Surveying Amplifier Technologies: Understanding Applications and Advantages

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Abstract. Amplifiers, crucial in analog circuitry, are assessed based on transmission gain and frequency response. Lower transmission gain yields flatter frequency response and less distortion, crucial for signal fidelity. Various amplifier types excel in distinct applications. Feedback amplifiers utilize loops to control gain, stability, and linearity, often employing operational amplifiers. They offer adjustable gain through feedback resistance ratios, crucial for diverse applications. Balanced amplifiers handle balanced signals, canceling noise and interference, ideal for long-distance transmission due to their dual-input setup that mitigates common-mode noise impact. Distributed amplifiers, prevalent in high-frequency domains, distribute gain across multiple stages along a transmission line. Despite requiring more transistors, they offer robust performance and adaptability, crucial in high-interference environments. Power amplifiers, divided into linear and switching types, deliver amplified signals with minimal distortion. Class A, AB, B, and C amplifiers balance gain, efficiency, and linearity, often necessitating compromises in design. Their distinct features and capabilities make them indispensable components across various industries, driving advancements in the same environment. Studying the comparison of distributed amplifiers, balanced amplifiers, power amplifiers, and feedback amplifiers in the same environment is significant for gaining a deeper understanding of their performance and applications in electronic circuits. The specific content may include comprehensive analysis and comparison of these amplifiers' working principles, performance metrics (such as gain, bandwidth, noise, etc.), power consumption, stability, cost, etc. Such research helps guide the selection and design in engineering practice to meet the requirements of different application scenarios and promotes further development of amplifier technology.

Keywords: Feedback amplifier, Balanced amplifier, Distributed amplifier, Power amplifier

1 Introduction

An analog circuit amplifier is an electronic device that enhances the amplitude of an input signal, typically used to amplify audio, video, and other analog signals. Common analog amplifiers include op amp and power amp. Op amp amplifiers are

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typically used in low-power, precision applications, while power amplifier amplifiers are typically used in high-power applications, such as audio amplifiers. These amplifiers can be adjusted by circuit parameters to achieve different magnification, bandwidth and input/output impedance to meet the needs of different applications. The analog amplifier has been developed for nearly 50 years since its birth, and its semiconductor manufacturing process and circuit design have made great progress in two key technologies. The current mainstream manufacturing processes include bipolar (BJT) manufacturing process, junction field effect tube (CMOS) manufacturing process, and bipolar - complementary metal oxide semiconducting combining BJT process and CMOS process Bulk (BiCMOS) manufacturing process [1].

2 Amplifier Technologies

2.1 Feedback Amplifier

A feedback amplifier is an electronic amplifier that utilizes the principle of feedback to control the amplifier's gain, bandwidth, stability, and other performance characteristics. It returns a portion of the output signal back to the input, mixing it with the input signal to form a closed-loop system. This feedback can reduce distortion, improve linearity and stability, and allows for performance adjustments as needed. Common types of feedback amplifiers include voltage feedback amplifiers and current feedback amplifiers.

2.2 Balanced Amplifier

A balanced amplifier is an electronic amplifier designed to handle balanced signals, which consist of two signals with identical amplitudes but opposite phases. They are commonly used in audio, communication, and measurement applications to cancel out noise and interference, thereby improving signal transmission quality and stability. Balanced amplifiers typically include differential amplifiers and differential input/output stages, which efficiently amplify input signals, increase signal-to-noise ratio, and exhibit good common-mode noise rejection.

2.3 Distributed Amplifier

A distributed amplifier is an electronic amplifier composed of multiple gain stages distributed along the transmission line. It's primarily used in high-frequency applications such as microwave and RF circuits. By distributing gain stages along the transmission line, it avoids the limitations of a single active device, allowing for higher overall gain and bandwidth. Distributed amplifiers offer low noise, high linearity, and wide bandwidth, making them suitable for applications like satellite communications, radar systems, and broadband networking.

