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An Audio Amplifier with Automatic Gain Control Functionality

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Abstract. This paper presents the design of an active biquad audio amplification circuit based on an AGC circuit. The objective of the study is to achieve frequency splitting and power amplification of audio signals by using an active biquad network. The entire circuit consists of three main modules: the preprocessing circuit, the high-pass and low-pass filtering circuits, and the power amplification circuit. In the design, a signal generator is employed as the signal source. The first stage of the preprocessing circuit utilizes an AGC circuit, which implements automatic gain control through negative feedback. The second stage filtering circuits employ passive filters, while the power amplification stage incorporates the specialized Hi-Fi power amplifier chip TDA2030. Voltage followers are used between different stages to ensure impedance matching. Through simulation verification, this design has been demonstrated to meet the requirements effectively, yielding highly satisfactory results.

Keywords. Automatic Gain Control (AGC), OPA228, TDA2030

1. Introduction

Sound signal acquisition and processing play pivotal roles in various domains, including communication systems, medical diagnosis and treatment, speech recognition, and natural language processing. Voltage signals generated by sound capture devices often exhibit significant amplitude variations. Traditional fixed gain amplification circuits are limited to enhancing the amplitudes of small signals[5].

This paper introduces a novel biquadratic audio amplifier with automatic gain control (AGC) functionality, showcasing its significance across diverse applications. Comprising pre-processing, filtering, and power amplification circuits, the amplifier achieves consistent output signal (VC) amplitude variation of <1 dB within the frequency range of 100 Hz to 20 kHz, accommodating input sinusoidal signal (VS) amplitude variations between 10 to 100 mV (RMS). Notably, this design offers advantages such as a wide frequency range and low power consumption. [1]The system block diagram is shown in Figure 1.

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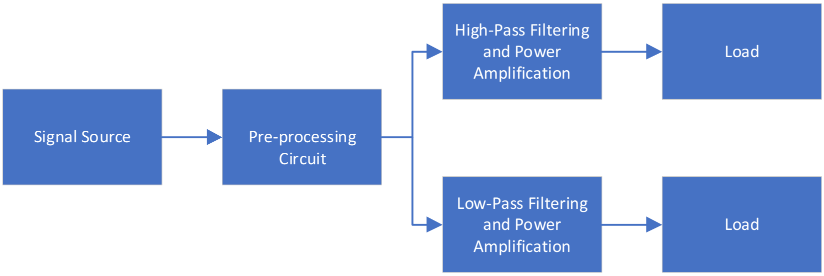


Figure 1. Block diagram of system principle

2. Hardware Design

2.1. Pre-processing circuit

The pre-processing circuit employs an AGC (Automatic Gain Control) circuit, deconstructed into fundamental circuits, with analog integrated circuits serving as core components. Each component forms a basic circuit. The first part is an analog multiplier. The second part comprises an in-phase proportional operational circuit, which serves as the output of the entire circuit. The third part involves a precision rectification circuit, yielding half-wave rectification for the in-phase proportional amplifier. The fourth part consists of an active filtering circuit, yielding the DC component. The fifth part encompasses a subtractor, with its output voltage u_{o4} fed into the analog multiplier, multiplied by the input voltage u_i. This introduces negative feedback, establishing a closed-loop system. By analyzing the operational relationships of these fundamental circuits, the functions of each circuit section become evident, leading to the derivation of the final output expression.[3]

We set the output voltage of the analog multiplier as u_{o1}, and set the output voltage of the in-phase proportional operational circuit as u_O. The output voltage of the precision rectification circuit is denoted as u_{o2}. The low-pass filtering circuit has a voltage amplification factor of A_u, and the output voltage of the differential amplification circuit is u_{O4}[2].

