

Very Large-Scale Integration Circuit and Its Current Status Analysis

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Abstract. The development of Very Large Scale Integration (VLSI) has become very relevant to our lives, and although many of the technologies have matured, scientists are still actively exploring and innovating them. This article is a basic introduction to the composition and advanced technology of large-scale integrated circuits, focusing on transistors and the basic components it consists of, as well as the design of integrated circuits, manufacturing and measurement technology. Very Large Scale Integration Circuit, the transistor is the most basic component of the original, to the low-power CMOS tube is the most widely used, they form a logic gate and storage elements, to achieve a variety of basic functions of the circuit, while the circuit also exists to provide signal distribution and interconnection of the clock network, the optimization of the design of the contemporary research is also a hot spot. In recent years, the progress of the chip can not be separated from the development of new technologies, SOC technology, low-power technology and detection technology plays an important role in the promotion.

Keywords: Very Large-Scale Integration, transistor, CMOS tube, SOC technology, low-power technology, detection technology.

1. Introduction

Very Large-Scale Integration Circuit (VLSI, Very Large-Scale Integration Circuit) is a technology that enables highly integrated electronic systems by integrating hundreds to millions of transistors and other electronic components onto a single chip. Very Large-Scale Integration Circuits have a wide range of applications in various fields, including computers, communications, consumer electronics, and medical devices. They can realize complex functions such as processing and storing data, graphics acceleration, signal processing, etc. Very Large-Scale Integration Circuits will continue to increase in size and functionality as technology continues to evolve, driving progress in the electronics industry.

In recent decades, Very Large-Scale Integration Circuits have evolved according to Moore's Law: the number of transistors in an integrated circuit chip doubles every two years [1]. Chips have been reduced in size proportionally to this law to achieve lower cost, higher speed, and lower power consumption. However, along with the size reduction, many physical problems have been highlighted, such as short-channel effect, parasitic resistance, parasitic capacitance, etc. In order to break through these problems, scientists have invented a number of new devices. In order to break through these, scientists have invented stress silicon technology, mixed orientation technology, FINFET technology and so on. At the same time, in order to reduce the power consumption of highly integrated, scientists invented a new type of tunneling transistor. Currently, scientists are no longer only limited to the manufacturing of VLSI, in its design, packaging and testing there are also a lot of breakthroughs, such as the integrated system-on-chip (SOC) and so on.

This paper is committed to the public in this era of information technology to do an entry-level popular science content, mainly introduces the basic components of the VLSI, as well as a variety of components constitute the basic unit, and introduces the current status of the VLSI as well as SOC technology, low-power and test-related content.

2. Basic Components of Very Large Scale Integration Circuit

Very Large Scale Integration Circuit contains several basic components or units, including logic gates, memory units, clock networks, wires, power supplies and input/output interfaces. Different power supplies provide different currents and voltages, wires are responsible for signaling and supplying current, and the others have their own roles to play, together forming a unified whole

2.1. Transistors

Transistors are the most basic as well as the most important units of VLSI chips, which are used to control the flow of current and for digital signal processing. Transistors can be categorized into switches, amplifiers, voltage regulators, oscillators, etc. according to their functions. According to the different structure and working principle, they can be divided into two types: Metal Oxide Semiconductor Field Effect Transistor (MOSFET) and Bipolar Transistor (BJT). However, MOSFETs are more widely used in VLSIs due to their low power consumption, high speed, small footprint, etc. MOSFETs can be broadly categorized into enhancement MOSFETs, depletion MOSFETs, and CMOS. Enhancement MOSFETs require a gate voltage higher than the threshold voltage for the charge to form a channel in the field effect transistor to allow the current to be conducted. Depletion types, on the contrary, require a voltage below to conduct, and therefore have more conduction capability than enhancement types. The metal-oxide-semiconductor (CMOS), on the other hand, uses both NMOS and PMOS in its fabrication, and it utilizes the switching characteristics of both types of tubes, as well as logic inversion, to implement various logic functions and form complex circuits [2]. The power consumption is very low as CMOS itself consumes almost no energy at rest and only a small amount of energy during state transitions. It is widely used in chip and circuit design by taking advantage of the strong anti-interference characteristics of the complementary NMOS and PMOS, coupled with its own high degree of integration.

