1

Introduction to Data Conversion and Processing

The proliferation of digital computing and signal processing in electronic systems is often described as "the world is becoming more digital every day." Compared with their analog counterparts, digital circuits exhibit lower sensitivity to noise and more robustness to supply and process variations, allow easier design and test automation, and offer more extensive programmability. But, the primary factor that has made digital circuits and processors ubiquitous in all aspects of our lives is the boost in their performance as a result of advances in integrated circuit technologies. In particular, scaling properties of very large scale integration (VLSI) processes have allowed every new generation of digital circuits to attain higher speed, more functionality per chip, lower power dissipation, or lower cost. These trends have also been augmented by circuit and architecture innovations as well as improved analysis and synthesis computer-aided design (CAD) tools.

While the above merits of digital circuits provide a strong incentive to make the world digital, two aspects of our physical environment impede such globalization: (1) naturally occurring signals are analog, and (2) human beings perceive and retain information in analog form (at least on a macroscopic scale). Furthermore, when digital signals are corrupted by the medium such that they become comparable with noise, it is often necessary to treat them as analog signals. For example, according to information theory, for a digital signal buried in noise, amplitude digitization and subsequent decoding ("soft decision decoding") can improve the bit error rate.

In order to interface digital processors with the analog world, data acquisition and reconstruction circuits must be used: analog-to-digital converters (ADCs) to acquire and digitize the signal at the front end, and digital-to-analog converters (DACS) to reproduce the signal at the back end. This is illustrated in Figure 1.1.

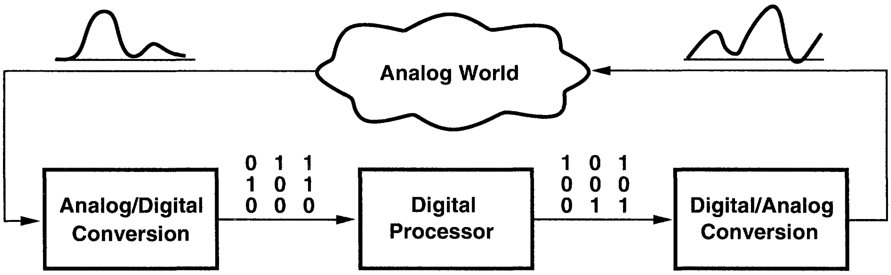

Fig. 1.1 Interface between analog world and a digital processor.

Data conversion interfaces find application in consumer products such as compact disc players, camera recorders (camcorders), telephones, modems, and high-definition television (HDTV), as well as in specialized systems such as medical imaging, speech processing, instrumentation, industrial control, and radar. We study one of these applications to illustrate the importance of both data conversion and digital processing in a typical product.

Figure 1.2 is a simplified block diagram of portable camcorder electronics [1]. The imaging front end consists of an array of charge-coupled devices (CCDs) that produce a charge output proportional to the light intensity. The charge packets from all the CCDs are sensed serially and converted to voltage, and the resulting signal is digitized by the ADC. Subsequently, operations such as autofocusing, image stabilization, luminance/chrominance (Y/C) processing, and zooming are performed using one or more digital signal processors (DSPs). The processed video signal is then converted to analog form and recorded on the tape.

While adding many features to the recorder and improving its user interface, the signal processing functions in Figure 1.2 are far too complex to be implemented in the analog domain. In fact, most of these functions have been added to camcorders simply because the ADC already provides the signals in digital form.