$$u_{O1} = ku_X u_Y = ku_I u_{O4} \tag{1}$$

$$u_O = (1 + \frac{R_2}{R_1})u_{O1} \tag{2}$$

$$u_{O2} = \begin{cases} 0 & \mathrm{u}_O > 0 \\ -u_O & \mathrm{u}_O < 0 \end{cases} \tag{3}$$

$$\mathrm{A}_u = \frac{U_{O3}}{U_{O2}} = \frac{1}{1+j\frac{f}{f_H}} \quad \left(f = \frac{1}{2\Pi R_5 C}\right) \tag{4}$$

$$u_{O4} = \frac{R_7}{R_6}(U_{REF} - U_{O3}) = \mathrm{A}_{u4}(U_{REF} - U_{O3}) \tag{5}$$

The formula can be derived from Eqs. (1), (2), and (5).

$$u_O = ku_I u_{O4} = k(1+\frac{R_2}{R_1})\frac{R_7}{R_6}(U_{REF}-U_{O3})u_I \qquad (6)^{[3]}$$

As the amplitude of the input signal u_I increases, the amplitude of the output voltage u_O also rises. This results in a decrease in A_u, ultimately causing a reduction in the amplitude of u_O. Under appropriate parameters, through the automatic adjustment of circuit gain, the amplitude of the output voltage u_O can remain relatively constant or exhibit minor fluctuations within a small range, even as the amplitude of u_I changes. The AGC circuit is shown in Figure 2.

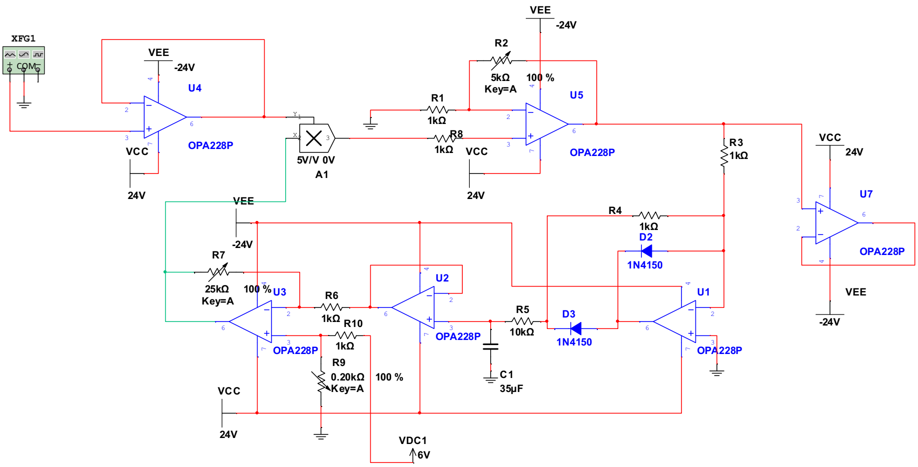


Figure 2. AGC circuit

2.2. High-pass and low-pass filters along with power amplification circuit

Audio amplification often requires the separation of high and low frequencies. A common approach is to employ an external crossover network, which splits the signal into two identical streams. One stream passes through a high-pass filter, while the other goes through a low-pass filter, effectively achieving the separation of high and low frequencies.

The parameters of the high-pass and low-pass filters directly impact the degree of separation between high and low frequencies. Therefore, adjusting the stopband attenuation rates to appropriate parameter values is essential to effectively achieve the desired separation of high and low frequencies. In this design, passive filters are employed for filtering circuits, where suitable values of capacitance and inductance are configured to meet the bandwidth requirements. The low-pass filter circuit and high-pass filter circuit are shown in Figures 3 and 4[4].

