

Analogue and Digital Circuits: Characteristic Deconstruction, Scene Adaptation, and Selection Strategies

Chen Li *

Jinling High School Hexi Campus, Nanjing, 210000, China

* Corresponding Author Email: fiwjefijiqjweif@163.com

Abstract. As technology advances, circuit design remains a core topic among engineers, and how to select the correct circuits for specific electronic applications is well worth studying. Currently, research focuses on various application scenarios, including cost, design, high speed/frequency, and high accuracy/precision. For instance, consumer electronics prioritize low cost and miniaturization, while aerospace demands ultra-high reliability and anti-interference capability. This paper will first introduce the different functions of digital and analog electronics. Then, they will be analyzed in detail across different application scenarios, and real-life examples will be used to directly prove which type is more suitable for typical scenarios. Finally, it is found that different scenarios require different types of electronics. Sometimes, using only one type of electronics fails to work properly digital and analog electronics need to be combined to deliver the best performance. The conclusion is that circuit design and construction will be improved with the help of AI technology and new materials in the future.

Keywords: Analogue electronics, Digital electronics, Selection analysis

1. Introduction

Integrated circuit is the core foundation of nowadays electronic information industry, as technologies evolve, it converts the simple circuit integration in the early time into very highly complex chips, integrated circuit is driving electronic devices towards high performance, low power consumption and miniaturization. In the whole series of integrated circuit, analogue electronics and digital electronics are two main important branches. Digital electronics is an important branch of electronic technology, it is mainly about the production, transmission, processing and storage of digital signals, and it is based on digital logic, it is generally used in computer, communication and automation, it is focus on the process of digital signals, use logical circuit design and digital signal processing technology, to make the storage, transmission, calculate and control. It also converts continuous signals into discrete digital signals, and we always present them in binary, which only has numbers 0 and 1, the basic unit of it is the logic gates. Analogue electronics is not limited to old technologies nor obsolete in modern devices, analogue electronic technology mainly deals with analogue signals, which are continuous in both time and amplitude (such as sound waves converted into electrical signals). It processes signals through circuits composed of semiconductor devices (diodes, triodes, etc.) without complex conversion steps, relying on the direct transmission of voltage and current changes to achieve functions like amplification and filtering.

Nowadays, most devices tend to combine the digital and the analogue electronics. Analogue electronics has a very simple working method, and it is very cheap to build it, it excels at signal conversion the signals, but it has very low ability to against the interference from outside environments like temperature, moisture, and other conditions, so it always can't achieve high accuracy. While the digital electronics have the core of discrete signals, and not like the analogue ones, it has very strong ability against the interference, it also has very strong ability to encode information to ensure its safety, but it need to rely on the analogue electronics to realize the initial collection of signals and final converting, one of the drawbacks of it is that it cost much more than analogue electronics.

According to this, this essay will further explore the real use of digital electronics and analogue electronics in different usage situations. And will focus on the low power consumption, like internet

of things and some wearable devices that very important to limit the use of energy, and how to choose and design the circuit to realize long battery life, and some high precision situation, like the signal detector on the medical devices, or the accurate feedback in industry control, analysis how to use circuit characteristics to protect the high precision in signal processing, and in high frequency and high speed situation, like high speed communication system, some information processing system in high performance calculation, then find a way to make circuit realize the strict requirement in this situation. Also, in some simple control situation like lights and temperature control, it needs the simplest way to design a low cost and easy circuit to make it work.

The significance of this study can first make sure the core status of application scenarios in the use of circuit technologies, different scenarios needs will have a direct and obvious influence on the performance index and design ideas of circuits. Only accurately match the scene, then the efficiency of circuits can be fully exerted. On the other hand, by further analyzing of the application of the two types of circuits in various situations, it is expected to get better circuit design methods. These methods can effectively solve many problems faced in such as power consumption control, higher performance, and high frequency operating situation, also providing strong technical support for the development of more efficiency and integrated circuit with high performance systems and helping the integrated circuit industry realize new achievement, innovation, and breakthrough in the electronics industry area.

