells

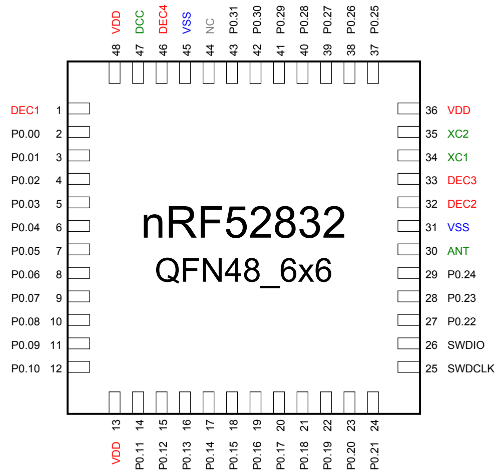

Fig. 1. Quad Flat No-Lead package outline of Nordic's nRF52832. Blue is ground, red is power, green is analog and black is digital input/output.

- Devices - metal-oxide transistors, bipolar transistors, capacitors, resistors, diodes, inductors, thyristors
- Technology - n-diffusion resistors, p-diffusion resistors, poly-resistors, unscilicided poly resistors, metal resistors

The hierarchy levels need different skills, usually split into analog, digital, signal processing, and firmware. Some functions, like a Bluetooth Low Energy Radio , need all four to work. Others, like infrastructure (power management, clocks), might not need signal processing or software to operate. There are extremely few analog blocks that don't have any digital input, or digital output.

It is rare to find one person doing firmware, signal processing, digital design, and analog design. I know of a handful among the 1000 employees in Nordic that have that ability. Usually, people are drawn to one of the four skills. Some of you may choose not to learn any of the skills, and that's OK, but you probably won't end up working on design of integrated circuits.

I don't know what it is, and I have no evidence to back this up, but if I brutally generalize it seems to me that:

- Digital - People that like details, a sense of control, knowing that what they make can be verified, people that like a true/false world.
- Signal Processing - People in love with mathematics, they can prove that the design they are making is optimal.
- Analog - People that are fine with gray zones, not knowing, not understanding. People that love physics, are tolerant towards change and challenges to world view. They know that all models for simulation are wrong, but some are useful.
- Firmware - People that like systems, and working close to end product.

VI. What

In this course we'll focus on two areas, analog and digital.

A. Analog

Full disclosure. I'm an analog designer, I've designed analog-to-digital converters on ICs that have now sold in the billions of devices. Since I'm an analog designer, much of what I say will be colored by that.

The real world is analog. The real world has voltages, currents, fields, charges, and all quantities are for most purposes are continuous in time and value. A few integrated circuits are pure analog, like the LM741 operational amplifier. Most integrated circuits are mostly digital. But all commercial digital integrated circuits have analog circuits inside them. Someone must make the voltages, clocks, and everything the digital needs to talk to the outside world. In this course we'll cover

- Devices - diodes, bipolars, transistors, capacitors, resistors, inductors
- How ICs are manufactured
- Basic transistor configurations, and their purpose.

B. Digital

Full disclosure. I've never done digital design in Verilog on a volume product, only on test-chips. But I know what you'll learn in this course, which is how to combine transistors into gates, data-paths and state machines. As for the verilog coding, all we'll do this semester is introduce the concept to you, so what I know is plenty. In this course we'll cover

- Digital Gates
- Sequencing
- Data-paths
- Memories
- Packaging, Power, Clock, I/O
- Methodology
- Verilog

VII. Conclusion

I hope that after this course you will know better the fundamental skill required for integrated circuit design. This is only the start of the journey though, and if it's hard to see where the journey will end, then remember to ask questions, and I'll put it into context.

References

[1] Brittain, Bardeen, Shockley "Point-contact transistor", online:https://en.wikipedia.org/wiki/Transistor