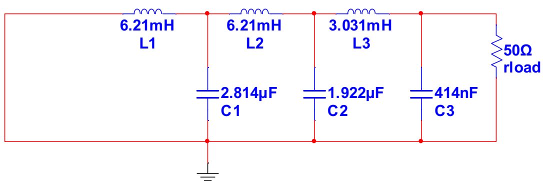


Figure 3. Low-pass filter circuit

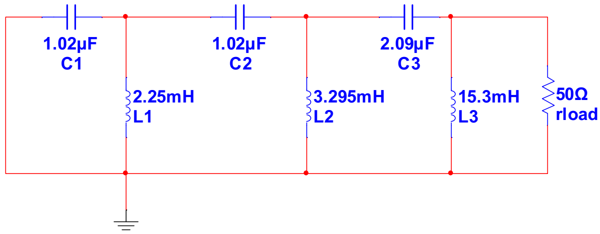


Figure 4. High-pass filter circuit

2.3. Power amplification circuit

Traditional methods involve using discrete components to build OTL (Output Transformer-Less Circuit) or OCL (Output Capacitor-Less Circuit) circuits for power amplification to drive speakers. However, both of these circuits have certain drawbacks for this design. The shortcomings of OTL power amplifiers include coupling the output with large capacitors, which restricts audio frequency response bandwidth, making them unsuitable for high-fidelity audio amplification. On the other hand, OCL power amplifiers require intricate tuning and necessitate the inclusion of protective circuits between the output and speakers.

This paper employs the TDA2030 chip to design the power amplification circuit. The TDA2030 operational amplifier is chosen due to its combined features of low noise, wide bandwidth, and high precision, making it an ideal choice for applications requiring both AC and precise DC performance. Additionally, its low static current and cost-effectiveness make it highly suitable for portable applications. The power amplification circuit is shown in Figure 5[6].