2. Differences in Digital and Analogue Electronics

2.1. Functions about Digital Electronics

The basic unit of a digital logic circuit is the logic gate processing unit, and memory generally stores data in binary form with the help of digital circuits [1]. Some errors may occur in digital electronics because the signal transmission methods of digital electronics are quite different. Digital electronics primarily uses 0s and 1s to represent information: it can convert analog signals to digital signals through A/D conversion, then transmit them after compression, encoding, and encryption. Finally, D/A conversion restores them to analog signals. During this process, quantization errors may occur. To avoid such errors, digital electronics uses serial or parallel encoding and automatically switches transmission modes based on data volume to prevent interference. One of the advantages of this transmission method is its strong confidentiality, as it can encode information using methods such as binary representation.

2.2. Functions about Analogue Electronics

Analog signals are represented as waveforms, characterized by continuity and prone to interference [2]. They are easier to use because they process signals directly, with no quantization error. Their working principle is close to the natural state of signal transmission, featuring a simple system structure and low cost. Because of its simple system structure, some high-tech devices either do not use this technology or adopt a combination of analog and digital electronics. Analog electronics, a fundamental subject in the field of electronic engineering, studies electronic devices and their applications in analog signal processing. In today's digital trend, although digital technology plays a leading role, analog electronic technology remains an indispensable foundation—especially in signal collection, processing, amplification, and power management. Analog signal processing has its own advantages in electronic technology operations: the system principle is simple, with no need for complex algorithm processing [1]. From smartphones to satellite communications, and from medical devices to industrial control systems, analog electronic technology is everywhere. With the development of artificial intelligence, the Internet of Things, and 5G technology, the demand for high-performance analog circuits continues to grow steadily, injecting new vitality into this traditional field.

3. Power Consumption

3.1. How Power Consumption Work in Digital and Analogue Electronics

The power consumption mechanisms of digital and analog electronics differ significantly. Power consumption is a core consideration for power-constrained scenarios such as portable devices and wireless sensor networks. The power consumption of analog electronics is mainly static—that is, when the circuit is in a no-signal or low-load state, it only needs to maintain the operation of simple components. As a result, there is no energy wasted on high-frequency switching actions. When enterprises use analog electronic technology, no complex operating procedures are required; besides enabling a faster overall process, it also helps effectively shorten the entire circuit cycle. This high operational efficiency has become the core value of this technology [3]. The power consumption of digital electronics is mainly dynamic, arising from the switching of logic gates or the charging and discharging of capacitors. Digital electronic technology adopts the sampling theorem, first sampling analog signals to ensure signal accuracy—thus, digital electronics achieves higher accuracy compared to analog technology [4]. This process, however, leads to additional power consumption. Driven by clock signals, transistors switch between cutoff and conduction states; each switching action wastes some energy, and dynamic consumption increases with clock frequency, making it clear that dynamic consumption is proportional to clock frequency. Although digital electronics can reduce standby power consumption by entering sleep mode, basic circuits like clock oscillators still have leakage power consumption. Moreover, when the device is turned on, ADC startup and data processing generate a momentary peak power consumption—this power consumption fluctuation poses a significant challenge to devices that rely on harvested energy for power.

3.2. How Power Consumption Work in Digital and Analogue Electronics

Thus, in low-power consumption scenarios, analog electronics is highly valuable in the medical field. Pacemakers, for example, rely on analog electronics: as they need to be implanted in the chest for long periods, they depend on a built-in lithium battery for power. Due to limitations on surgical trauma and patient tolerance, pacemakers must operate without external power for several years. During this period, they need to accurately detect cardiac electrical activity and deliver pacing pulses as required—low power consumption and high reliability are the core criteria for circuit selection, making analog electronics the preferred choice.

Assume that the core functional modules of a pacemaker—the cardiac electrical signal sensing circuit and the pacing pulse output control circuit—are both implemented using only analog circuits. When sensing cardiac electrical signals, the heart generates a weak electrical signal (approximately 0.5–4 mV) with each beat. This continuous analog signal is directly amplified by a low-noise amplifier, which suppresses human power frequency interference and body noise via a differential amplification structure, boosting the cardiac signal to a detectable range of 0.5–1 V. The amplified continuous signal requires no A/D conversion and is directly sent to an analog threshold comparator. When the signal amplitude exceeds the set threshold, the comparator outputs a high level to trigger the subsequent control logic.