The performance required of the data conversion circuits used in video systems such as that of Figure 1.2 varies from one application to another. In portable camcorders, a conversion rate of a few tens of megahertz with 10-bit resolution is adequate, but the power dissipation (and preferably the

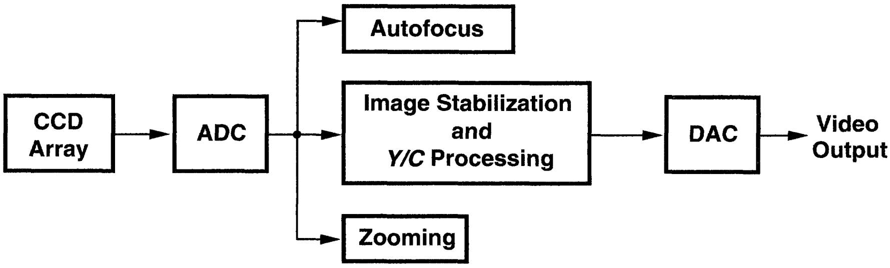

Fig. 1.2 Simplified block diagram of a portable camera recorder electronics.

supply voltage) must be minimized. In HDTV, speeds as high as 70 MHz are desirable, whereas in high-quality studio recording, resolutions of 12 to 14 bits are necessary.

Since data conversion interfaces must deal with both analog and digital signals, their design becomes increasingly difficult if they are to maintain comparable performance with their corresponding digital systems, i.e., not appear as a bottleneck in the signal path. This is because the primary trade-off in digital circuits is between speed and power, whereas that in analog circuits is between any two of speed, power, and precision (including resolution, dynamic range, and linearity). Furthermore, the operation of both analog and digital circuits on the same chip leads to coupling of the noise generated by the digital section to the sensitive signals in the analog section. This coupling occurs via shared supply lines, substrate currents, or cross talk between adjacent lines.

High-performance data conversion systems have often been built as hybrid structures, wherein different parts of the system are designed in different technologies and placed and interconnected on a common (nonconducting) substrate. This flexibility usually allows hybrids to achieve a higher speed than their monolithic counterparts—the key to their survival. However, issues such as cost, reliability, and power dissipation have created a trend toward implementing these interfaces in monolithic (VLSI) technologies and ultimately integrating an entire data processing system on a single chip. Most of the architectures and design concepts described in this book are used in both hybrid and monolithic applications, but the emphasis is on the latter type.

The integration of data conversion systems in VLSI technologies entails difficulties due to scaling, the very technique adopted to improve the performance of *digital circuits*. As supply voltages and device dimensions are reduced, many effects occur that are not predicted by the ideal scaling theory. For example, dynamic range becomes more limited, intrinsic gain of devices degrades, and device mismatch increases. In addition to these problems, many other analog design issues such as device noise and accurate control of device characteristics are usually ignored in optimizing VLSI technologies, and *modeling* of devices is typically performed with little concern for parameters important to analog design. Consequently, obtaining the required precision becomes the primary concern in analog and mixed analog-digital circuits, often necessitating conservative design and sacrifice in speed and power dissipation.

Let us now closely examine the data conversion interfaces of Figure 1.1. The analog-to-digital (A/D) interface converts a continuous-amplitude, continuous-time input to a discrete-amplitude, discrete-time signal. Shown in Figure 1.3 is this interface in more detail. First, an analog low-pass filter limits the input signal bandwidth so that subsequent sampling does not alias any unwanted noise or signal components into the actual signal band. Next, the filter output is sampled so as to produce a discrete-time signal. The amplitude of this waveform is then "quantized," i.e., approximated with a level from a set of fixed references, thus generating a discrete-amplitude signal. Finally, a digital representation of that level is established at the output.

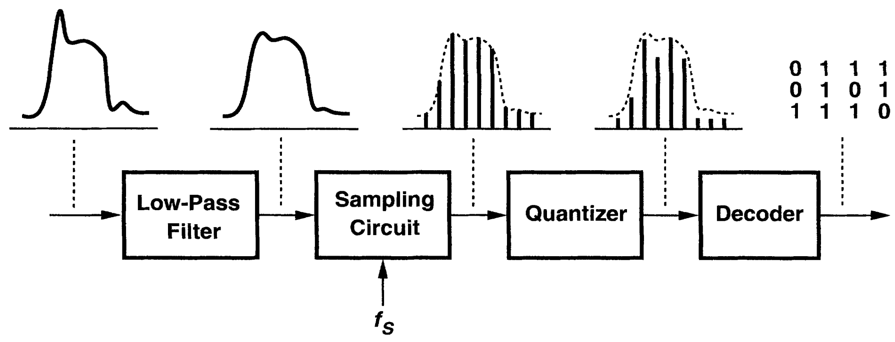

Fig. 1.3 Detailed analog-to-digital interface of Figure 1.1.

