Introduction to Mixed-Signal, Embedded Design

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Preface

This textbook was developed for upper-level undergraduate, and first-year graduate level, curricula. It addresses three important aspects of embedded mixed-signal systems: (a) the defining characteristics of embedded applications, (b) embedded mixed-signal architectures, and (c) top-down design and design activities for developing performance-satisfying, optimized implementations. Although the authors have attempted to make the material presented here as self-contained as possible, the student will find it helpful to take advantage of the bibliographies at the end of each chapter, and the companion laboratory manual available online.

Embedded applications involve: (i) interfacing to analog signals and digital data, (ii) functionality sensing, control, actuation, data computation, and data communication, functionality; and (iii) design and performance constraints that must be satisfied by the system implementation. In addition to considering the general challenges of designing mixed-signal, embedded systems, various analog and digital interfaces and interfacing modules, for example, interfaces to temperature sensors, tachometers, and LCDs, filters, analog-to-digital converters (ADCs), quantizers, interrupt subsystems, and digital communication components based on standard protocols, e.g., SPI, UART, and I2C, are discussed in detail.

The topics discussed include the hardware and software used to implement analog and digital interfaces, for example, $\Delta\Sigma$ ADC topologies and circuits, various filter structures, amplifiers and other signal-conditioning circuits, PWMs, timers, I/O ports, interrupt service routines (ISRs), high-level communication primitives (APIs), firmware routines, and data structures for handling multiple, but similar, peripheral devices.

The authors have chosen Cypress Semiconductor's Programmable System on (a) Chip (PSoC) to illustrate many of the key points developed in this text. This choice was based largely on the fact that PSoC provides a broad range of the various components of a typical mixed-signal embedded system, for example, A/D and D/A converters, UARTs, $\Delta\Sigma$ modulators, filters, programmable gain amplifiers, instrumentation amplifiers, comparators, DTMF dialer, counters, timers, digital buffers, digital inverters, LCD and LED support, sleep timers, watchdogs, MUXs, PWMs, random sequence generators, flash temperature sensors, eand so on, and all in a single chip.

Detailed design examples are presented throughout the text as illustrative examples of embedded systems, such as, interfacing to temperature sensor, tachometer and fan, tachometer ISR, SPI and UART implementations, SPI- and UART-based task communications, and ISR for decimation in $\Delta\Sigma$ ADCs. Recommended exercises are also provided at the end of each chapter.

The embedded functionality treated here can be divided into four broad categories: (1) control dominated systems, which are specified as finite state machines (FSM), (2) data-dominated applications expressed as acyclic dataflow graphs (ADFG), (3) multitasking systems defined as task graphs, and (4) multimode systems specified as control and dataflow graphs. In addition, depending on the semantics of execution with respect to time, embedded mixed-signal systems are continuous-time, discrete-time, and event-driven (reactive) systems.

There are different types of embedded functionalities presented, for example, temperature controller systems, stack-based operations, subroutines for unsigned multiplication, bit manipulations, sequence detector applications, scalar products of two vectors, and several examples of communicating tasks. Regarding analog functionality, the material includes comparators, instrumentation amplifiers, filters, $\Delta\Sigma$ ADCs, differential and common mode amplification, and several signal conditioning front-ends.

This text emphasizes the importance of performance constraints and requirements in determining the optimal implementation of an embedded application. The performance attributes considered are cost, time-to-market, size and weight of the implementation, real-time constraints, and data accuracy. Constraints can be classified into global constraints, if they refer to the overall system, and local constraints, if they are related to the individual modules and subsystems. Constraint transformation is the relating of the global constraints to the local constraints, including the correlations between analog and digital constraints. Performance profiling is often used for computing the performance-criticality of functional blocks.

Several specific constraint transformation procedures, such as, relating the required processing accuracy/bandwidth of the input signals to the signal-to-ratio requirement and sampling frequency of the ADC, and to the latency constraint of the digital processing are presented. Other examples include correlating the maximum bit rate of a serial input to the processing latency of the processing algorithm, studying the impact of the memory access mechanism and time on the total execution time of an application, estimating and reducing the timing overhead of data communication, handling predefined timing limits for the tachometer ISR, and improving system performance by architecture customization to the application's characteristics.

This textbook also specifies the performance attributes that describe analog and mixed-signal modules, for example, the nonidealities of continuous-time analog blocks (e.g., OpAmp finite gain, poles, zeros, input and output impedances, distortion, offset, power supply rejection ratio, saturation, slew rate, and circuit noise), the nonidealities of switched capacitor blocks (e.g., the nonzero switch resistance, channel charge injection, clock feedthrough, and finite OpAmp gain), and the concepts of quantization noise power, signal-to-noise ratio (SNR), dynamic range (DR), and power spectrum density in ADCs. Finally, the text models the dependency of the ADC performance on circuit nonidealities (e.g., jitter noise, switch thermal noise, integrator leakage, and OpAmp bandwidth, slew rate, saturation and noise).

The final chapter provides descriptions of two case studies, which reiterate the design flow for embedded systems, and ends by introducing some of the current challenges related to design automation for analog and mixed-signal systems.

LEGAL NOTICE

In this textbook the authors have attempted to teach the techniques of mixed-signal, embedded design based on examples and data believed to be accurate. However, these examples, data, and other information contained herein are intended solely as teaching aids and should not be used in any particular application without independent testing and verification by the person making the application. Independent testing and verification are especially important in any application in which incorrect functioning could result in personal injury, or damage to property.

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