Different Structures of Audio Power Amplifiers

Jiawei Sun *

School of aeronautics and astronautics, Zhejiang University, Zhejiang, China

* Corresponding Author Email: 3200100689@zju.edu.cn

Abstract. In recent years, the world's technological advancements have been continuously improving, with semiconductor technology developing rapidly. As a result, power amplifier circuits have also seen rapid development and widespread application. There are various types of power amplifier circuits, among which the one specifically designed for amplifying audio is the audio power amplifier. Serving as an electronic amplifier, the audio power amplifier can amplify low-power electronic audio signals to levels capable of driving devices, making its presence noticeable in many audio systems. Understanding audio amplifiers better can enhance the sound quality of audio equipment, improve device power efficiency, and reduce energy waste. Therefore, researching audio power amplifiers is crucial. Many factors affect the operation of audio power amplifiers, with the most important being the structure of the audio power amplifier. Through the study of the A, B, AB, and D structures of audio power amplifiers, it can be observed that AB class amplifiers mix the characteristics of A and B class amplifiers and are widely used, while D class amplifiers operate as switch-mode amplifiers, with a more complex design but extremely high efficiency.

Keywords: audio power amplifier; structure; efficiency.

1. Introduction

In 1906, the electron tube was invented, and within the next year, music was demonstrated to be transmissible via radio waves. In 1915, the first amplification systems for voice and music appeared [1]. Since then, there has been a rapid increase in the demand for collecting, transmitting, and reproducing music, leading to the rapid development and widespread application of power amplifier circuits. There are various types of power amplifier circuits, among which the one specifically designed for amplifying audio is the audio power amplifier. Audio power amplifiers are essential components of audio equipment, playing a crucial role in sound output. As electronic amplifiers, audio power amplifiers can amplify low-power electronic audio signals, enabling them to reach levels sufficient to drive devices, and they are commonly found in many audio systems. A better understanding of audio amplifiers can improve the sound quality of audio equipment by reducing distortion, expanding frequency response range, enhancing signal-to-noise ratio, and consequently improving the efficiency of power usage, thereby reducing energy waste. Additionally, superior audio power amplifiers can make audio systems more compact, providing higher performance within the same area and thereby enhancing product competitiveness. Furthermore, research on audio amplifiers covers various aspects such as circuit design and signal processing, thereby driving progress in these technologies during the development of audio amplifiers. As a signal enhancement module, according to the type of output device, the amplifier can be divided into many categories and audio power amplifier is one of these types.

As a signal enhancement module, according to the type of output device, the amplifier can be divided into many categories and audio power amplifier is one of these types. According to the operating method, audio amplifier also can be divided into many categories, which are more widely used are class A power amplifier, class B power amplifiers, class AB power amplifiers and class D power amplifiers.

2. Classification of Audio Power Amplifiers

2.1.Class A Power Amplifier

The way the class is organized Among the various classes of amplifiers, a power amplifier is the most basic. As shown in Fig. 1, this power amplifier consists of only one transistor, which remains conducting throughout the whole operating cycle, indicating that the conduction angle is π. Quiescent point is on the midpoint of the load line to better minimize nonlinear distortion, so the distortion of the class A power amplifier is small compared to other power amplifiers. When the amplifier starts working, the transistor requires a large direct current, thus consuming a lot of energy and leading to very low efficiency, the theoretical efficiency turns to only 25% to 50%. Meanwhile, the amplifier is always in operation. It consumes a lot of energy and generates a lot of heat, which also brings Thermal problems and restricts the application range of Class A amplifiers. Few people design class A amplifier, let alone develop it. Only some very small power devices, such as radio, use the power amplifier.

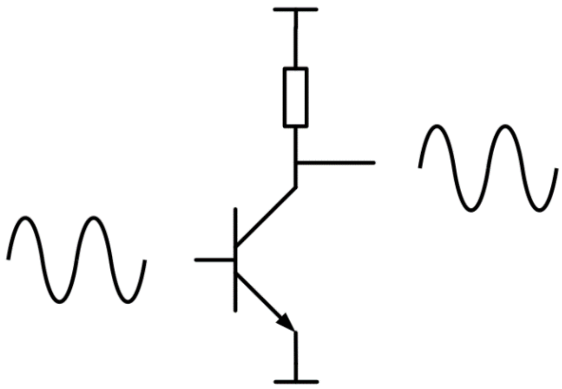

Fig. 1 circuit design of a class A power amplifier [2]