2.4 Power Amplifier

A power amplifier is an electronic device designed to increase the power of a signal. It takes a low-power input signal and boosts it to a higher power level suitable for driving speakers, transmitting signals over long distances, or powering other loads. Power amplifiers are commonly used in audio systems, radio transmitters, and other applications where high power output is required. They come in various classes such as Class A, Class AB, and Class D, each with its own advantages and disadvantages in terms of efficiency, linearity, and distortion.

3 Comparison and Discussion

3.1 Comparison of the Four Amplifiers

Feedback amplifiers can be broadly divided into two types: 1) Positive feedback: part of the output signal is fed back to the input end, increasing the amplitude of the input signal. Positive feedback is not usually used in amplifier design because it tends to cause instability and oscillation; 2) Negative feedback: a part of the output signal is fed back to the input and subtracted from the input signal to reduce the gain of the overall amplifier. Negative feedback helps improve amplifier stability, linearity and bandwidth, and reduces misalignment and nonlinear distortion.

Feedback amplifiers typically use an operational amplifier (op-amp) as the basic building block. In a feedback amplifier, the gain of the amplifier can be controlled by adjusting the ratio of the feedback resistance to the input resistance. This design provides a flexible way to tune the performance of the amplifier and adapt it to different application requirements.

In the process of judging the reflection of feedback polarity in a circuit, the most effective and basic method is instantaneous polarity method. The input signal exists in the circuit, and its instantaneous polarity to the ground needs to be specified, so that the method can be used to determine the instantaneous polarity of the potential and the flow direction of the current, and these contents will be different at different points in the circuit. In this case, it is necessary to implement a step-by-step judgment, so that the instantaneous polarity can be clearly reflected in the output signal. This is also the basis for judging the reflection of instantaneous polarity in feedback signals. If the instantaneous signal is fed back into the output process, the opposite phase is generated in the instantaneous signal with the original input signal, which will reduce the reflection of the net input signal in the amplifier, which will lead to negative feedback. If the feedback signal in the input pole has the same phase as the instantaneous signal of the original input signal, it will increase the representation of the net input signal in the amplifier, thus promoting the production of positive feedback [2].

Voltage feedback amplifier (VFA) is an early type of amplifier. The structure and input impedance of the in-phase and inverting input terminals of the VFA are basically the same. In the differential mode and common mode form, the input impedance is generally more than 10Ω, the VFA structure block diagram is shown in Fig. 1 [3].

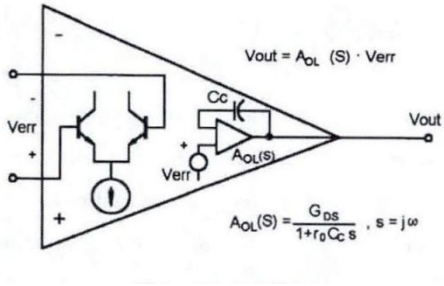

Fig. 1. Voltage feedback amplifier.

The structure of the current feedback amplifier (CFA) is clearly different from that of the VFA in that the input is a unit gain buffer connecting the in-phase and anti-phase segments. The input impedance of the in-phase end and the inverting end is very different. The input impedance at the in-phase end is generally more than 10Ω, and the inverse phase end is generally 0. The structural block diagram of CFA is shown in Fig. 2 [3].

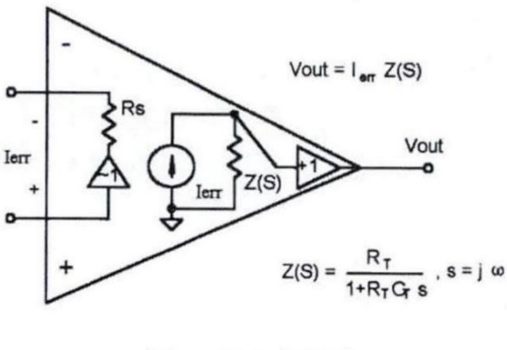

Fig. 2. Current feedback amplifier [3].