The ratio of the sampling rate f_S to the signal bandwidth distinguishes two classes of A/D converters. In "Nyquist-rate" ADCs, the sampling frequency is, in principle, slightly higher than twice the analog signal bandwidth to allow accurate reproduction of the original data. In "oversampling" converters, on the other hand, the signal is sampled at many times the Nyquist rate and subsequent digital filtering is utilized to remove the noise outside the signal bandwidth. These two classes require vastly different architectures and design techniques. In this book, we consider only Nyquist-rate converters. For oversampling data conversion, the reader is referred to the literature [2, 3].

The digital-to-analog (D/A) interface at the back end of the system shown in Figure 1.1 must convert a discrete-amplitude, discrete-time signal to a continuous-amplitude, continuous-time output. This interface is depicted in more detail in Figure 1.4. First, a D/A converter selects and produces an analog level from a set of fixed references according to the digital input. If the DAC generates large glitches during switching from one code to another, then a "deglitching" circuit (usually a sample-and-hold amplifier) follows to mask the glitches. Finally, since the reconstruction function performed by the DAC introduces sharp edges in the waveform as well as a sinc envelope in the frequency domain, an inverse-sinc filter and a low-pass filter are required to suppress these effects. Note that the deglitcher may be removed if the DAC is designed so as to have small glitches. Also, the inverse sinc filtering may be performed *before* D/A conversion, i.e., in the digital domain.

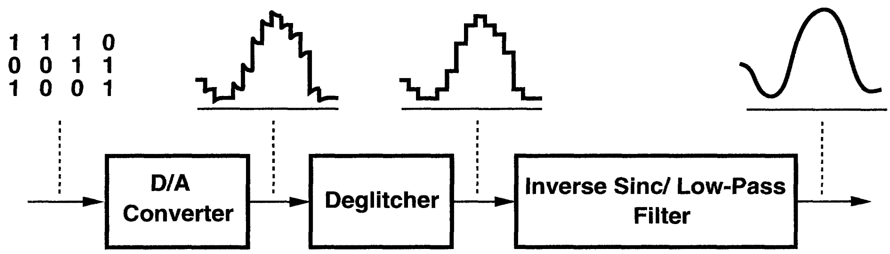

Fig. 1.4 Detailed digital-to-analog interface of Figure 1.1.

Figures 1.3 and 1.4 indicate that acquisition and reconstruction of data entail a great deal of mixed-signal processing: filtering, sampling, quantization, and digital encoding at the front end, and D/A conversion, sampling, and filtering at the back end. The design of data conversion interfaces demands a good understanding of various trade-offs in these operations as well as architecture and circuit techniques that improve the performance by relaxing these trade-offs.

In this book, we study sampling concepts and techniques in Chapters 2 and 3, D/A conversion in Chapters 4 and 5, and A/D conversion in Chapter 6. The important building blocks needed in performing these operations are described in Chapter 7, and methods of achieving high resolution in Chapter 8. Testing and characterization are the subject of Chapter 9.

REFERENCES

[1] A. Matsuzawa, "Low-Voltage and Low-Power Circuit Design for Mixed Analog/Digital Systems in Portable Equipment," *IEEE J. Solid-State Circuits*, vol. SC-29, pp. 470-480, April 1994.

[2] J. C. Candy and G. C. Temes, Editors, *Oversampling Delta-Sigma Data Converters*, IEEE Press, New York, 1992.

[3] S. Norsworthy, R. Schreier, and G. C. Temes, Editors, *Delta-Sigma Converters*, IEEE Press, New York, 1994.