2.2. Logic Gates

Logic gates are the basic building blocks of digital circuits used to process and manipulate binary signals, which consist of transistors in various combinations and connections. The output of an AND GATE goes high only when all inputs are high. A simple two-input AND GATE can be realized using two NMOS transistors and one PMOS transistor. The two inputs are connected to the gates of each of the two NMOS, and the sources of the two NMOS are connected to the V_{dd} supply and to the source of the PMOS. The drains of the NMOS and PMOS are connected together as the outputs of the AND GATE. The output of the OR GATE goes high only when at least one of the inputs is high. A simple two-input OR GATE can be realized using two PMOS transistors and one NMOS transistor. The two inputs are connected to the gates of each of the two PMOS, and the sources of the two PMOS are connected to the V_{dd} supply and to the drain of the NMOS. the gate of the NMOS is used as the output of the OR GATE. The output of the NOT GATE is opposite to the input. A simple NOT GATE can be realized using a PMOS transistor and an NMOS transistor. The input signal is connected to the gate of the NMOS, the gate of the PMOS is grounded, and the source of the NMOS is connected to the V_{dd} supply and to the channel of the PMOS. the drain of the NMOS is used as the output of the NOT GATE. And other gate circuits can be composed by the above three logic gates through logical relationships. Various kinds of logic gates can be combined together to build more complex digital logic circuits, such as adders, multipliers, multiplexers, etc.

2.3. Memory Cells

The memory unit also consists of various transistors. It not only temporarily stores calculation results and long-term storage of programs and data, but also enables data transfer, data processing, and program control, and plays a vital role in the complex calculation as well as control tasks of the chip. Memory can be categorized into two types, static memory (SRAM) and dynamic memory (DRAM), which are used for applications such as cache and main memory, respectively.

SRAMs use a flip-flop circuit to store data. The flip-flop circuit consists of several transistors, usually two complementary CMOS (common gate, common source) transmission gates. One of these transistors is used to build a bistable flip-flop, which can store one bit of data. SRAMs form a memory cell by arranging these flip-flops into a matrix. Because SRAM's memory cells are based on flip-flop circuits, they can be read and written quickly, but take up relatively more chip area.

DRAM uses a capacitor to store data and its transistor is used to control the charging and discharging process of the capacitor. DRAM memory cell consists of a capacitor and a transistor which is used to control the data stored in the capacitor. For writing, the charge is charged into the capacitor and for reading, the charge in the capacitor is read through a sense line. Due to the simple structure of DRAM memory cells, they can be arranged more closely together to provide higher storage density. However, DRAM requires periodic refresh operations to keep the data correct and therefore has some limitations in terms of access latency and system complexity.

In addition to this, there are memories such as flash and EEPROM in the VLSI. Flash memory is a non-volatile memory that is typically used to store firmware, operating systems, and other programs. EEPROM is an erasable memory that allows data to be read and written repeatedly.

2.4. Clock Networks

In the design of a VLSI, it is very important to provide a suitable clock network. Its most basic function is to provide a unified timing control signal to ensure that the various modules of the chip operate in a defined time sequence. Through the distribution and coordination of clock signals, it can ensure that the operation of each module of the chip is carried out under the correct clock beat, thus ensuring the normal operation of the whole chip.

The clock network consists of a clock line, a clock power supply, and a clock distribution circuit. The clock line is the main component of the clock network, which is responsible for transmitting the clock signal from the clock source to each module in the chip. The clock distribution circuit is responsible for distributing the clock signal to each module in the chip. It includes clock buffers, clock dividers, clock selectors, etc. The clock buffer is used to amplify and drive the clock signal to ensure that the signal is accurately transmitted to the target module. The clock divider is used to divide the clock signal to provide clock signals of different frequencies. The clock selector is used to select the desired clock signal from multiple clock sources.

