A USER'S HANDBOOK OF SEMICONDUCTOR MEMORIES

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To

SUSAN, STEPHEN, JEFFREY, and DAVID

PREFACE

The increasingly rapid proliferation of semiconductor memories—bipolar and MOS—vying to replace magnetic cores as the main storage element in computers and minicomputers, requires that the practicing engineer keep abreast of state-of-the-art developments. Manufacturers of computer peripheral terminals and instrumentation are increasingly using semiconductor memories in their products. In the past four years, the state of the art for memories has progressed from 64-bit TTL and *p*-channel MOS RAMs to units such as 4K, and 16K *n*-channel RAMs, 1K Schottky TTL RAMs, 4K I^2L RAMs, 1K CMOS RAMs, 32K ROMs, CMOS/SOS RAMs, 65K CCD memories, 256-bit CMOS CAMs. These increases in circuit density, complexity, and processing technology present the user with many different options for his system design. He must be aware of all options to achieve an efficient and cost-effective design.

This book provides practicing design and systems engineers, engineering students, and other interested readers with a comprehensive overview and some insight into the various semiconductor memory technologies and the advantages of each; a detailed discussion of the various categories of semiconductor memories; how the technology is married to a circuit design to yield the final product; and different applications of the final product. The material has been assembled from independent literature to serve as a design guide for the practicing engineer.

This is not a book that delves into the details of the design of monolithic semiconductor integrated circuits; however, it does cover enough semiconductor processing and monolithic design to enable the user to become familiar with the design goals and the relationship between design goals, process techniques, and final products, to make the application decision easier. It also describes specific applications and the design details of specific memories in enough depth to interest the experienced designer. A general background is assumed in semiconductor integrated circuit processing terminology, semiconductor physics, and circuit design theory. Engineering students will be able to follow the book if they have been exposed to a course on semiconductor devices.

I wanted to write a book that can be read and used—a general purpose book that uses present-day popular memories as illustrative examples. This book is organized in six sections: Chapter 1 introduces the subject; Chapter 2 presents the various semiconductor processing technologies; Chapter 3 discusses shift registers and FIFOs; Chapter 4, read-only memories and programmable logic arrays; Chapter 5, random-access and content-addressable memories and Chapter 6, charge-coupled devices.

A wide variety of technological disciplines and such state-of-the-art subjects as 4K and 16K RAMs, I^2L technology, ion implantation, CAMs, PLAs, FIFOs and CCDs are also discussed.

Chapters 3 through 6 deal with the intricacies, advantages and disadvantages of the various types of memory cells for each category of memory; its organization and design is presented; examples of popular generic IC memories are discussed to show how technology and circuit design combine to yield a given product; interface considerations for the memory are presented; and typical applications are discussed.

Throughout the book, emphasis is on using the popular IC memories as illustrative practical examples, and there are summaries of the popular commercially available device types.

Because of the need to provide a printable manuscript, the examples of commercially available memories are only illustrative rather than exhaustive in that all available generic part types and/or manufacturers are not discussed. I have tried to give a representative cross section of the most widely used device types.

I thank all the manufacturers of the products discussed for permission to use their material. Without them this book would not have been possible. Finally, I would like to thank Carol Lopez and Diane Beer for their painstaking efforts in typing the manuscript from sometimes illegible handwritten notes.

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Sunnyvale, California

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CONTENTS

Chapter One

INTRODUCTION

LOGIC MEMORY SYSTEMS[1]

A typical logic memory system consists of four basic units: the interface unit, the arithmetic or function unit, the control unit, and the memory unit. Each of these units is discussed briefly.

The Interface Unit

The interface unit ensures signal compatibility between the system and the outside world. In the past there has been difficulty in interfacing between metal oxide semiconductor (MOS) and bipolar integrated circuits (ICs). Now, however, MOS ICs are being designed for compatibility between diode- and transistor-transistor logic (DTL and TTL). MOS can now be driven from DTL or TTL, and vice versa. This allows users to get the best of both MOS and DTL-TTL worlds. Where MOS is a relatively poor performer (e.g., in high speed portions of a system or when power driving is required), it pays to use a bipolar integrated circuit. In the remainder of the system, MOS can be employed in appropriate spots; thus each type of circuit can be exploited without having to use special interface circuits.

The input to an MOS IC looks like a reverse biased diode. Thus the current requirements are negligible and the device can be considered to be voltage operated.

[1] *Semiconductor Memories,* edited by Jerry Eimbinder, John Wiley & Sons, 1971, Chapter 11, "MOS Application Areas." Reprinted by permission.

A common misconception is that an MOS IC input, because of its high input impedance, is inherently noise sensitive. In practice, the IC's input is directly coupled to the output of the previous stage. Thus the impedance seen by the noise signal is the parallel combination of input and output impedance, and this is generally less than 10 Ω. Experience has shown that MOS integrated circuits can work efficiently in very noisy environments, such as alongside induction motors.

The output from an MOS integrated circuit has two important characteristics. First, it is a voltage output principally suited to driving other MOS circuits. Second, an MOS IC can be operated as a voltage-controlled resistor.

These characteristics allow MOS ICs to drive other circuits requiring only a few milliamperes of current; if greater currents are required, an output buffer can be provided.

The Arithmetic Function Unit

The arithmetic function unit performs some operation on data. Here the two prime considerations are speed and cost. If speed is the more important factor, a bipolar solution is probably called for. If cost is the main parameter, MOS is undoubtedly the type of circuitry to use.

It is unusual with MOS to supply a specific add or subtract function. Generally this operation is so straightforward that it is provided wherever it is required. This is an important point, since with bipolar circuitry it is common to provide a general add/subtract unit that is time multiplexed to meet the various needs in the system. This method obviously complicates the control logic, and it also means that uncomfortably high circuit speeds must be used to achieve a lower overall system speed. With the MOS approach, arithmetic units are provided as required, thus simplifying the control logic and making circuit speed and system speed fall more closely into line. It is important not to confuse circuit speed with system speed.

MOS techniques are currently proving very useful in counting and dividing applications. There are currently circuits that perform bidirectional decade counting with binary-coded decimal (BCD) outputs and presetting. Long divider chains giving many decades of division are also easily realized with MOS. One of the simplest MOS circuits is the shift register, and there are a great number of uses to which it can be put; for example, long divider chains or random number generations can be formed readily using feedback techniques with shift registers. Clock frequencies in this application can go up to 5 MHz. In addition to straightforward arithmetic functions, there is generally a need for more sophisticated functions. Again, shift register techniques can be used to good effect. For example, it is easy to construct a digital differential analyzer using these techniques, and the element can then be put to other uses, such as providing exponential and logarithmic functions.

A read-only memory (ROM) can be programmed to provide any required function—usually by considering the ROM to be equivalent to a look-up table. Thus square root functions, sine-cosine functions, and logarithmic functions can be readily performed. Interestingly, this device affords a means of performing functions at high speed, for although circuit speed is slower than that obtainable with bipolar circuitry, there are no subroutine or carrying delays. Thus there is no need for a sophisticated speed-up function such as a look-ahead carrying system.