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Original research article

Importance of low power electronic circuit design and its impact on energy consumption

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Abstract: In the modern world, Integrated Circuits (ICs) are an essential component of any electronic device, and it is practically impossible to imagine a world without them. When addressing energy consumption or environmental issues, many people, including researchers, tend to focus solely on power plants. However, today, there are billions of electronic devices, each containing numerous ICs, such as mobile phones, tablets, televisions, laptops, refrigerators, vacuum cleaners, cars, and more. In other words, a large portion of our modern energy consumption is attributed to electronic devices. Thus, reducing power consumption in each of these devices could significantly impact global energy consumption and environmental pollution. This paper emphasizes the importance of low-power Integrated Circuits and their potential to reduce worldwide energy consumption. It also briefly explores relevant technologies that contribute to energy efficiency in circuits, avoiding unnecessary complexities.

Keywords: low power; Integrated Circuit; fabrication technology; electronic devices; power loss; energy consumption

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1. Introduction

The increasing growth and widespread adoption of electronics, particularly portable devices such as smartphones, tablets, and laptops, is undeniable. **Table 1** shows the number of smartphone mobile network subscriptions worldwide from 2016 to 2022, with forecasts from 2023 to 2026[1]. With the rising usage of these devices, managing power consumption and battery life has become crucial.

Table 1. The number of smartphone mobile network subscriptions worldwide from 2016 to 2022, with forecasts from 2023 to 2026[1].

Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Smartphone users (billion)	3.575	4.303	4.907	5.436	5.758	6.165	6.422	6.719	6.936	7.158	7.322

This table shows that the number of users increases every year. Mobile phones are just some of the electronic devices that require energy consumption for their operation. In all these devices, power consumption and battery life play a fundamental role.

Nowadays, due to the increasing growth of portable devices such as mobile phones, tablets and laptops, or any device that needs a battery, maintaining the battery charge is important. Consequently, efforts are now focused on minimizing energy consumption to ensure efficient use of resources and reduce costs associated with energy consumption. Moreover, lower energy consumption also results in reduced waste heat, which can damage devices and lead to additional cooling costs, impacting device reliability.

Preserving and protecting the environment is one of the critical and important issues in the world. On the other hand, one of the major issues in the world is global warming[2]. The burning of fossil fuels in order to provide the required energy produces greenhouse gases, leading to air pollution. Furthermore, as a result of the depletion of the ozone layer due to greenhouse gases, global warming also occurs.

Some scientists and researchers believe that some problems, such as rising sea levels, are the result of irreparable damage to the planet by humans that lead to climate change. Amidst the global concern for environmental preservation, climate change is a significant issue. The burning of fossil fuels for energy production leads to greenhouse gas emissions and air pollution, contributing to global warming. To combat this, many scientists advocate for investments in clean energy and renewable resources.

As energy consumption continues to escalate, the environmental challenges grow as well. One way to address this is by reducing the energy consumed by electronic devices such as mobile phones and household appliances like televisions and refrigerators. Billions of devices in the world are used by humans, most of which use electrical energy. Thus, if it is possible to reduce power consumption in electronic circuits, the amount of energy consumed worldwide will be considerably reduced. In other words, since billions of devices worldwide rely on electrical energy, designing electronic devices with low power consumption can significantly decrease global energy consumption.

Rechargeable devices, like mobile phones, depend on power plants for charging. Therefore, if these devices can maintain their battery charge for longer periods, or consume less power overall, it would lead to a considerable reduction in global energy consumption. Now suppose that methods and technologies are developed to design electronic devices that consume less energy consumption, as a result, the amount of energy consumed worldwide will decrease dramatically.

This paper aims to straightforwardly explain the importance of reducing power consumption in electronic devices and the use of low-power electronic circuits. By doing so, it seeks to familiarize designers and the public with the reasons for their significance. The paper also provides an overview of reasons for power loss in ICs and transistors, as well as fabrication technologies useful for reducing power consumption.

