Implementation of Automatic Gain Control Circuit Based on AD603 Chip

Yuankai Gao

School of Information and Communication Engineering, Beijing University of Information Science and Technology, Beijing, China
2021010822@bistu.edu.cn

Abstract. Automatic gain control circuits (AGC) are important control circuits in communication, broadcasting and radar systems. In this paper, through theoretical analysis, simulation and circuit debugging, an automatic gain adjustment amplifier circuit whose output is stabilized at a specified voltage value is designed and implemented. The circuit uses the principle of constant current source to monitor the output of variable gain amplifier (VGA), and feeds back the difference between the output voltage and the set value to the gain control terminal of the VGA, so as to realize the function of automatic gain adjustment. In order to improve the bandwidth capability, an emitter follower is connected to the output of the AGC circuit, and a Darlington tube is selected to replace the transistor therein, thus further improving the bandwidth capability of this circuit. In addition, a full-wave rectifier and voltage regulator circuit is used to provide a stable voltage for this circuit. Through experimental testing and verification, the circuit achieves the function of stable output of specified voltage peak-to-peak waveforms under different input frequencies and input voltages, and realizes the design requirements.

Keywords: Automatic Gain Control Amplifiers, Variable Gain Amplifier, Radio Follower.

1 Introduction

In wireless communication systems, the received signal is easily affected by many factors such as obstacles, transmitter power, and the distance between the transmitter and the receiver, which makes the signal received by the antenna have large variations [1]. Due to the random strength of the signal received at the front-end and the large dynamic range of the signal, if it is directly input into the signal processing circuit, it will lead to the system processing accuracy is affected. AGC circuit solves this problem.

Automatic gain control has very broad application prospects in the field of satellite, radio communication, signal processing, etc. In satellite communication systems, the received signal generally has unpredictable power, and due to the multicarrier signals and redundant signals vary in a large dynamic range. For satellite receiving system basically must have AGC circuit [2] soft. In the field of radio communication,

Y. Yue (ed.), *Proceedings of the 2024 International Conference on Mechanics, Electronics Engineering and Automation (ICMEEA 2024)*, Advances in Engineering Research 240,
https://doi.org/10.2991/978-94-6463-518-8_38

software radio technology is an emerging technology, which can provide a variety of services, and has a multi-frequency operation, programmable, reconfigurable and other points to achieve a flexible radio system. The general implementation of AGC circuits requires the use of VGAs in the feedback loop for implementation. The implementation of surround and software radio designs also requires the application of VGA in AGC circuits [3]. In the field of signal processing, signals such as video, audio and images are often processed using HDR techniques. In this technique, AGC algorithms help to move the dynamic range to the right place in the audio signal. Combining AGC with HDR increases the dynamic range of audio. In addition, HDR AGC reconstructs the audio signal as close to the source as possible [4].

The AD603 is a single-channel, low-noise, controlled-gain amplifier with a linearly and continuously adjustable range of gain variation [5], and then an emitter follower is added to increase its bandwidth capacity. The AGC designed and manufactured in this paper automatically adjusts the gain of the amplifier according to the amplitude of the input signal voltage so that the output is stabilised at the specified voltage value and the amplifier is loaded with a 200Ω resistive load.

The project should achieve the following basic functions:

1) Input sinusoidal voltage signal range: 100mVpp to 1Vpp (peak to peak Vpp).

2) Input signal frequency range: 100Hz to 1MHz.

3) The output voltage is maintained at 2 Vpp (peak-to-peak Vpp), with the smaller the deviation the better, and without significant distortion.

The following extended functions are added to the basic functions:

1) Input sinusoidal voltage signal range from 10mVpp to 1Vpp, the output can be maintained at 2Vpp, the smaller the deviation the better.

2) The input sinusoidal voltage signal range is 10mVpp to 1Vpp, and the output voltage can be preset in any range from 1Vpp to 2Vpp.

