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Analog, Digital and Mixed-mode Signal Processing

1.1 Digital Signal Processing

The widespread use of digital signal processing systems is due to many factors including reliability, reproducibility, high precision, freedom from aging and temperature effects, low cost and efficient computational algorithms. Furthermore, the revolution in the microelectronics field [1–3] has been characterized by a continuous increase in the level of integration leading to complete systems being integrated on a single chip, that is, systems on a chip (SoC) [3–5].

1.2 Moore's Law and the "Cleverness" Factor

The integrated circuit dates back to around 1960. Since then, the number of devices on a chip has increased dramatically in line with an observation [1, 2] predicting a doubling every year. Now, millions of transistors can be manufactured on a single chip allowing phenomenal processing capability. If we define a pixel as the smallest spot on a chip that can be controlled in the fabrication process, then this will determine the contribution of device miniaturization and chip area to the content of the chip. This contribution can be measured by the quantity A/S where A is the chip area and S is the pixel area. As progress continued, it was found that the number of devices on a chip was actually increasing *faster* than A/S. This additional growth was a result of "clever" techniques of exploiting the space on the chip. These include forming thin-film capacitors on the side holes etched into a chip instead of on the surface, and self-aligned structures where part of the device is used as the mask in the fabrication process. Next came the effect of the wiring on limiting the size of the chip. This, again, has been tackled [1] by the "cleverness" of increasing the number of wire layers.

1.3 System on a Chip

Such a system comprises *application specific integrated circuits* (ASICs). Examples are the single-chip TV or the single chip camera, and the ever-emerging new generations

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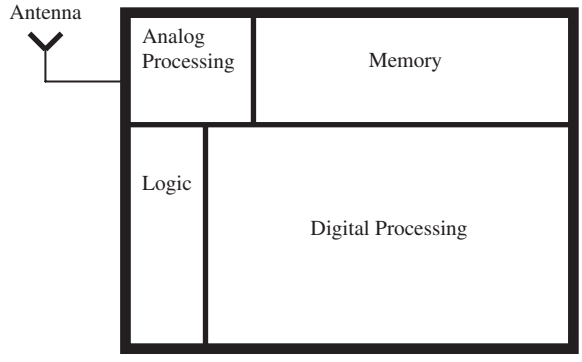

Figure 1.1 System on a chip (SoC)

of integrated telecommunication systems particularly in the mobile communication area. Such systems include *analog* and *digital* sections on the same chip where the technology of choice has been CMOS and possibly BiCMOS. Most functions on these chips are implemented using *digital signal processing* circuits. However, analog circuits are needed as an interface between the system and the real world which is, of course, analog in nature. Figure 1.1 shows a typical SoC containing embedded digital signal processors, embedded memory, reconfigurable logic, and analog circuits to interface with the analog continuous-time world.

The design of signal processing systems with low-power requirements is one of the most important areas of research [6, 7] which together with the need for high speed and density of integration have led to great advances in technology and clever circuit design methods [8].

1.4 Analog and Mixed-mode Signal Processing

The trend to replace, for example, analog filters by digital filters is understandable in view of the advantages of digital filters. However, there are some functions on the processor which will always remain analog [4]. These are the following:

(a) At the input of the system, signals from a sensor, microphone, antenna or cable must be received, amplified and filtered, that is *processed* and brought to a level that permits digitization with acceptable signal to noise ratio and low distortion. Here, we need low-noise amplifiers (LNAs), variable gain amplifiers (VGAs), filters, oscillators and mixers. Applications are:
   - Data and biomedical instrumentation.
   - Sensor interfaces such as airbags and accelerometers.
   - Telecommunications receivers such as telephone or cable modems and wireless telephones.

(b) At the output of the system the signal is reconverted from digital to analog form and strengthened so that it can drive an external load such as an antenna or a loudspeaker with low distortion. Here we also need buffers, filters, oscillators and mixers. Applications are the following
   - Telecommunications transmitters

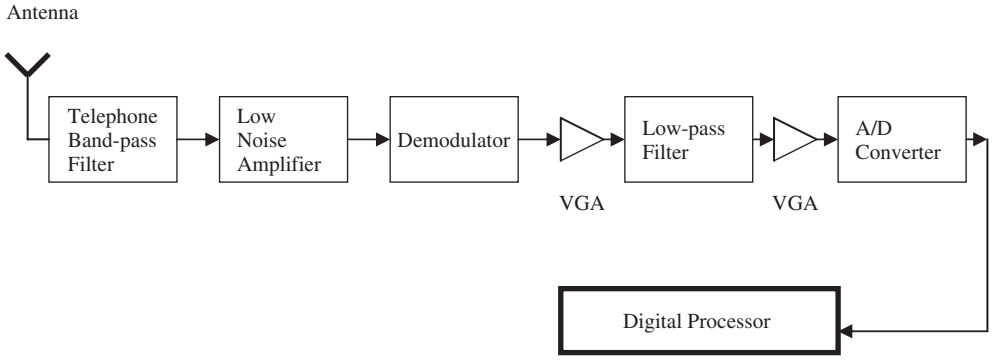

Figure 1.2 The analog and digital parts of a mobile telephone/Bluetooth receiver section

- Audio and video, such CD, SACD, DVD and Blueray
- Loudspeakers
- TV
- PC monitors
- Hearing aids

(c) Mixed-mode circuits are also needed for the interface between the analog and digital parts. These include sample and hold circuits for the sampling of signals, analog to digital (A/D) converters as well as digital to analog converters for signal reconstruction. These are mixed-mode circuits.

(d) The integrated circuits discussed above need stable references for their operation which are analog voltage and current sources and crystal oscillators.

Figure 1.2 illustrates the above points with the block diagram of a mobile telephone/Bluetooth receiver section [9]. This highlights the fact that both analog and digital circuits coexist on the same chip employing CMOS technology, and also the interrelationship between analog and digital signal processing.

1.5 Scope

Now, what do we need to know in order to be able to design a system on a chip? Our knowledge must include the following:

1. Methods of description of both analog and digital signals in the time and frequency domains.
2. Methods of description of the systems which process the signals. We need to do this for both analog and digital systems.
3. Design techniques for analog circuits such as amplifiers, integrators, differentiators, and most importantly: filters taking into account the non-ideal effects.
4. Integrated circuit implementations of analog circuits using CMOS technology.
5. Design of digital filters taking into account the finite word-length effects inherent in all digital processors.
6. Random signals require special methods for their description and processing, leading to the subject of adaptive filters. These, together with the related topics of linear prediction, estimation, and system modelling are essential.

7. Modern design techniques of discrete-time filtering using switched-capacitor techniques, since these are particularly amenable to implementation using VLSI techniques.
8. Design of A/D and D/A converters since these act as the interfaces between the digital and analog parts of the system.

Detailed treatment of the above topics is the aim of this book. To facilitate the numerical calculations, and to be able to study the responses of systems and evaluate their performances, we need a powerful software package. MATLAB® is a good choice, and it is used throughout the book.