2. Why Integrated Circuits are important?

On the one hand, most of the devices that are used include an electronic section, and today, Integrated Circuits (ICs) are the main part of any electronic circuit. On the other hand, each electronic device has several ICs and each IC has its own responsibility. Therefore, to reduce energy consumption, it is necessary to decrease the power consumed by the electronic section. In other words, in order to reduce energy consumption in devices, energy consumption in ICs should be reduced.

On the one hand, regarding each IC consists of many transistors, the power loss in transistors should be decreased to reduce the whole energy consumption in devices. There is a question about the importance of decreasing power loss in transistors! Why is power consumption really important in a transistor?

In 1965, Gordon Moore predicted that the number of transistors on a chip would double roughly every two years[3–8]. The study of Weste and Harris[3] shows that the number of transistors in Intel microprocessors dramatically has increased from about a few thousand in 1970 to about a few billion in 2005. Therefore, it is necessary to decrease the power loss in transistors.

Hence, some technologies are required to have low power loss. In other words, these technologies should be low power loss and low current leakage. Thus, in section 3, this paper reviews some fabrication technologies that are suitable for low-power applications.

3. Power loss and fabrication technologies

When it comes to designing a circuit, there is always a need to choose a technology that should be chosen according to the requirements. Energy consumption plays a vital role in choosing technology.

In general, power loss in transistors is divided into two main categories. The first category is related to the time the gate is ON and receiving information, and the second category is related to the time the gate is OFF called static power. Technology has an important role in terms of static power.

In theory, when the transistor is off, it should not waste power. But in practice, it is faced with a low current passing through the transistor called leakage current, which leads to power loss. On the other hand, part of these losses is related to new technologies that increase the leakage current. This type of loss has several subgroups, including subthreshold current, punch through current, Drain Induced Barrier Lowering (DIBL), Gate Induced Drain Leakage (GIDL), reverse bias diode and gate oxide tunneling.

When the gate-to-source voltage is below the threshold voltage, the transistor is in the subthreshold region or weak-inversion region. In theory, there is no current between the source and drain of a MOSFET. However, in practice, there is a current between the source and drain of a MOSFET called subthreshold leakage.

In new technologies, due to the shortening of the channel length, the drain and the source have become closer to each other. Therefore, the carriers are able to move between the drain and the source. This phenomenon creates a current called punch through.

In addition, due to the shortening of the channel length, the increase in the drain voltage leads to a phenomenon called Drain Induced Barrier Lowering (DIBL), which is considered one of the leakage currents.

Another leakage is called gate-induced drain leakage (GIDL) where the gate overlaps the drain. This leakage is caused by gate induction on a part of the drain that overlaps with it.

In a transistor, there are P and N regions. These regions may create a diode. If the diode is reversed biased, a low leakage current flow through it.

Each of these leakage currents may be in the range of a few nanoamperes to a few microamperes, which alone are not large. But in new electronic devices like laptops that include numerous ICs, there are a lot of transistors. For example, today the number of transistors in a microprocessor may be around several millions or several billions. As a result, the sum of these leakage currents will be very large, which causes a lot of losses.

Leakage currents depend on technology, and as the channel length of transistors gets shorter, these leakage currents are increasing. Also, static power depends on fabrication technology. Therefore, by choosing a suitable technology, it is possible to reduce power losses and improve the amount of energy consumed. Ultimately, by reducing energy consumption in transistors and ICs, the whole energy consumption worldwide can also be reduced.

This section reviews two fabrication technologies. These are among the most used ones and can be used for low power applications.

By reducing the leakage currents, it is possible to reduce losses at the technology level. In old technologies such as 250 nm, 350 nm and 500 nm, designers and researchers deal with supply voltages of more than 2.5 V and threshold voltages of more than 0.6 V. Static power is low in these technologies[9]. But these technologies are not suitable for high-frequency applications. Today, due to the growing demand of users for devices with high processing speed, there is a need for technologies that can operate at high frequency. In other words, it is predicted that high clock speed will be needed in the future[10]. These technologies suffer from high leakage currents. Therefore, the use of them leads to a dramatic increase in static power loss. Moreover, with the development of technology, the supply voltage has decreased[10], but the threshold voltage has not changed much.