However, the design of different clock networks often has an impact on the performance of the chip. Reasonable layout of the clock lines and reduce the amplitude change of the clock signal, slope, etc., can reduce the electromagnetic interference between the clock lines, and at the same time reduce the chip's sensitivity to external interference, improve the electromagnetic compatibility of the chip and so on. Therefore, the design and optimization of the clock network is an important part of the system design, can be considered from the following aspects, such as rational planning of the clock wiring and clock distribution circuit design; design of the clock tree (composed of clock lines, clock distribution circuits and clock buffer network), taking into account the delay of the clock signal, power consumption and electromagnetic interference and other factors.

3. Current Status of Very Large Scale Integration Circuits

In the past days, the development of the chip follow Moore's law development, in order to match the chip size reduction, photolithography wavelength also continued to shorten, now known to be the shortest is produced by the Netherlands ASML EUV, its wavelength is as small as 13.5 nm. However, with the reduction of the chip size, a variety of physical level of the problem is endless, such as the short channel effect, parasitic resistance, parasitic capacitance, etc. To solve these problems, scientists have invented FINFET transistors to solve the short channel problem, the invention of copper interconnections to solve the problem of parasitic resistance, etc. [3] In order to solve these problems, scientists have invented FINFET transistors, gate nanowires to solve the short-channel problem, and copper interconnects to solve the parasitic resistance problem. At the same time, along with the size

reduction, chip power consumption is increasingly high, the existence of the device power consumption limit makes the current device technology development is shrinking from the same proportion of the golden age (happy scaling era) towards power scaling (power scaling) of the post-Moore era (post-Moore era), to solve the excessive power consumption has become the hot spot of the research in recent years. The solution to excessive power consumption has become a hot research topic in recent years. [4] It can be said that the improvement of chip performance cannot be separated from the support of various advanced technologies.

3.1. SOC Design

As the technical difficulty of miniaturizing chips increased, scientists began to focus on designing more chips to meet market needs, and so systems-on-chip (SOCs) were born. A SOC is a system-on-chip (SOC) in which a supplier provides the core of a common or general-purpose circuit, and the circuit is designed at the system level by a Specialized Integrated Circuit (ASIC) designer. [5] Such single-chip systems can integrate modules such as CPU, DSP, RAM, RF, A/D and D/A converters. Unlike simply reducing the size, SOC are functionally integrated. Also, within the circuit, the modules are connected via a high-speed, low-latency internal bus, which improves the efficiency of data exchange, resulting in improved system performance and responsiveness, and the production cost becomes lower.

SOC technology cannot be realized without the maturity of embedded design. The most important feature of embedded design is the use of IP cores, which are pre-designed circuit function modules for use in ASICs or FPGAs/CPLDs. [5] The introduction of IP cores allows the designer to save a lot of design time by only having to consider other parts of the design and the interconnections with the IP cores. Another major feature of SOC is the increased use of software development. By using software, SOC chips can become highly flexible and programmable. The software can be programmed to realize different functions and business logic, making the SOC chip adaptable to various application scenarios and needs.

Functionality can be customized and updated more quickly with software than with customized hardware solutions. The same results can be achieved more quickly through software updates and optimizations than by designing and producing new hardware versions to implement new features. In addition to this, software plays an important role in system integration and interactivity, as well as in updating and upgrading the functionality of the SOC chip. The simultaneous design of hardware and software also puts high demands on designers and requires tacit cooperation between teams. Figure 1 shows the SOC design flow based on IP modules.[5]