2.2.Class B Power Amplifier

As shown in Fig. 2. Class B power amplifier has one more transistor than a Class A amplifier. Its quiescent point is on the cutoff point, so when the system inputs a signal, the transistor only operates for half a week, indicating that the conduction angle is π/2. So, the collector only outputs half of the sine wave, thus increasing the distortion. To reduce the distortion, general class B amplifiers are constructed in a push-pull configuration with a pair of transistors, so that each transistor can operate half for a week to form a complete sine wave to reduce distortion.

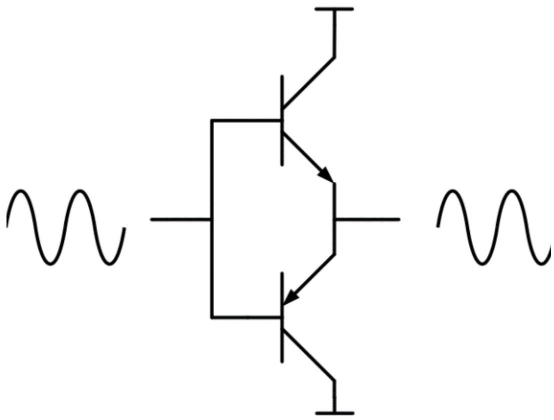

Fig. 2 circuit design of a class B power amplifier [2]

Ideally, the state of one transistor is conducting and another is cut off, as time goes on, the two transistors alternate between the conducting and cutoff states. When the state of the transistor is cut off, the quiescent current is always 0, avoiding the loss of energy and reducing heat production. Class

B power amplifiers are significantly more efficient than class A power amplifiers. When it comes to defective devices like silicon power transistors operating in a sinusoidal B-stage push-pull fashion, L. Baker identified a linear processing technique in 1962 that takes the limiting scenario into account and forecasts the conversion efficiency, power output, and power dissipation [3]. Additionally, the efficiency of a Class B power amplifier in its optimal condition may be computed using this theory. A class B power amplifier should ideally have an efficiency of 78.5%. [3]. However, due to the two transistors conducting alternately, if the input signal is from 0.6V to 0.6V, both transistors are unable to conduct, which will produce serious cross-over distortion, bad linearity, and in turn damage the sound quality of the audio signal. To reduce this effect, class AB operation introduces a small quiescent current. Class AB power amplifier will get the details in the following text. Like A, class B amplifiers also have serious drawbacks which make them difficult to be used in a wide range.

2.3.Class AB Power Amplifier

Class AB amplifier is produced by combining a class A and a class B amplifier. It combines the features of amplifiers classified as A and B. Transistors in the AB amplifier don’t fully work alternately. Its conduction angle is greater than half a week. The transistor starts conducting although the input signal is close to 0, Instead of needing an input signal reaching 0.6v to start conduction as in the Class B power amplifiers. There is a small quiescent current between two transistors, and a linear zone forms around the middle because of this quiescent current, creating a smoother transition, so Class AB power amplifiers do not suffer from crossover distortions as severe as those of Class B. However, like class A amplifier, the forward bias voltage results in a smaller quiescent current, so even if there is no signal input, there will be energy loss in the system, but it consumes less energy and is more efficient than the Class A amplifier, though not as efficient as the Class B amplifier. Ideally, its maximal efficiency is about 60% to 70% [4]. Class AB power amplifiers are equivalent to combining the respective advantages of Class A and Class B amplifiers. So, it gets low distortion and high efficiency.