New electronic devices such as laptops and smartphones use new technologies for high operation speed, technologies that have high leakage current, and due to numerous transistors in these devices, energy consumption dramatically increases. Considering that billions of mobile phones and laptops are used in the world, whole energy consumption increases drastically. Therefore, to reduce energy consumption in the world, one solution is to reduce energy consumption in devices such as mobile phones and laptops.

The most famous and widely used and at the same time the cheapest technology in the design of Integrated Circuits is Complementary Metal-Oxide-Semiconductor (CMOS) technology. This technology is widely used in digital circuits. Because power is lost only when switching, theoretically. One of the advantages of this technology is that it puts analog and digital parts together on one chip, which reduces the cost. On the other hand, what led to the development of this technology was its ability to reduce the length of the channel and thus improve its performance at high frequencies.

Despite the advantages that CMOS technology provides to designers and researchers, it also faces some problems. Among these challenges, problems caused by parasitic capacitors, sub-threshold slope, latch-up, short-circuit current and leakage currents can be mentioned[11]. Although this technology has its own perks, to design devices that consumed low energy consumption, there is a need for technologies to somehow overcome some of these challenges because CMOS technology faces limitations for applications that require low energy consumption.

There are two main problems with CMOS technology. The first challenge is related to the drain capacitor with the substrate and the source capacitor with the substrate, which limits the speed and increases the output capacitance. The second problem is related to the connection of the drain and source to the substrate, which causes the leakage current of the reverse-biased diode. In order to partially overcome the two mentioned challenges, silicon-on-insulator (SOI) technology has been introduced and it can be useful for low-power ICs.

To make a silicon-on-insulator (SOI) transistor, a silicon substrate is considered. Then an oxide layer is placed on it and a layer of silicon is placed on this oxide layer, and the transistor is made on it. This technology is called silicon on insulator.

The main difference between CMOS and SOI is the existence of an oxide layer that reduces parasitic capacitors and leakage current due to the removal of parasitic capacitors and the connection of the source and drain to the substrate.

SOI transistors can be divided into two categories: Partial Depleted Silicon on Insulator (PD-SOI) and Fully Depleted Silicon on Insulator (FD-SOI)[12]. The FD-SOI transistor has a thin body, which keeps the charge inside the transistor constant and prevents the body voltage from fluctuating. The second category is the PD-SOI transistors, whose body is thicker, and their fabrication is easier. However, the voltage of the body also changes as a result of the changing of charge inside the body. The threshold voltage also changes as a result of this.

The main advantage of the SOI transistor is the reduction of parasitic capacitance due to the presence of an oxide layer, which causes both the speed to increase and the frequency response to improve. On the other hand, the power consumption is also reduced due to the reduction of the output capacitors. Another important advantage is the reduction of the leakage currents. In these transistors, due to the presence of an oxide layer and buried oxide, latch-up does not occur[13,14].

The PD-SOI transistors suffer from the problem of memory effect[12]. This means that the voltage of the body depends on the past information. As a result, when the body voltage changes, the threshold voltage also changes. This makes it somewhat difficult to predict the behavior of the circuit. Therefore, the use of these transistors in applications like differential amplifiers is challenging. Also, there is a leakage current between the drain to the body and the source to the body. On the other hand, the presence of a bipolar transistor between the drain-body-source causes, if the drain voltage increases suddenly, this bipolar transistor to be momentarily turned on and causes the source and drain to be connected to each other.

4. Conclusion

This paper tried to show in a simple and effective way that there are innovative solutions to reduce worldwide energy consumption and to reduce energy consumption, you should not only think of power plants. This paper showed that given that there are many electronic devices in the world, such as mobile phones and tablets, an effective way to reduce energy consumption in the world is to reduce the energy consumed by electronic devices. This paper showed that in order to reduce the energy consumption in electronic devices, the energy consumption in ICs and transistors should be reduced. In this paper, some useful fabrication technologies for the design of electronic circuits with low energy consumption were briefly reviewed, and the features of each were briefly mentioned. The purpose of this paper was to draw the readers' attention to the importance of low power circuits and avoid complicating the issues.

Conflict of interest

The author declares no conflict of interest.

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