2 Programme Design and Validation

2.1 AGC Circuit Principle

The AGC circuit is a control circuit that adjusts the gain of the amplifier circuit by itself as the input signal strength changes. When the amplitude of the input signal varies greatly, it is able to keep the amplitude of the output signal unchanged or vary only within a small range. The gain of the circuit is automatically adjusted according to the amplitude of the output signal, and the AGC circuit does not become inoperative because the input signal is too small, nor does it saturate the amplifier circuit because the input signal is too large. Common AGC control methods are classified as Feedforward AGC (abbreviated as FF-AGC), and Feedback AGC (abbreviated as FB-AGC)[6]. Feedforward AGC is an open-loop control method that sets the gain value in advance based on the expected power of the signal without the need for real-time feedback of the signal's power information. The advantage is that it is simple, fast, and not prone to stability problems, but it may not be able to adjust the gain in time to adapt to changes in the signal power. Feedback AGC is a closed-loop control method, which adjusts the gain value of the gain controller by comparing the feedback signal (usually the power of the received signal) with the reference signal (the set target power) to bring the power of the received signal up to the set target power . The benefit is better stability and fast response to changes in signal power, but there may be oscillation problems.

2.2 Programme details

This project designs a feedback AGC circuit. The circuit consists of two parts: an automatic gain amplifier circuit and an output driver circuit (see Fig. 1).

The first part of the circuit is the Auto Gain Amplifier, the controller consists of a Variable Gain Amplifier (VGA) and a gain control circuit. The VGA is implemented by an AD603 chip, the control part controls its gain by comparing the output value to a reference value and provides an analogue gain control signal to the VGA to achieve the output voltage required in the project, which is held at 2 Vpp.

The second part of the circuit is the emitter follower. Due to the high impedance and weak load capacity of the previous AGC output, it was necessary to add an additional driver stage at the output. By connecting an emitter follower with high input impedance and low output impedance to the output of the AGC circuit, we have improved the loading capability of the output of the gain control circuit to meet the 200 Ω resistive load of the amplifier required in the title, ensuring proper operation of the circuit.

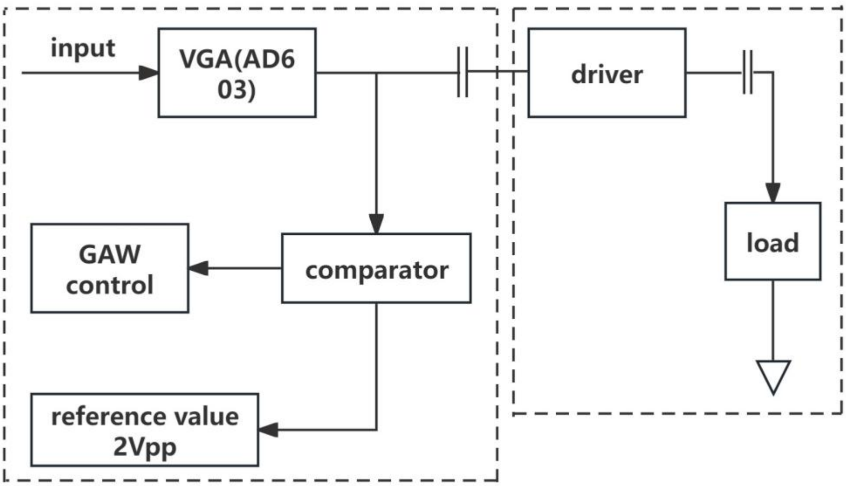

Fig. 1. Automatic Gain Amplifier Circuit Diagram.

3 Theoretical Calculations and Analyses

Firstly, the basic principles of VGA circuits need to be explained. As the input signal amplitude changes, there will be a corresponding change in the DC voltage (AGC voltage), which can be used to control the amplification of the variable gain amplifier (or control the attenuation of the variable attenuation circuit). When the input signal amplitude is large, the amplification of the AGC voltage-controlled variable gain amplifier decreases (or the attenuation of the variable attenuation circuit increases); when the input signal amplitude is small, the amplification of the AGC voltage-controlled variable gain amplifier increases (or the attenuation of the variable attenuation circuit decreases). When the input signal amplitude is small, the amplification of the AGC voltage-controlled variable gain amplifier increases (or the attenuation of the variable attenuation circuit decreases). Variable gain amplifier gain change method mainly has artificial (or mechanical) and programmed control two categories of specific methods have a variety of. Theoretically, the gain of the amplifier can be changed by changing the feedback resistance or input resistance of the integrated operational amplifier (op-amp) [7]. This project uses the manual way to change the size of the gain.

