PART III

# Digital Integrated Circuits



There are two indisputable facts about digital systems. They have dramatically changed our lives; and the digital revolution is driven by microelectronics.

Evidence of the pervasiveness and influence of digital systems can be found by thinking of what we do in our daily lives. Digital circuits exist in almost every electrical appliance we use in our homes; in the vehicles and transportation systems we use to travel; in the telephones and, most obviously, the cell phones we use to communicate; in the medical equipment needed to care for our health; in the computers we use to do our work; and in the audio and video systems and the radio and TV sets we use to entertain ourselves. Indeed, it is very difficult to conceive of modern life without digital systems, none of which would have been possible without microelectronics.

Although the idea of a digital computing machine was conceived as early as the 1830s, early implementations were very cumbersome and expensive mechanical devices. The first serious digital computers using vacuum tubes appeared in the 1930s and 1940s. These early computers used thousands of tubes and were housed literally in many rooms. Their fundamental limitation was low reliability: vacuum tubes had a finite life and needed large amounts of power. Had it not been for the invention of the transistor in 1947 ushering in the era of solid-state electronics, digital computers would have remained specialized machines used primarily in military and scientific applications.

By the mid 1950s, the first digital logic gates made of discrete bipolar transistors became commercially available. The invention of the integrated circuit in the late 1950s was also key, leading to the first digital IC in the early 1960s. Early digital ICs were made of bipolar transistors, with the most successful logic-circuit family of this type being transistor-transistor logic (or TTL), which dominated digital circuit design, until the early 1980s.

Bipolar was replaced by NMOS, and NMOS by CMOS, again predominantly because of power dissipation and the need to pack more and more transistors on each IC chip. Bearing out Moore's law, which predicted in 1968 that IC chips would double the number of their transistors every two to three years (see Section 13.5), digital ICs have grown from a few transistors to 2.3 billion devices and to memory chips with 4 Gbit capacity.

Part III aims to provide a brief but nonetheless comprehensive and sufficiently detailed exposure to digital IC design. Our treatment is almost self-contained, requiring for the most part only a thorough understanding of the MOSFET material presented in Chapter 5. Thus Part III can be studied right after Chapter 5. The only exceptions to this are the last two sections in Chapter 14, which require knowledge of the BJT (Chapter 6). Also, knowledge of the MOSFET internal capacitances (Section 9.2.2) will be needed.

Chapter 13 is the cornerstone of Part III. It provides an introduction to digital circuits and then concentrates on the bread-and-butter topic of digital IC design: the CMOS inverter and logic gates. Today, CMOS represents 98% of newly designed digital systems. The material in Chapter 13 is the minimum needed to learn something meaningful about digital circuits; it is a must study!

Chapter 14 builds on the foundation established in Chapter 13 and introduces three important types of MOS logic circuits and a significant family of bipolar logic circuits. The chapter concludes with an interesting digital circuit technology that attempts to combine the best of bipolar and CMOS: BiCMOS.

Digital circuits can be broadly divided into logic and memory circuits. The latter is the subject of Chapter 15.