

Systematic Analysis and Research on Integrated Circuit Design Optimization

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Abstract. After decades of development of integrated circuits, there has been great progress in all aspects. These advances are reflected in the optimization of manufacturing processes and circuits. When designing a circuit, considering the production cost and the performance of the circuit, the optimal design of the circuit is always a very important link. In this paper, two kinds of optimization ideas are introduced. One is from the point of view of the physical design of the circuit, two methods are introduced, which are adjusting the input power and reducing the circuit device. The other is to optimize the circuit from the point of view of algorithm. Genetic algorithm and simulated annealing algorithm are introduced. After optimizing the circuit, the circuit energy consumption is reduced, the circuit delay is reduced, the circuit runs faster, and the overall performance is also improved. In the future, with the development of related technologies, the optimization of integrated circuits will be faster.

Keywords: Integrated circuits; optimization; algorithm.

1. Introduction

An integrated circuit refers to a collection of frequently used electronic components, such as resistors, capacitors, and transistors, along with the interconnections among these components. Through the semiconductor fabrication process, they are meticulously combined to create a circuit with a specific function. This technology involves integrating semiconductors, resistors, capacitors, and other essential components necessary for a circuit to perform a designated function onto a compact silicon substrate. Subsequently, these integrated elements are meticulously interconnected, soldered, and encased within the confines of an electronic device's protective housing [1].

The realm of integrated circuit technology encompasses both chip fabrication techniques and design methodologies. Its essence lies predominantly in the adeptness with which processing equipment is wielded, processing techniques are executed, packaging and testing are conducted, and mass production is streamlined. In this article, methods of optimizing the integrated circuit will be introduced. The first aspect is from the point of view of physical design, introducing the adjustment of input power and the reduction of electronic devices used in circuit design, and then introducing some study cases to analyze the optimization results. Another aspect is to introduce the optimization of integrated circuits at the algorithmic level. This paper will introduce two kinds of circuit parameter optimization algorithms, one is genetic algorithm, and the other is simulated annealing algorithm. Using these algorithms will get better circuit parameters, so as to get the purpose of optimization.

2. The development of integrated circuit and its optimization necessity

2.1. History of integrated circuit development

The origin of integrated circuits can be traced back to the 1950s. At that time, Bell LABS and Texas Instruments in the United States were studying how to integrate multiple transistors together to form a complete circuit system. In 1958, Jack Kilby and Robert Noyce successfully built the first integrated circuit at Texas Instruments, which consisted of a transistor and several resistors. This marked the birth of the integrated circuit [2]. In the early 1960s, small-scale integrated circuits began to appear. They typically contain 10 to 100 transistors and can be used to make both digital and analog circuits. The manufacturing process of this integrated circuit is relatively simple, the cost is also

relatively low, so it has been widely used. In 1963, F.M. Vanlass and C.T. Saah first proposed CMOS technology. Later, in the mid-1960s, mid-scale integrated circuits began to appear. They typically contain 100 to 1,000 transistors, which can be used to make the controller, memory and other components of a computer. The manufacturing process of this integrated circuit is more complex, requiring the use of lithography technology and chemical etching technology, and the cost is relatively high. In 1966, the United States RCA company developed CMOS integrated circuits, which laid a solid foundation for the development of large-scale integrated circuits today, which is a milestone. By the early 1970s, large-scale integrated circuits began to appear. They typically contain 1,000 to 10,000 transistors and can be used to make high-performance electronics such as microprocessors and memory chips. The manufacturing process of this integrated circuit is very complex, requiring the use of high-precision processes such as lithography technology, chemical etching technology, and ion implantation technology, and the cost is also very high. In 1971, the world's first microprocessor, the 4004, was introduced by Intel, using the MOS process, which was a landmark invention. In the early 1980s, very large-scale integrated circuits began to appear. They typically contain 10,000 to 100,000 transistors, which can be used to make high-end electronics such as high-performance computers and communication devices. The manufacturing process of this integrated circuit is more complex, requiring the use of higher precision processes and more advanced equipment, and the cost is more expensive [3]. Since the 1990s, the level of integration has continued to improve, so that the chip can accommodate hundreds of millions of transistors, while the function is more diversified, covering various fields such as computing, communication, entertainment and so on. Fig 1 shows the timeline of the development of the integrated circuits.