Professor Jianping Guo from Sun Yat-sen University has designed a buck converter powered by a single lithium battery. His team proposed a built-in operating mode tracking technology based on a compensator, which utilizes the linear relationships between compensator gain and frequency, and between frequency and load current, to reflect load changes through the dynamic characteristics of the compensator output—enabling smooth mode switching between light and heavy loads. Meanwhile, static power consumption is reduced through amplifier multiplexing, eliminating the need for an additional load detection circuit. Chip test results show that, with a single lithium battery input (2.7 V–4.2 V), the converter only requires approximately 150 nA of quiescent current and achieves a conversion efficiency of over 90% under a load range of 10 μ A–500 mA, which can significantly extend the battery life of IoT devices.

4. Circuits Design and Cost

4.1. Differences in Digital Electronics and Analogue Electronics in Design

In terms of design and cost, the design of analog electronics relies mainly on engineers' experience and needs to focus on details such as impedance matching, noise suppression, and temperature drift. However, in scenarios requiring simple functions, analog electronics can implement many programs with only a small number of components and at very low cost. A key advantage of analog electronic technology is its simplicity and ease of use, which greatly reduces the workload for staff. Even staff without professional training can quickly take over the work—this significantly shortens the time spent on circuit development in projects, improves work efficiency, and saves engineering costs to a certain extent [5]. In contrast, digital electronics requires very high design standards. Its core logic is represented by code and chips, so in simple scenarios, digital design can seem like over-engineering. It requires additional components and engineers with strong programming skills, which consumes a lot of time and money. The costs of the two technologies also differ. Due to the low investment required for analog electronic technology, its applications are limited to less advanced fields. In contrast, digital electronic technology requires substantial investment, allowing it to be applied to high-end equipment and giving it broad development advantages [6].

4.2. Examples in Choosing Circuits for Low Cost and Simple Design

Here is an example of a water heater, which is a typical simple control system. Its core requirement involves only two actions: stopping heating when the water temperature reaches the set value, and starting heating when the temperature falls below the set value. Since no extra components are needed, analog electronics is the optimal choice for this design.

There are three main components: a bimetallic strip thermostat, a heating tube, and a power indicator light. The bimetallic strip is placed inside the heater and in direct contact with water. It typically uses two types of metals with a large difference in thermal expansion coefficients. When the temperature rises, the two metals expand unequally; once the temperature reaches the threshold, the strip touches mechanical contacts to cut off the circuit, stopping the heating tube. The heating tube is connected to the thermostat in the same circuit and is controlled solely by the circuit—it operates when the circuit is closed and stops working when the circuit is open. This requires no complex logical calculations or additional components. The indicator light is connected in parallel with the heating tube, turning on or off to remind the user whether the water has finished heating: when the tube is energized, the light is on, and vice versa. No screen for display or data collection is needed; a simple light can perfectly indicate when the water is ready for a shower.

There is a design scheme for a high-precision electronic scale, originally developed by a research team. It controls its error within 1%. This design uses a cantilever resistance strain gauge as the sensing unit, breaks free from the limitations of digital logic, and exhibits excellent stability against electromagnetic interference. This scheme demonstrates the value and impact of simple analog electronic configurations.

5. Circuits Accuracy and Resolution

5.1. Differences in Accuracy and Resolution between Digital electronics and Analogue Electronics

Accuracy and resolution are the core standards for measuring the signal processing capability of electronic systems. The distinct differences between analog and digital electronics in this regard make them suitable for different scenarios.

The resolution of analog electronics is theoretically infinite, but it is never truly infinite due to component accuracy and circuit design limitations—unlike digital systems, it has no upper limit imposed by the number of quantization bits. This characteristic gives analog circuits an advantage in

low-frequency, high-precision scenarios, such as weight signal conditioning for precision balances and output calibration of reference voltage sources. However, improving the accuracy of analog circuits comes at a high cost: high-precision components are typically 10–100 times more expensive than standard ones, and circuit design must account for environmental factors like temperature, humidity, and electromagnetic interference (e.g., using shields to reduce external electromagnetic interference, or temperature compensation circuits to reduce variations in component characteristics caused by temperature. Moreover, analog circuit accuracy is difficult to significantly improve through post-development debugging. If the accuracy is found to be insufficient after circuit design is completed, it is often necessary to replace components or modify the circuit—resulting in a long R&D cycle and increased costs.