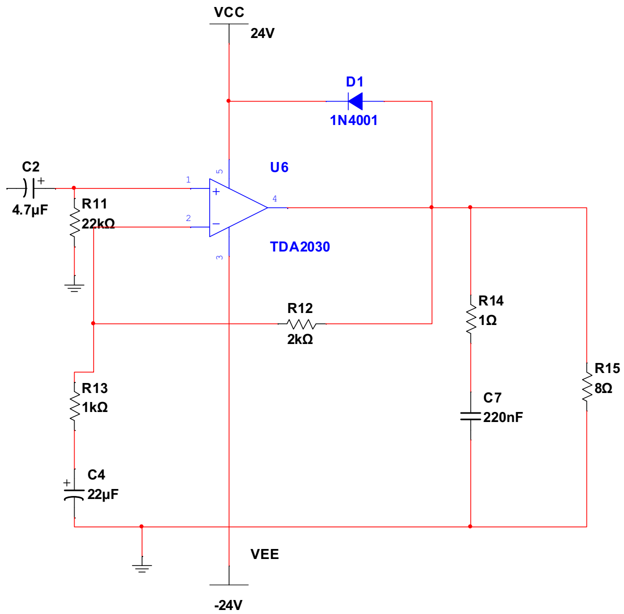


Figure 5. Power amplification circuit

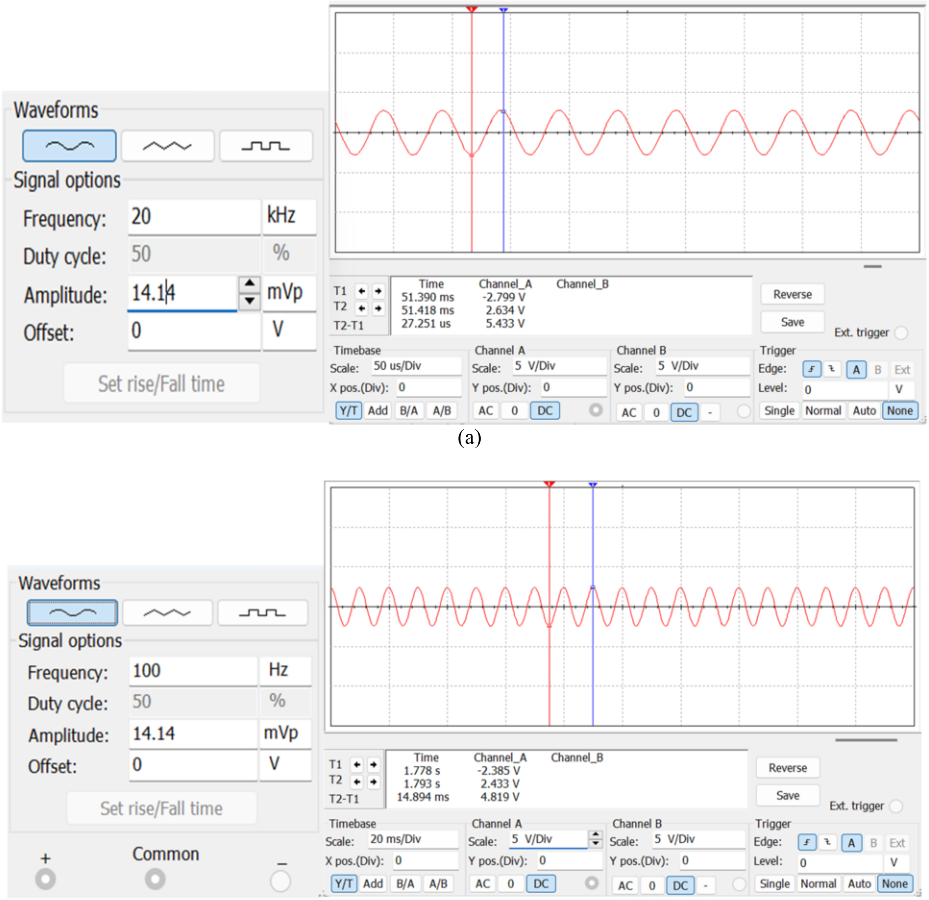
3. Circuit simulation test

Both the design and simulation of this project are implemented by using Multisim 14.0 software, which is a highly popular Electronic Design Automation (EDA) software widely employed for electronic circuit analysis, design, simulation, and various other tasks in the field.

We have divided the testing process into two main segments. The first part involves evaluating the AGC functionality of the pre-processing circuit. The second part focuses on verifying whether the parameters of the high-pass and low-pass filters, as well as the power amplification circuit, meet the expected requirements.

3.1. AGC circuit functionality testing

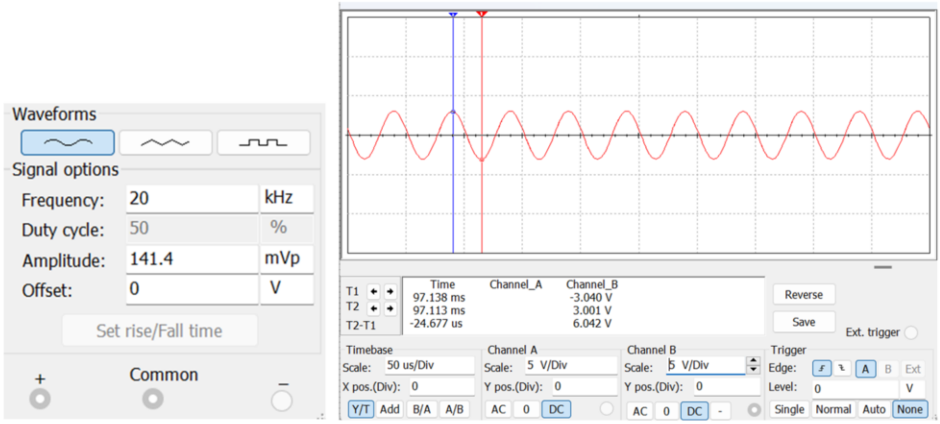
The testing is divided into two steps, with each involving the examination of the AGC circuit's output amplitude variations for input amplitudes of 10 mV and 100 mV respectively. The test results can be found in Figures 6 and 7.



