MOS DIGITAL ELECTRONICS

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PREFACE

As a result of the incredible progress in micro-electronics, the sizes of MOS transistors have been fast approaching physical limits. The feature size has become comparable to the diffraction limit of the visible light, commonly used in the making or processing of the tiny integrated circuits. The complexities of electronic systems that can be put or integrated on a single solid-state chip have also been increased to the point that it is hard to test and verify the product circuit. But once the reliable circuit or its solid-state chip is made, it is of tremendous usefulness, efficiency and economy. On the other hand, the making of MOS circuits has reached an orderly maturity, in spite of the fact that any real progress is tedious and difficult. Needless to say that there is a wealth of technical information in forms of books and journals, which describe systematically the digital MOS circuits from the basic physics of devices, logic to large systems and their fabrication processes.

Digital electronics involves discreet signals and events, precisely dictated by appropriate logic functions. Fundamentally all complex functions are built upon a few elementary simple logic. Solid state circuits perform logic as continuous physical changes, which represent and result in corresponding designated discreet stable logic levels. It is the purpose of this book to take the approach that emphasizes the physical changes, while carefully keeping track on how the digital functions result.

It begins with the basic necessary physical concepts for the single MOS transistor, and shows how each part of the transistor works together to give continuous outputs, as the current-voltage equation of I_{ds} approximates. The operations of various components of the inverter in the NMOS or CMOS are described in different voltage-current regions. These give then a total picture of the inverters, whose configuration is the starting points of the MOS logic family.

A commonly used jargon in describing the solid state circuitries through their evolution to smaller dimensions is scaling. For it, there are many new physical and practical problems that need to be studied in detail. Some essential characteristics remain in the current-voltage relation of the MOS transistor. The considerations of the scaling with respect to sizes, resistances and voltages as well

as characteristic time constants are treated in a unified equation for MOS devices (transistors and inverters) for each of its sub-family with various clever schemes and load devices.

The designs of the MOS logic family are flexible. They do not necessarily need a fixed configuration in terms of circuit structures and layout. This book presents many examples of basic logic circuits and common logic functions, as they are realized in the MOS families. The complex logic functions therefore can be constructed in many ways to achieve minimum circuit complexities and areas and maximum speed and power saving. Using this freedom, this book further emphasizes the advantage in building clocked synchronous systems or logic state machines. The central roles of efficient simple clocked data registers and highly optimized logic are demonstrated. Many basic clocked logic devices are introduced. Some of them are described as simple finite state logic machines.

The usual devices with enhancement or depletion loads consume considerable power, because the load devices may be on or current carrying most of the time, while the driver devices are on half of the time on the average. Considerable amount of power can be saved if the load device can shut off for a large fraction of the time. For such purpose, the (Complementary MOS) CMOS family of logic circuitry is introduced. The driver group and load group or devices are seldom on at the same time. A current logic scheme is used for the finding and determination of the complementary nature of the CMOS logic devices. For a clocked CMOS system, further circuit saving scheme can be used, so the number of load devices are reduced to a minimum. Again the use of the current logic is extended to cover the operation of this case.

The role of all capacitances in a MOS circuit is critical. It stores the charges and affects the speed of the circuits, as it charges and discharges. The book discusses several topics, concerning the physical effects of the capacitances. Its effects can be minimized to make the circuit faster. It can also be utilized to perform many unusual operations.

For large and more complex logic systems, one would need to build more powerful MOS transistors, more organized ways to get the minimized logic and states. This is especially important and necessary in the modern computerized design environments. In the second half of this book, formal ways to achieve such goals is introduced. And the methods so developed can be put into the computer for large tasks for automatic and systematic solutions, as they are commonly carried out.

With all the basic elements understood and defined, one then can proceed

to consider larger logic systems. The starting point is the finite state machine. The state machines are more complex and have the ability to make choices of next steps or decisions based on the present state of the machine as represented by the outputs and the present state of the input variables. They are realized by devices such as programmable logic arrays or programs stored in memory. The commands and communications among different logic machines or components are carried out or linked on buses.

The book also presents the ways the circuitry and systems can be described on paper and particularly by softwares. The designs and their descriptions therefore may resemble software programming. The information is organized to provide connectivity information and layout of circuitry over the two-dimensional chip area. The connectivity is contained in functional descriptions with associated input and output logic variables. When this is realized in actual layout, the physical structures have many processing layers, which are summarized in representative symbols. The symbols are relatively few; they provide an efficient method of descriptions.

There are many layout styles; they are optimized in different specific applications and design requirements. For example, the gate-array is used for relatively simple circuitry; standard cells can provide fast turn-around and efficient logic building blocks; and fully custom-design could give optimized circuitry for the entire system. Simple rules for layout are given, as examples, for general considerations.

Finally, one must know whether the design can work as expected. This is related to the problem of simulations and debugging. Present design systems and methodologies rely on software descriptions of the intended circuits to alleviate complexities and inflexibilities of the making of actual model of the circuitry, before the final solid-state chip is made. The modifications are then easier. With the circuit descriptions, one can simulate and test the circuit to gain quite complete understanding of the design. The book discusses and introduces two major extreme kinds of software simulators: logic and physical. Other intermediate kinds may have some advantages of each.

This book assumes background courses in elementary electricity and differential equations. It really requires good grasp of the physical contents from the mathematical equations and the circuitry. The second half of the book requires some knowledge of discreet mathematics and computer programming to appreciate fully the aims of the various presentations, which lead to automation of error free designs. The concepts are developed with actual basic

circuits and their applications in mind. This book has provided examples for the gists of discussions. It is most important to work with actual circuits to see how the concepts and some abstractions are realized, developed and expanded in practical large systems, so that concepts and their potentials are understood in terms of and based on concrete objects and experiences, among complexities.

*April, 1987
New York*

Stephen Shao-Chung Cheng

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