The resolution of digital circuits is strictly limited by the number of quantization bits. Its accuracy improvement path is clear but has a physical upper limit: resolution can be directly enhanced by increasing quantization bits. In industrial automation, 16-bit ADCs already meet the accuracy requirements of most scenarios, while 24-bit or even 32-bit ADCs are widely used in high-precision measurement devices. The accuracy advantage of digital circuits also lies in their ability to compensate for hardware deficiencies through algorithmic calculations. For example, oversampling technology can significantly improve resolution without increasing the ADC's quantization bits. In successive approximation ADCs, only one comparator is needed, but its speed must be approximately the product of the total number of bits and the sampling rate, and its accuracy must match that of the ADC itself. In contrast, comparators in pipelined ADCs do not have such strict speed and accuracy limitations [7]. The accuracy improvement of digital circuits is constrained by two factors: first, sampling rate. High quantization bits usually mean longer sampling times; for high-frequency signals, high-bit ADCs may fail to meet real-time sampling requirements. Second, hardware cost. A 24-bit ADC is typically 5–10 times more expensive than a 16-bit ADC, and processing high-bit signals requires a higher-performance processor—further increasing system costs.

5.2. Examples of Audio Circuits Design

One comparative example is in audio storage technology: a device that uses only analog technology is the vinyl record. Music playback relies on circuit operations centered on the conversion and transmission of continuous signals. The grooves on the record's surface store continuous physical variations corresponding to sound. When the stylus passes through these grooves, mechanical vibrations are converted into weak continuous electrical signals—analog signals whose amplitude and frequency change in real time with sound intensity and pitch.

The signal first enters a front-end amplifier, where transistors amplify the weak current generated by the stylus. The enhanced signal then passes through a filter circuit to remove noise, before being transmitted to a power amplifier to further boost signal power and drive the loudspeaker. Finally, the loudspeaker converts the electrical signal back into mechanical vibrations, restoring the original sound. This process is very straightforward: no complex A/D conversion or encoding/decoding steps are required, as the signal remains continuous. The circuit structure is simple and low-cost, embodying the characteristics of "intuitive principles and ease of operation" inherent to analog electronic technology.

However, limited by hardware precision, the signal is prone to distortion due to component performance or external interference—this is the limitation of analog circuits in high-precision scenarios. Nowadays, nobody uses vinyl records; instead, people use phones or computers to listen to audio, as they mainly rely on digital electronics. In digital systems, noise is reduced through high quantization bits and digital filtering algorithms, making them more controllable in high-frequency and high-precision scenarios.

6. Circuits in High Frequency and High Speed

6.1. Differences between Digital Electronics and Analogue Electronics in High Frequency and High Speed

In high-frequency and high-speed communication scenarios, analog and digital circuits exhibit different signal processing characteristics. Based on their respective core principles, they complement each other and jointly support the efficient operation of base station systems. From the perspective of the underlying logic of signal processing, analog circuits take direct native processing capability as their core advantage and can directly handle GHz-level high-frequency signals. With a linear processing architecture composed of transistors, capacitors, inductors, and other components, they can achieve rapid responses in nanoseconds or even picoseconds. This processing method eliminates the need for a "sampling-quantization-encoding" process, which not only avoids the risk of distortion during signal conversion but also ensures real-time signal transmission with minimal delay—making analog circuits a key support for high-frequency signal front-end processing.

However, digital circuits depend on the strict Nyquist sampling criterion, which clearly requires that the sampling frequency be greater than twice the maximum frequency of the signal. In engineering practice, to ensure signal integrity, the sampling frequency is usually increased to more than five times the signal frequency. For example, when processing 10 GHz signals, it must be matched with a high-sampling-rate ADC (analog-to-digital converter) with a sampling rate higher than 20 GHz. Digital circuits use high-speed digital signal processors to perform complex logic operations and large-capacity caches to temporarily store and process data. However, this series of operations inevitably introduces microsecond-level delays. At the same time, their architectural complexity and power consumption are significantly higher than those of analog circuits, so they are more suitable for in-depth processing of low- and medium-frequency signals, such as demodulation, decoding, and coding of digital signals.