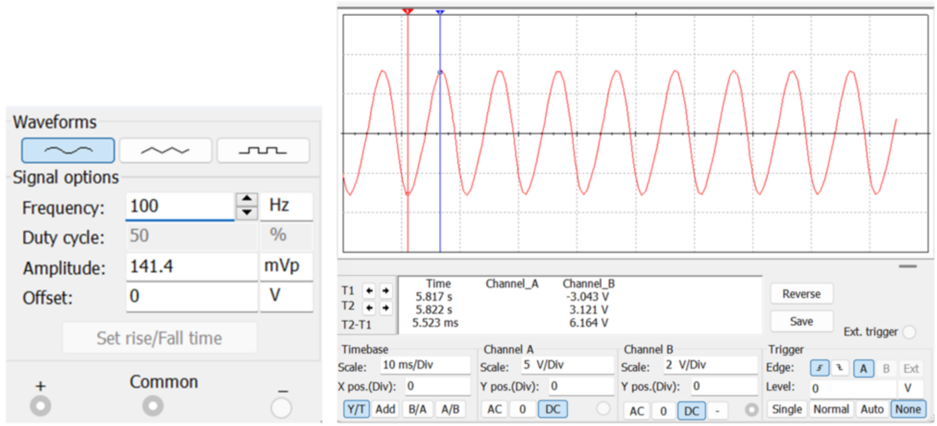
(a)

(b)

Figure 6. (a) The input of 10 mV at 20 kHz; (b) The input of 10 mV at 100 Hz



(a)



(b)

Figure 7. (a) The input of 100 mV at 20 kHz; (b) The input of 100 mV at 100 Hz

To meet the requirement of amplitude variation ≤1 dB within the frequency band, calculations indicate that the output should remain within the range of 2.1 V to 3.22 V when the input voltage amplitude varies between 10 mV to 100 mV. The test results reveal that, following the AGC circuit, distortion is absent in all cases except under extreme conditions, and the output broadly satisfies the frequency band amplitude variation criterion.

3.2. Functionality testing for high-pass and low-pass filters

The testing is conducted in three steps. Step 1: We use a Bode analyzer to measure the amplitude-frequency characteristics of the high-pass and low-pass filters; Step 2: We observe the amplitude-frequency characteristics to identify the 24 dB/octave attenuation for both the high-pass and low-pass filters; Step 3: We perform high and low-frequency tests on the output of the high-pass filter and the low-pass filter while observing any distortion. The test results can be found in Figures 8 and 9.

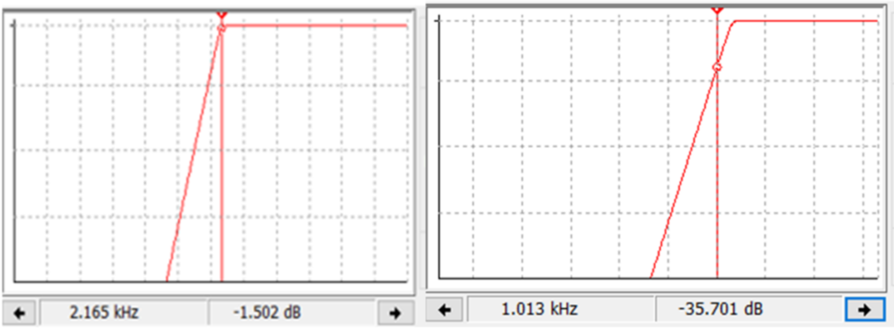


Figure 8. High-pass filter cutoff frequency and attenuation

Figure 9. Low-pass filter cutoff frequency and attenuation

After testing, the high-pass filter has a cutoff frequency of 2.165 kHz, and the low-pass filter has a cutoff frequency of 1.987 kHz. The stopband attenuation for both filters meets the requirement of 24 dB.

4. Summary

This paper presents a biquad audio amplification circuit with automatic gain control (AGC) functionality. In the preprocessing stage, an AGC circuit is employed to ensure automatic gain control, thereby enabling effective amplification within the input amplitude range of 10 to 100 mV. High-pass and low-pass filters are utilized to split the input signal at 2 kHz, successfully achieving the desired frequency separation. Subsequently, amplification is separately applied to the high-frequency and low-frequency signals. Through testing, the overall design is found to be comprehensive and reliable, effectively meeting the amplification requirements for audio signals.

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