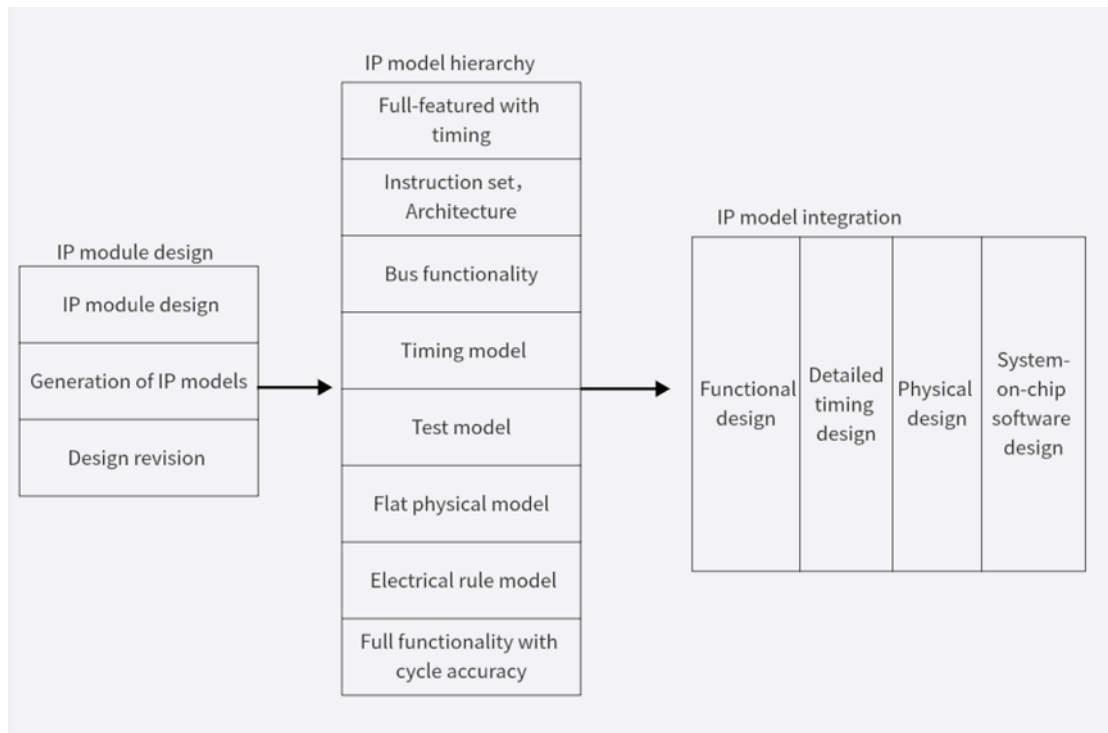


Fig. 1 SOC design based on IP modules. (picture credit: Original)

3.2. Low power design

As scientists pursue a higher degree of integration of chips, the problem of increasing power consumption on the chip is also becoming more and more prominent, and excessive heat generation also makes the performance of the chip somewhat lower. The total power consumption of an integrated circuit is divided into three parts: dynamic power consumption, static power consumption and circuit interconnection power consumption. [6] Dynamic consumption is mainly caused by changes in the state of the circuit, such as the short-circuit current formed by the conduction of the MOS tube and the consumption caused by capacitor charging and discharging (also known as switching power), of which the switching power consumption accounts for the main part. Static consumption, on the other hand, is not caused by component changes, and it mainly consists of leakage current and waiting current consumption. Leakage current consists of reverse-biased junction leakage current, gate leakage current, and the tiny subthreshold current that exists between the source and drain below the threshold voltage; whereas waiting current is a natural phenomenon that refers to the gradual drop in voltage due to charge leakage when the circuit maintains a level state.

According to the principle of static consumption, we can reduce the leakage current and thus reduce the static consumption by increasing the threshold voltage, trihydrazine technology can solve this problem, and can also be reduced by using high K material instead of silicon dioxide and other methods to reduce parasitic capacitance. Another common method is to control the turn-on voltage, it is designed with the idea of having the power supply turn off when the CMOS tube is idle, for this scientist add a sleep transistor in front of the gate circuit to control it. This approach reduces the performance of the chip, but the reduction in power consumption is significant.