It enjoys great popularity among audio power amplifiers and has many relevant studies. In 2004, Chengzhou Wang placed PMOS devices side-by-side with NMOS devices used as amplification units The technique increased the two-tone IM3 and adjacent-channel leakage power by roughly 8 dB over a broad range of output power, while maintaining a constant overall capacitance at the amplifier's input. The linearity of class-AB power amplifiers can be enhanced by using this strategy as a nonlinear capacitance compensation method [5]. In 2022, Hanqi Gao created a two-stage power amplifier with an off-chip adjustable LC load network and on-chip power transistors using 130 nm CMOS technology. The matching network was optimized to finish the iterative circuit/EM co-simulation from IC to PCB levels. The power amplifier produces an output 1-dB compression of 18.1 dBm when powered by a 2.5 V voltage source, according to the observed result. Its maximum gain is 27.8 dB, its saturation power is 24.2 dBm, and its power additive efficiency (PAE) is 43.8%. Class AB amplifier is provided by this study for applications under 1 GHz and it has great linearity [6]. In the same year, Suvashan Pillay designed and analyzed the frequency and power characteristics of a dual-gate (DG) MOSFET-based class AB amplifier attributable the excellent characteristics of the DG MOSFE for low-power and low-noise applications and voltage regulation, using a 2-watt audio amplifier driving an 8-ohm load through a 100-millivolt input signal, covering the typical audio frequency range of 20 Hz to 20 kHz typical audio frequency range [7]. It wasn't until recent years that More sophisticated amplifiers, such Class D and Class G amplifiers, started to supplant Class AB power amplifiers.

2.4.Class D Power Amplifier

2.4.1 Operating principle and analysis

Class D amplifier is different from the first three power amplifiers because it converts the input audio signal into a PWM signal and enlarges the digital signal by amplifying the PWM. It is a switching power amplifier that can turn the output on or off continuously without any other levels.

As a digital amplifier, Class D amplifier has extremely high efficiency and smaller footprint than analog circuits. Class D amplifiers are mainly divided into three main parts: pulse modulator, switching amplifier, and low-pass filter. Pulse modulator consists of a triangular wave generation circuit and a comparator, it converts the audio input analog signal into a PWM signal, due to the characteristics of the triangular wave signal sampling, the PWM signal duty cycle is proportional to the input signal amplitude. The operating principle is that the input audio signal is a sine wave. The triangle wave generator circuit outputs a triangle wave signal and the signal frequency will be much higher than the input signal. To get higher accuracy, the frequency of the sampling signal needs higher than before, which can properly improve amplifier's linearity and the signal-to-noise ratio, Consequently, the sampling frequency is often greater than ten times that of the highest audio signal frequency. The comparator compares the sine wave and triangle wave input signals; if the sine wave input signal's amplitude is larger than the triangle wave's, the comparator outputs a high level, producing a PWM signal with a duty cycle higher than 50%.

On the contrary, when the amplitude of the triangle wave amplitude is greater than the amplitude of the sine wave input signal, the comparator outputs a low level, resulting in a PWM signal with a duty cycle of less than 50%. To ensure that distortion due to sampling wouldn't occur, it is necessary to ensure that the peak-to-peak value of the triangle wave is greater than that of the input signal, so that PWM modulation signals with different duty cycles can be obtained. The switching amplifier consists of two MOS tubes that are switched on and off by a PWM modulating signal to output a PWM signal with an amplitude between the supply voltages and a constant duty cycle, with a good current drive capability. As the device is switching, it is in the cut-off state when there is no signal input, which reduces power consumption and results in high power efficiency. The low-pass filter converts the amplified PWM signal and reduces the audio signal. According to the characteristics of the low-pass filter, when the duty cycle of the PWM signal is large, the capacitor charging time is larger than the discharging time, and the output level is higher; when the duty cycle of the PWM signal is small, the capacitor charging time is smaller than the discharging time, and the output level is lower. Finally, the reduced audio signal is obtained, and the output audio signal is linearly amplified with the input signal.

2.4.2 Research status

Class D power amplifier design is simple and has highly efficient. There are many related studies. In 2004, A.R. Oliva used the classic frequency compensation technique for voltage feedback loops to Make a multi-loop voltage feedback Class D switching audio amplifier that is less expensive and does not include a filter. The modulation uses unipolar pulse [8]. In 2020, B Tang optimized the MOS full bridge circuit of the post power output and conducted simulations on various modules such as the output drive circuit and comparator. The circuit achieved an output power of over 10W under a 15V power supply and 8 Ω load condition, with a frequency response ranging from 20 Hz to 20 kHz. This technique allows the Class-D power amplifier to achieve an efficiency of 91.8%, providing a Class-D amplifier design with high efficiency. [9]. Duo Xu conducted an analysis in 2021 of the front-end bipolar output LLC converter operating mode of a class D amplifier system as well as the effect of the amplifier on the LLC converter's operation during switching cycles. The results showed that the class D amplifier voltage-pumps the bipolar output voltages during both positive and negative audio cycles, which has a negative impact on the efficiency and operation of the front-end bipolar output LLC converter as well as the class D amplifier. Consequently, they provide a symmetrical bipolar output LLC converter and a system including class D amplifier with half-bridge and high efficiency (HB-CDAA) [10]. In 2023, Yeun Jeong Park designed an efficient, Class D power amplifier using a full-bridge structure consisting of GaN elements [11]. Table 1 compares four audio power amplifiers.