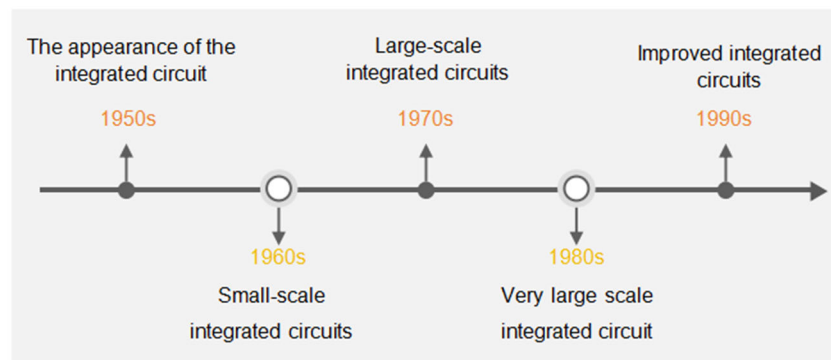


Fig. 1 The timeline of the development of the integrated circuits (Photo/Picture credit: Original)

2.2. Integrated circuit development challenges

With the development of the integrated circuits, the manufacturing technique of the integrated circuits has been promoted. The material to produce a single device has also been better. However, at the level of integrated circuit design, there are many ways to improve. A large integrated circuit needs to use thousands of basic devices, which undoubtedly increases the complexity of the entire system, making the circuit will have higher delay, more energy consumption, and other problems, while the cost is high [4]. Enhancing design quality yields a cascade of advantages, rendering the circuit system notably more efficient, economically viable, and power frugal. This confluence of virtues invariably facilitates streamlined manufacturing endeavors. Thus, in the complex combinations that form highly complex integrated circuits, the task goes beyond merely meeting the logical functional requirements of the customer. This imperative entails a comprehensive assessment encompassing system-wide efficiency dynamics and fiscal prudence. Therefore, the design process requires a delicate balance to expand functionality and economic viability. The quest for chips, characterized by increased operational efficiency and reduced costs, has plagued the field of digital circuit design, generating a continuous drive for innovative solutions and enhanced optimization methods.

3. Optimization method at circuit design level

In the process of the development of the integrated circuit, the goal to design a better chip has not changed. Designers from all over the world have figured out various kinds of methods to make the circuit better on the physical level. This article will introduce some common methods to optimize the circuit and the positive effect after the circuit being altered.

3.1. Modify the power supply of the digital circuit.

In the domain of digital circuits, a diverse array of inputs and outputs joints together, with the power supply predominantly serving as the bedrock for input energy or signal propagation. When the signal passes through the intricate circuit, the inevitable power dissipation ensues, and the entire system is dissipated. It's noteworthy that an amplification in the power supply magnitude correlates with a commensurate escalation in the circuit's power dissipation. Intriguingly, such an elevation in the power supply can potentially exert undue stress on select transistors, potentially culminating in their impairment. Paradoxically, an overly elevated power supply engenders a conundrum of damage and inefficiency. On the contrary, insufficient power can cause numerous repercussions, making the circuit not work, or sometimes preventing the realization of specified functional requirements. Striking the delicate equilibrium between power supply and circuit functionality is an intricate feat, necessitating meticulous calibration to avert compromise between efficiency, operability, and system integrity. Power supply optimization plays a crucial role in the realm of digital circuit design, aiming to strike a delicate equilibrium between performance, power efficiency, and dependability. Through adept manipulation of the supply voltage, it becomes feasible to curtail power consumption, protract the longevity of the circuit, and mitigate thermal dissipation, all while ensuring that the stipulated performance benchmarks are duly met. This intricate interplay between voltage modulation and circuit dynamics engenders a comprehensive strategy that ushers in a multitude of benefits, encompassing energy conservation, enhanced sustainability, and augmented overall system robustness. Xianqing Yan has put forward a point that modify circuit power supply to a proper range will avoid the high-speed digital circuit to be damaged and will save energy [5].

3.2. Use fewer transistors in the circuit

The utilization of fewer transistors in a circuit can yield several advantages, encompassing aspects of design simplicity, power efficiency, and cost-effectiveness. A circuit with fewer transistors tends to have a simpler and more straightforward design. This can result in reduced complexity during the design and verification phases, leading to shorter development cycles and potentially fewer design errors. Transistors are also the primary contributors to power consumption in a circuit. By using fewer transistors, the overall power dissipation of the circuit can be lowered. This is particularly beneficial for applications where power efficiency is critical, such as in battery-operated devices or energy-efficient systems [6, 7]. Each transistor occupies physical space on the integrated circuit. Using fewer transistors can lead to a smaller chip area and reduced overall size of the circuit. Fewer transistors will reduce manufacturing complexity and potentially lower production costs. With fewer components, the overall reliability of the circuit can improve. Fewer transistors mean fewer potential points of failure, resulting in a more robust and dependable system. In some cases, circuits with fewer transistors can operate at higher clock frequencies due to reduced capacitance and propagation delays. This can lead to improved performance in terms of speed and throughput. Fewer transistors can simplify debugging and testing processes. Identifying and rectifying issues becomes more manageable when dealing with a reduced number of circuit elements. Yu Zhao introduced in an article that an adder could be built in 28 transistors originally. The full adder design is slightly ahead based on CMOS logic, and a new 8-tube 1-bit full adder has been realized in China. Compared with the original full adder, it has great advantages in power consumption, speed, and power delay product [8].