3.2 Balanced Amplifier Features

The balanced amplifier features a dual-input setup, with each input receiving the positive and negative segments of the balanced signal, effectively reducing the impact of common mode noise and enhancing signal resilience against interference. With a typically high common-mode rejection ratio (CMRR), it adeptly mitigates interference from common-mode signals while maintaining effective amplification of the differential signal. Additionally, its output signal mirrors this balance, aligning with the input signal's symmetry. Furthermore, the amplifier's design prioritizes suppressing common-mode interference stemming from power supply and grounding sources to uphold the accuracy and stability of the output signal. Balanced amplifiers are often used in applications such as audio, communications, and sensor interfaces, especially when signals need to be transmitted over long distances, as they provide better signal quality and anti-interference capabilities.

The bandwidth and output power of single-ended power amplifiers are very limited, so it is possible to consider coupling two power amplifiers to expand the bandwidth, which is a common balanced power amplifier. The two amplifiers can be coupled by quadrature coupler or Wilkinson power distribution/synthesizer, where the Wilkinson power splitter is large and the relative bandwidth is narrow, so the application scenarios are very limited. A significant advantage of balanced power amplifiers is that when one of the amplifiers is damaged or fails, the other amplifier can still operate normally, although the gain will be reduced, but it will greatly improve the fault tolerance of the system. This structure has smoother gain, higher stability, and better input-output standing wave ratio compared to structures with extended bandwidth of resistive/reactive elements [2].

In Fig. 3, there are n amplifiers cascaded, drain and gate in turn connected to a transmission line with characteristic impedances of Zd and Zg and spacing of ld and lg. As the signal passes through each amplifier tube, it is amplified, so the distributed power amplifier will have a large gain. The signal that is not transmitted will be consumed on the resistance, and because the gate and drain transmission lines are low-pass L-C structures, the cutoff frequency is very high, so the distributed power amplifier will have a relatively large bandwidth. However, distributed power amplifiers require more transistors, so the use of packaged transistors will result in a large circuit size and relatively large cost [4].

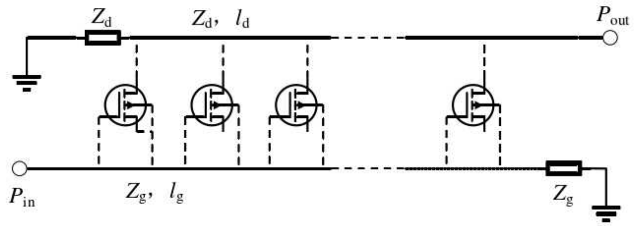

Fig. 3. Distributed power amplifier [4].

3.3 Characteristics of Distributed Amplifiers

Distributed amplifiers excel in a wide frequency range, commonly employed in high-frequency domains such as microwave and RF fields. Leveraging power distribution across multiple units, they effectively lower overall noise levels, thereby enhancing signal quality. Additionally, they boast high gain by harnessing the collective gain of multiple units, surpassing the capabilities of a single amplifier. Moreover, distributed amplifiers offer higher output power, proving invaluable for applications demanding increased power output. Their robust design equips them with strong anti-interference capabilities, ensuring stable performance even in high-interference environments. Furthermore, their adaptability shines through as they can be easily adjusted and optimized to meet various application scenarios and signal requirements.

The structure of the distributed amplifier is shown in Fig. 4, consisting of N identical transistors cascaded together. The input signal travels along the gate transmission line, and each transistor amplifies the signal and feeds the output signal into the drain, creating a traveling wave on the drain transmission line. The selection of the appropriate propagation constant and the length of the gate and drain transmission lines makes the output signals of each transistor in phase superposition. A load is placed at each end of the grid and drain transmission lines to absorb the reverse traveling wave. In the distributed amplifier structure, both the gate and drain-source capacitors of the transistor can be regarded as components of the gate and drain transmission lines, so a wide operating bandwidth can be achieved [5].