The reason for the formation of dynamic consumption can be seen, it is mainly related to the clock frequency, the voltage of the power supply and the load of the circuit. From the power consumption analysis, it is known that the clock frequency and dynamic power consumption are directly proportional to each other, so reducing the clock frequency is an effective way to reduce dynamic power consumption. [7] Flexibly changing the frequency according to the different scenarios is one of the most commonly used methods nowadays, and this method is often used together with lowering the supply voltage to jointly reduce the power consumption. Similar to the method of eliminating static power consumption, shielding the clock network while performing certain tasks is also

commonly used, and this method also reduces the consumption of cabling due to high frequency at the same time.

Of course, it is also possible to use a lower power consumption transistor to solve the problem, and scientists have invented a new type of tunneling transistor on this basis. The tunneling transistor is a device based on the operation principle of carrier interband tunneling effect, and its subthreshold slope is lower than that of the previous transistors, which enables it to operate at very low voltage and realize ultra-low power circuits. [8]

3.3. Testing technology

Testing is carried out throughout the design, manufacturing and packaging of VSLIs, and as chips become more and more integrated, testing becomes more and more difficult. Testing of ICs can be broadly categorized into three types, namely, design verification testing, mass production testing and application verification testing. Design verification test is carried out in the chip test stage, is the basic function and performance of the chip all aspects of the test, including the product in the three-temperature conditions of the functional test, static characteristics of the parameter test and dynamic characteristics of the parameter test, its role is to make corrections to the design, to determine the boundaries of the device work parameters in order to formulate the final device datasheets, and for the production of the test to develop a suitable test program. The mass production test eliminates unqualified products in the mass production process. Application verification test is to test the chip in different applications in a variety of limit data test, often different users test content is not the same.

The main components of testing include circuit function testing as well as circuit parameter testing. Commonly used methods include scan path testing, built-in self-testing, and boundary-scan testing. Scan path test is commonly used in timing circuits, which abstracts the timing circuit into a flip-flop and a circuit network, and then replaces the flip-flop with a scanning flip-flop to achieve the scanning purpose. Built-in self-test (BIST) method is to add the test network inside the chip at the beginning of its design, which simplifies the test, but increases the complexity of the chip and puts higher requirements on the design. According to the needs of different fault types, the circuit of BIST test can also adapt to changes, either memory, a logic circuit or other analog circuits, etc., in the use of the split into memory BIST and logic BIST.[9] Scanning path test, on the other hand, is a scanning test of the connection between the chip pins and the core logic. This is because the interfaces of different parts of the chip produced by different manufacturers may be different and must be standardized so that a uniform test interface can be used between different manufacturers.

At present, IC test equipment mainly includes ATE test system, probe table and sorting machine. Among them, ATE is the core machine for detecting chip performance. China's chip test equipment development started late, weak technical reserves, the current stage of China's integrated circuit ATE is basically monopolized by foreign countries. According to statistics, the U.S. Teradyne (Teradyne), Japan Dewan (Advantest), the U.S. Agilent (Agilent) and the U.S. Corydon (Xcerra) occupies more than 80% of the domestic market share of integrated circuit test equipment. Especially in the high-end field, Japan Advantest's V93 series equipment and Teradyne's UltraFLEX equipment, representing the highest level of IC test equipment. [10]

4. Summary

Although many of the technologies of integrated circuits have matured by now, research and innovation by scientists around the world is still in full swing. This paper starts with the classification of transistors and describes the advantages and disadvantages of NMOS, PMOS and CMOS. The paper then discusses the various basic components of VLSI composed of transistors, such as gate circuits, clock networks, etc., and categorizes them to clarify the role of different devices. This paper then focuses on the current state of integrated circuit development, focusing on the current advanced technology of integrated circuits. Firstly, it introduces the SOC technology commonly used in high-end chip design, explains the concept of SOC, the process and its core technology, then explains the

source of high-power consumption of the chip in the post-Moore era and the idea of solving them, and then talks about the concept of test technology and the development of the domestic and international development situation. Very Large-Scale Integration Circuit has profoundly changed people's lives, and will promote emerging industries such as, cloud computing, artificial intelligence and so on to maturity. This paper is a summary of the contributions made by previous and current generations in the field of integrated circuits and is a reference for those who are new to this field.

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