Preface

Embedded systems acquire data directly from the physical world and directly act on the physical world. Building such systems requires not only elaborate skills when it comes to designing hardware and software, a solid understanding of the physics of the application and of the physical behavior of the devices used for building the system is at least equally important. In my experience it is the physics which to a large extent determines the architecture of the finished system.

The book grew out of the courses I taught at the University of Applied Sciences FH-Joanneum and at the University of Salzburg. Its main audience are students of computer science and related disciplines in the last year undergraduate and first year graduate levels, who are adventurous enough to pack their computers and leave cyberspace for the physical world, where nature decides whether an idea works or not. A practicing engineer may also find entertainment in the more advanced chapters of the book. A reader should be familiar with engineering mathematics and with signals and systems in particular. Familiarity with a simulation tool such as the Simulink® system helps as does familiarity with computer algebra software like Maxima, Maple™, or Mathematica®. No knowledge of physics beyond what is taught in high school is necessary.

I strongly believe mathematical reasoning about a physical situation is a crucial part of understanding the situation. Therefore, I emphasize mathematical modeling. Whenever possible I derive analytical models of the reality at hand from first principles. Whenever I need a fact whose derivation is beyond the scope of the book, I state this clearly. The book contains a list of acronyms. In the text however, I try to avoid jargon and acronyms as much as possible.

Most chapters contain exercises. I answered all exercises in Appendix D. I moved some arguments into exercises which I felt do not fit into the main development. The provided answers close some gaps the reader might feel the main treatment has. Most chapters contain suggestions for lab exercises too. Naturally, I provide no answers for these.

The first four chapters cover the basics necessary for designing embedded systems. Chapter 1 defines the term embedded system. It motivates how these systems form a natural hierarchy with measurement and control systems at the bottom. The material in this book focuses on this bottom layer. The chapter goes on to introduce models for physical reality and models of computation.

Chapter 2 summarizes the mathematical tools we need in the rest of the book. A well-prepared reader may skim over the chapter and use it later as reference. For the not so well-prepared reader the material together with the given references to the textbook literature can act as guide to the subjects to be learned.

Chapter 3 introduces some basic electrical engineering. It discusses electrical charge, voltage and current, and the associated measurements. It treats resistors, capacitors, and inductors with emphasis on the mathematical description of their behavior. An experienced reader may skip this chapter. Readers without prior exposure to the basics of electrical engineering are encouraged to study the chapter.

Chapter 4 is a compact introduction to digital electronics. It analyzes the properties of the different types of outputs motivating the need for more than two logic levels. Next, it focuses on the temporal behavior of combinatorial circuits including logic races. In the discussion of sequential circuits it again emphasizes the temporal behavior of flip-flops; it covers metastability and motivates the synchronous design discipline. The chapter next describes the realization of state machines in synchronous logic. Systems comprising several clock domains and synchronization follow. After some words on the realization of digital circuits the chapter ends with a first view of the analog problems plaguing fast logic circuits. Readers not familiar with metastability are encouraged to read the chapter.

Each of the following chapters comprises what I call a technical essay. In a technical essay I try to tell a complete story along a well-chosen line of development. The story usually evolves across boundaries between disciplines. To a certain extent such an essay is my personal take on the subject, reflecting my personal experiences and opinions as much as the accepted knowledge in the areas the story touches.

The first two essays can be read in arbitrary order. Both should be read before venturing into one of the last four essays. Chapter 5 contains an essay on programmable devices. The line of development I have chosen for the story follows the sequence of decisions one has to make when designing the digital part of an embedded system. The story starts out with the three architectures for handling external events—event driven, time driven, and polling. It introduces peripheral devices as coprocessors relieving the main processors from mundane but time-critical tasks. After looking at static and dynamic RAM the story goes on to look at ways to deal with memory hierarchies. Finally, it is time to introduce the three possible types of execution engines—embedded microprocessors, digital signal processors, and programmable logic. Two case studies, one signal processor based and the other using programmable logic apply some of the discussed techniques to real designs.

Chapter 6 is an essay titled analog electronics—signal conditioning and conversion. The line of development follows the steps we take when designing the analog part of a system. Starting with the block diagrams of three sampled data systems—a control system, a measurement system, and a digital radio—the story dives into filters and sampling. After stating design rules for anti-aliasing and reconstruction filters it touches upon data converters. The converters' sampling clock gets a special treatment. The second part of the story is devoted to analog building blocks, to active discrete components and to circuits. At first reading, the second part of the story may be skipped.

Chapter 7 tells similar stories of six siblings—six switchmode power converters. The parallel treatment tries to emphasize the importance of switching when we want to achieve high efficiency in energy conversion processes.

The last four essays may be read in any order. These essays are case studies describing systems I have built. The essay in Chap. 8 continues treating energy conversion, this time looking at electrical motors. The story develops along the line physics, programs, circuits. It starts out with a somewhat detailed look at electromagnetism and magnetic materials. Armed with this knowledge it develops the classical model of a permanent magnet synchronous motor—a type of motor finding use in applications from toys to electric vehicles. The story continues with applying control strategies to the model with mixed results. The simple strategy does not work—but close examination of the model gives us clues for a strategy that works—field-oriented control. With this strategy as plan of attack the essay continues with issues arising in the software for such a control scheme in order to end with the circuit of a low-voltage power stage and some measurements produced with this power stage.

The last three essays use Fourier transform methods. The essay in Chap. 9 is the least challenging in terms of the mathematics used. A reader less experienced with Fourier transforms is encouraged to start here. The line of the story loosely follows physics, programs, circuits. The story shows how to make precise measurements admit overpowering interference using a method called lock-in detection. Using Fourier series it analyzes the workings of the lock-in principle and some of its variants. Next, it discusses several ways of implementing the principle. Then the story applies the lock-in principle to signal conditioning for strain gauges—the sensor elements in force and torque sensors. The essay then turns to making simultaneous measurements with a single detector and states conditions so that the measurements do not disturb each other. Finally, it puts this principle to use when constructing the software and the circuit of an optical sensor for measuring moisture content in substrates such as paper.

Chapter 10 contains an essay on short-range radar for measuring speed and distance. Again the book's subtitle applies. Starting with the Doppler effect the story shows how to convert the information contained in the reflected signals at very high frequencies down into a much lower frequency range. It then unpacks the full Fourier apparatus in order to come up with an algorithm based on computing a discrete Fourier transform, for computing the speeds of the targets visible the radar systems. During this development the story shows us the relationship between the time we spend observing the reflected signal for a measurement and the speed resolution the algorithm produces. Next, it turns to measuring distances and introduces the frequency modulated continuous wave radar. After turning to a circuit, which uses a commercially available radar module, the story ends with some software issues and a sample measurement.

Chapter 11 is an essay on making nature compute Fourier transforms using two mirrors and a beam splitter. The story develops along the themes physics, programs, circuits again. The story discusses a spectrometer for infrared radiation. A spectrometer computes the intensity distribution with respect to wavelength in an incoming beam of light. The beam of light contains information about the chemical compositions of the substances it has interacted with. Therefore, these instruments are used for performing chemical analyses. After looking at light waves and their properties the story goes on to present several types of infrared spectrometers. It analyzes the trick with the two mirrors and the beam splitter—the Michelson interferometer—in detail. Next it presents the signal processing performed in the actual instrument. The essay finishes with covering auxiliary functions and the optical setup.

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