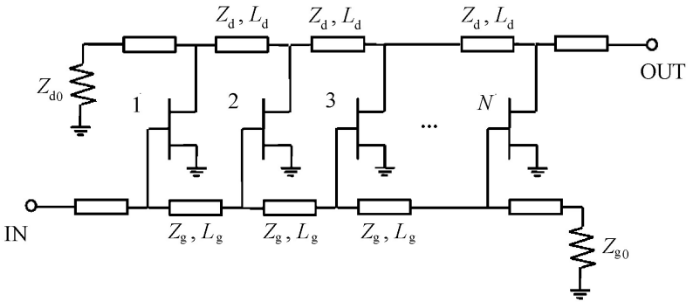

Fig. 4. The structure of the distributed amplifier [5].

The first type of distributed amplifier adopts a single-stage structure, which is cascaded by 4 identical pHEMT tubes, and its block diagram is shown in Fig. 5. The second type of distributed amplifier adopts a two-stage cascade structure, and each stage amplifier is cascaded by two identical pHEMT tubes, and its block diagram is shown in Fig. 6. The short-circuit microstrip line is selected at the input end of the amplifier for impedance matching, which can play a certain role in electrostatic protection. A series RC branch is used to replace the terminal resistors of the gate and drain in the traditional distributed amplifier structure to reduce the additional DC power consumed by the resistors, thereby improving efficiency. In addition, a set of open microstrip lines is added between the two stages of the distributed amplifier II to adjust the interstage matching [5].

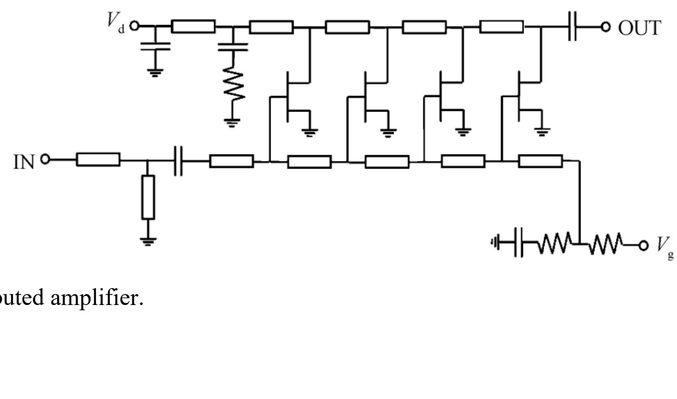

Fig. 5. Distributed amplifier.

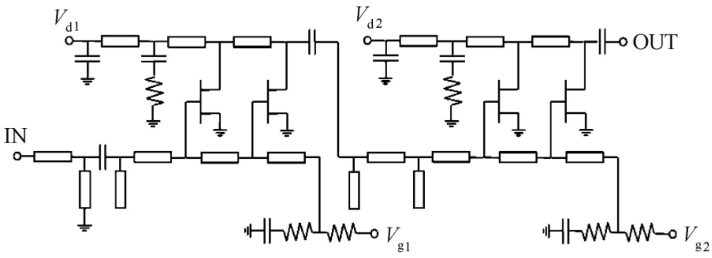

Fig. 6. Distributed amplifier [5].