6.2. Application Examples of High Frequency Circuits in High Speed Scenarios

In the architecture design of base station systems, this "analog-digital" division of labor and cooperation is further refined throughout the entire signal chain process. Signals received by a base station initially exist as high-frequency RF signals, with a frequency range spanning hundreds of MHz to several GHz. These signals need to be processed by the analog circuit module: a low-noise amplifier (LNA) amplifies weak signals while suppressing noise; a mixer converts the high-frequency signals into intermediate-frequency (IF) signals; and an analog filter then removes clutter generated during the conversion process, clearing obstacles for subsequent digital processing. At this stage, the high-frequency real-time processing capability of analog circuits is fully utilized to ensure the signal maintains good integrity before entering the digital domain.

After analog processing is completed, the digital circuit module takes over the core work: a high-sampling-rate ADC samples the IF signal and converts the continuous analog signal into a discrete digital signal. Next, a high-speed DSP completes demodulation and decoding of the digital signal in sequence, restores the original data via complex algorithms, adds error-correcting codes, and enables data interaction and protocol analysis through logical operations. Notably, in emerging scenarios such as 6G near-field communication, distributed base stations also need to synchronize with external clocks via 10G networks to further optimize the processing accuracy of digital circuits—allowing single-terminal throughput to reach over 500 Mbps and cell total throughput to expand to 1–2 Gbps.

From the perspective of overall cooperation, base station systems form a complementary "analog circuit + digital circuit" architecture. Analog circuits, leveraging their advantages of minimal delay and high response speed, undertake the reception, amplification, and frequency conversion of high-frequency signals, providing high-quality signal inputs for digital processing. Digital circuits, relying on flexible algorithms and powerful computing capabilities, complete in-depth signal analysis and data interaction. The seamless integration of the two not only solves the real-time processing

challenge of high-frequency signals but also meets the complex processing requirements of low- and medium-frequency signals.

7. Conclusion

In conclusion, it is crucial to integrate analog and digital electronics in today's context. Analog electronics features a simple working principle and is very inexpensive to construct. It excels at signal conversion but has a weak ability to resist external interference from factors like temperature and humidity, making it difficult to achieve high accuracy. In contrast, digital electronics—centered on discrete signals—boasts strong anti-interference capabilities and robust information encoding to ensure security. However, they need to rely on analog electronics for initial signal collection and final conversion, and one of their drawbacks is that they cost significantly more than analog electronics.

Nevertheless, each has unique advantages that the other lacks. For example, in telephone communication, analog electronics convert sound waves into electrical signals, while digital electronics handle information encoding and long-distance transmission. In modern cameras—especially devices requiring high-quality imaging—analogue circuits process original image signals (or light signals), and digital circuits process these signals more accurately. This shows that only by integrating the two can we meet technical demands in complex scenarios and drive electronic systems toward greater efficiency, higher accuracy, and better stability.

In the future, the deep integration of analog and digital circuits will become a global mainstream direction. Some chips can integrate core modules of both circuit types, significantly reducing device size and power consumption. New materials such as graphene can reduce the static power consumption of analog circuits, better meeting the needs of low-power scenarios. Meanwhile, AI technology will drive a leap in the accuracy of digital circuits. Through deep learning-driven adaptive algorithms, it can dynamically compensate for quantization errors and optimize filtering effects, promoting electronic systems to become more efficient, precise, and energy-efficient.

References

- [1] Qiu Yu. Analyze the advantages, disadvantages and applications of analog electronic technology and digital electronic technology. *Electronic Technology and Software Engineering*, 2019, (15): 55-56.
- [2] Xu Hongxia. Research on the distinction and practical knowledge between analog circuit and digital circuit. *Changjiang Information and Communication*, 2022, 35(02): 159-160+167.
- [3] Zhang Ruihua. Advantages and disadvantages of analog electronic technology and digital electronic technology and their applications. *Digital Communication World*, 2021, (02): 128-129.
- [4] Yu Jijin. Advantages and disadvantages of analog electronic technology and digital electronic technology and their applications. *Science and Technology Innovation*, 2018, (30): 153-154.
- [5] Zhang Bao. Research on the advantages and disadvantages of analog electronic technology and digital electronic technology and their applications. *Science and Technology Innovation*, 2020, (18): 81-82.
- [6] Cao Yumeng. The difference and application of digital electronic technology and analog electronic technology. *Electronic World*, 2020, (19): 174-175.
- [7] Dai Guoding. Research on power noise collaborative optimization design method for digital analog hybrid circuits. Supervisor: Zhuang Yiqi Xi'an University of Electronic Science and technology, 2005.