Table 1. Four audio power amplifiers comparing

Classification	Operating mode	Ideal efficiency	Advantage	Disadvantage
Class A	current source	25% to 50%	simple structure	low efficiency
Class B	current source	78.5%	high efficiency	high degree of distortion
Class AB	current source	60% to 70%	Between A and B	cross-distortion
Class D	switch	50% to 100%	high efficiency	Difficult to design

3. Summary

The usage scenarios for audio amplifiers are extremely diverse, hence designing one entails considering numerous influencing factors. These include environmental factors such as temperature and waterproofing ratings, as well as the intended use of the audio equipment, whether it's for stationary placement, suspension, or portable carry, all of which may affect the amplifier's performance. Additionally, consideration must also be given to the performance and cost implications resulting from transistor usage. However, the most significant factor affecting audio power amplifiers is their structure, which is the main research objective. It is observed that Class A audio amplifiers, while having a simple structure, exhibit low efficiency, hence their limited practical use. On the other hand, Class B audio amplifiers, although efficient, suffer from severe distortion, thus their usage is limited, and research on them is scarce. Class AB audio amplifiers, is mixture of A and B, offering a balanced solution, leading to widespread application and significant development in recent years. However, the most promising among them is the Class D amplifier, working based on PWM modulation. Despite its high design complexity, it boasts extremely high efficiency, with ideal efficiency even reaching 100%. Hence, it is evident that Class D audio amplifier is superior to other amplifiers, despite the potential for higher costs. Studying the structure of audio amplifiers can lead to better efficiency of audio power amplifiers and improved sound output of audio systems, which is crucial for the development of audio systems.

Acknowledgement

Thanks for Zhejiang University of Technology for their assistance.

References

[1] Duncan B. High performance audio power amplifiers. Elsevier, 1996.

[2] Lei Z W, Li P. Class D audio power amplifier design. University of Electronic Science and Technology of China, 2002.

[3] Baker L. Power dissipation in class B amplifiers. IRE Transactions on Audio, 1962 (5): 139-145.

[4] Bortoni R, Seara R. On the design and efficiency of class A, B, AB, G, and H audio power amplifier output stages. Journal of The Audio Engineering Society, 2002, 50(7/8): 547-563.

[5] Wang C, Vaidyanathan M, Larson L E. A capacitance-compensation technique for improved linearity in CMOS class-AB power amplifiers. IEEE Journal of Solid-state Circuits, 2004, 39(11): 1927-1937.

[6] Gao H, Wu X, Yang Y, et al. A high linearity class AB power amplifier for sub-1 GHz applications. IEEE MTT-S International Wireless Symposium (IWS), 2022, 1: 01-03.

[7] Pillay S, Srivastava V M. Realization with fabrication of double-gate MOSFET based class-AB amplifier. International Journal of Electrical and Electronic Engineering & Telecommunications, 2020, 9(6): 399-408.

[8] Oliva A R, Ang S S, Vo T V. A multi-loop voltage feedback filterless class-D switching audio amplifier using unipolar pulse-width-modulation. IEEE Transactions on Consumer Electronics, 2004, 50(1): 312-319.

[9] Tang B, Deng J, Zhou C, et al. Design of a high efficiency class-D audio power amplifier. IEEE International Conference on Artificial Intelligence and Electromechanical Automation (AIEA), 2020: 385-391.

[10] Xu D, Zhou G, Huang R, et al. High efficiency half bridge class-D audio amplifier system with front-end symmetric bipolar outputs LLC converter. IEEE Transactions on Industrial Electronics, 2020, 68(2): 1220-1230.

[11] Park Y J, Lee K Y. High-efficiency, high-power class-D power amplifier with 50W output using GaN devices. IEEE Twelfth International Conference on Ubiquitous and Future Networks (ICUFN), 2021: 44-47.