Common wide band amplifiers are resistance-reactance matching amplifiers, feedback amplifiers, balanced amplifiers and distributed amplifiers. The distributed amplifier cascades several transistors together along the transmission line to achieve good gain and matching over a wide frequency band. Compared with other band-completion amplifiers, distributed amplifiers are widely used in the design of band-completion amplifiers, although they have higher power consumption and larger circuit area, but they can achieve full band amplification, and the gain and noise performance are moderate. Distributed amplifier technology was first proposed by Percival in 1936, and after Ginzton et al proposed "distributed amplification" in 1948, the technology began to get widespread attention and application. Distributed amplifier circuits are simple in structure and suitable for monolithic integrated circuits [4]. The signal that is not transmitted will be consumed on the resistance, and because the gate and drain transmission lines are low-pass L-C structures, the cutoff frequency is very high, so the distributed power amplifier will have a relatively large bandwidth. However, because distributed power amplifiers require more transistors, the use of packaged transistors will result in a large circuit size and relatively large cost [5]. Distributed amplifiers, also known as Traveling wave amplifiers (TWA), are composed of multistage gain units, gate and drain transmission lines, and have good broadband performance. The gain-bandwidth product of traditional amplifiers is limited by the parasitic parameters of active devices, and there is a contradiction between bandwidth and gain in operating frequency. Distributed amplifier through the gate, drain transmission line and gain unit input and output parasitic capacitors to form a gate, drain artificial transmission line ATL, the gain unit generated by the output signal in phase superposition, by the terminal impedance to absorb the reverse traveling wave in the circuit, so as to solve the transistor parasitic capacitance caused by the gain roll down, to achieve broadband processing of the input signal, while having a good in-band increase Benefit flatness performance [6].

3.4 Basic Characteristics of Power Amplifier

According to the working mode of the bulk tube in the power amplifier, it can be divided into linear power amplifier and switching power amplifier. Among them, linear: the power amplifier can be subdivided into A, AB, B, and C according to the bias of the transistor. In a linear power amplifier, the transistor works as a current source, and in a switching power amplifier, the transistor is used as a switch. The application scenarios of different types of power amplifiers are also different, Class A amplifiers have good gain and linear characteristics, and Class AB amplifiers are often used in the design of low noise amplifiers. It is worth emphasizing that the indicators of power amplifiers are mutually restricted, and the design process often needs to reflect the idea of compromise [7]. Due to the influence of transistor parasitic parameters, the gain and efficiency of the power amplifier will decrease with the increase of frequency, and the higher the frequency, the faster the decline rate of the high frequency part. In this case, the non-uniformity of gain and efficiency will not only affect the bandwidth performance of the power amplifier, but also affect the communication quality and the life of the communication equipment. In order to improve the gain deterioration and efficiency deterioration of the power amplifier at high frequencies, an RLC positive feedback circuit can be added between the drain and gate of the transistor. The added RLC circuit allows the transistor's feedback current to be in phase with the input current at high frequencies, thereby compensating to some extent for the gain and efficiency of the power amplifier at high frequencies [8]. In the design of power amplifier, the stability of the amplifier circuit is the most important factor, and the second important factor is the gain of the amplifier circuit. Gain is an important performance parameter of power amplifier, and it is also a basic parameter for designing power amplifier. The power amplifier gain is defined in several ways, such as the conversion power gain G and the available power gain Ga and the working power gain Gp (also known as the power gain) [9]. In addition, the nonlinearity of power amplifiers can also produce cross-modulation terms that interfere with adjacent channels. To measure this phenomenon, the nonlinearity of power amplifiers is often characterized by a two-tone test [10].

4 Conclusion

In the realm of electronic amplification, distributed amplifiers efficiently distribute input signals across multiple gain stages, offering high bandwidth and low distortion for high-frequency applications. Power amplifiers specialize in delivering high power output with minimal distortion, ideal for driving speakers or high-power devices. Balanced amplifiers mitigate common-mode noise and interference, providing improved signal integrity and noise rejection in communication systems or audio applications. Feedback amplifiers utilize feedback loops to stabilize gain, enhance linearity, and reduce distortion, collectively contributing to the advancement of electronic systems across various industries with their unique capabilities and applications in the same environment. In the same environment, distributed amplifiers stand out for their uniform signal amplification characteristics, while balanced amplifiers are favored for their ability to suppress noise and improve signal quality. Power amplifiers are renowned for their high power output, and feedback amplifiers excel in accuracy and stability.

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