4. Algorithmic optimization

With the advancement of computer technology, computers and related algorithms can be used to assist the optimal design of circuits. The optimization here refers to the optimization of the relevant parameters of the components in the circuit, such as the size of the resistance and capacitance, and the size of the transistors. In this article, we will introduce some algorithms that have been used frequently in recent years, and their optimization effects on circuits.

4.1. Genetic Algorithm

Genetic algorithm is an optimization algorithm inspired by biological evolution. It simulates the processes of heredity and evolution to find optimal solutions to problems. The genetic algorithm starts with a randomly generated initial population, with each individual representing a potential solution to the problem. The size of the population and the encoding mode of the individual are important parameters of the algorithm, in the circuit is the transistor size, resistance value, capacitance value, etc. The fitness function is calculated for each individual to measure the degree of its superiority in the problem. The fitness function is designed according to the characteristics of the problem, usually a function of the optimization goal, such as maximizing or minimizing a certain metric. In the selection operation, the principle of "survival of the fittest" in evolution is simulated, and individuals with higher fitness are selected as the parents to produce the next generation. The selected parent individual performs gene cross operation to produce a new offspring individual. Cross-operation simulates the process of gene exchange in biological evolution, and through the combination of genes, an individual with new characteristics is produced. After the crossover, some individuals are mutated to randomly change some of their gene values. A new population is then created, which contains both parent and offspring individuals. The fitness assessment, selection, crossover, and mutation operations are repeated until the stop condition is met [9]. In the optimization design of common gate, Jing Ba used genetic algorithm to optimize the source voltage, load resistance and width of MOS tube, and got the optimized parameters [10]. Ranran Zhou used rule-guided genetic algorithm to optimize the circuit, and the overall performance of the circuit is improved [11].

4.2. Simulated Annealing

The simulated annealing algorithm is a probability-based optimization algorithm inspired by the solid annealing process. It is used to find the optimal solution in the complex search space, especially for solving combinatorial optimization problems. In a simulated annealing algorithm, you first need to define an energy function, also known as a cost function or an objective function, to evaluate the merits of each solution. This function is usually the metric to be minimized or maximized, such as performance, cost, distance, etc. The algorithm starts with an initial solution that is randomly initialized in the search space or generated by other methods. This initial solution can be random, or it can be a heuristic solution to the problem. The algorithm introduces a temperature parameter, which controls the exploration and randomness in the search process. The higher the temperature is, the more easily the algorithm accepts the difference solution, and thus has a greater probability to jump out of the local optimal solution. The lower the temperature, the more the algorithm tends to accept the better solution. The algorithm searches for the optimal solution through several iterations. In each iteration, the algorithm selects a new solution from the neighborhood of the current solution. The selection of new solutions can be based on certain strategies, such as random selection, local search, etc. For the selected new solution, an acceptance probability is calculated according to the Metropolis criterion. If the new solution is better, then accept the new solution; If the energy of the new solution is higher, accept the new solution according to a certain probability. This probabilistic acceptance mechanism enables the algorithm to jump out of the local optimal solution and contributes to the global search. After each iteration, the temperature parameter is gradually reduced to reduce the probability of accepting the difference solution. This cooling strategy makes the algorithm gradually converge to the global optimal solution during the search process. The algorithm will terminate under

certain conditions, such as reaching a certain number of iterations and the temperature lowering to a certain degree. When terminated, the algorithm outputs the final found solution as an optimization result [12]. Pavitra Y J uses a simulated annealing algorithm to find a globally optimal solution to a given function. After the experiment, the circuit energy is saved up to 33.33% and the speed is increased by 2.0 times [13].

5. Conclusion

The first conclusion is that the optimization of the physical design of the circuit makes the circuit simple, and the same function can be achieved by using fewer devices, reducing energy consumption, reducing circuit delay, and improving speed. There are many functional modules in an integrated circuit, which can be optimized in design, and there is still a lot of work to be done in the future.

The second conclusion is that with the help of computer algorithm, the parameters in the circuit can be optimized, the power consumption can be reduced, and the circuit performance can be better. With the continuous development of computer technology, better algorithms can help designers find more suitable device parameters, so that the circuit performance is better.

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