According to the above principle, after searching for information, the author decided to use AD603 chip for the design of this project.AD603 is a product of American ADI company, which is an integrated operational amplifier with 90 MHz bandwidth, adjustable gain, low noise and other characteristics. Its gain in decibels is linearly related to the control voltage, and we can automatically adjust the gain of the circuit to the appropriate range by setting the gain. The programmable gain of the AD603 is linearly related to the control voltage.

The programmable gain range of the AD603 is determined by the connections between the pins. The gain is between -11 ~ +30d for a bandwidth of 90MHz and between +9 ~ +41d B for a bandwidth of 9MHz (chip pin see Fig. 2).

Fig. 2. AD603 Pinout [8].

As shown in Fig. 3, the internal working circuit of AD603 consists of 3 parts. The first part is the linear gain control part, the relationship between gain and voltage is 40d B/V; the second part is composed of R-2R ladder network, the gain range is 0~-42.14d B. The third part is a precision passive input attenuator and fixed gain amplifier of 31.07~51.07d B. The third part is a precision passive input attenuator and fixed gain amplifier of 31.07~51.07d B. The third part is a precision passive input attenuator and fixed gain amplifier.[8] The signal added to the input of the ladder network (VINP) is attenuated and output from the fixed gain amplifier, the amount of attenuation being determined by the voltage added to the gain control interface. The gain adjustment has nothing to do with its own voltage value, but only with its difference VG. Since the input resistance at the GPOS/GNEG end of the control voltage is as high as 50MΩ, the input current is very small, resulting in a reduced influence of the on-chip control circuit on the external circuit providing the gain control voltage. The gain range of the amplifier is different when the VOUT and FDBK pins are connected differently. When pin 5 and pin 7 are shorted, the gain of the AD603 is 40Vg+10, which is in the range of -10~30dB, and when pin 5 and pin 7 are disconnected, the gain is 40Vg+30, which is in the range of 10~50dB, and if a resistor is connected to pins 5 and 7, the gain will be in the middle of the two above mentioned ranges.

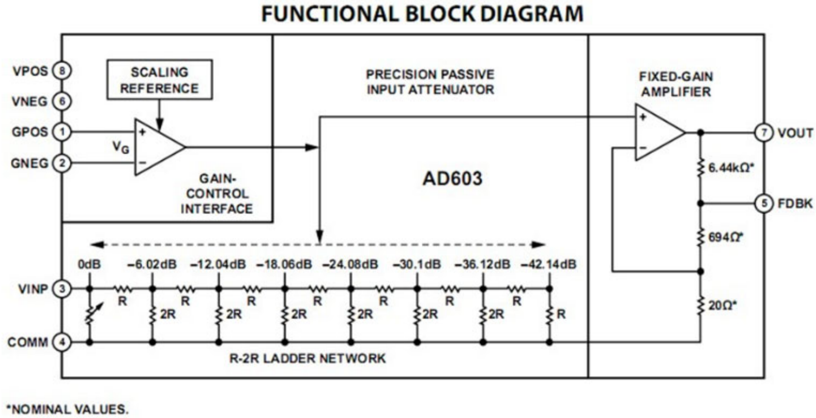

Fig. 3. AD603 internal structure diagram [8].

After checking the operation manual, the gain range of a single chip is 42.14dB, in order to enhance the gain effect and range of the circuit, this project adopts two chips in cascade to expand the gain range of the circuit to 84.24dB (see Fig. 4). When the output signal of the output corner (pin 7) enters the filter consisting of Q2 and R8, it will be compared with Q1 to generate the difference of the collector current, and then input to the GPOS corner (pin 1) as the output signal of the output corner (pin 7), and then the output signal of the output corner (pin 7) will be used as the output signal of the output corner (pin 8). The difference in collector current is then input to the GPOS angle (pin 1) and is used as the output signal of the output angle (pin 7). The collector current difference is then input to the GPOS angle (pin 1). The current input to the 10V stabilizing voltage at the GPOS (pin 1) and GNEG (pin 2) terminals produces a voltage difference compared to the reference value, which is input to the r-2r resistor ladder network for control, and its amplification is automatically adjusted to stabilize the output 2Vpp signal by automatically adjusting the amplifier gain.

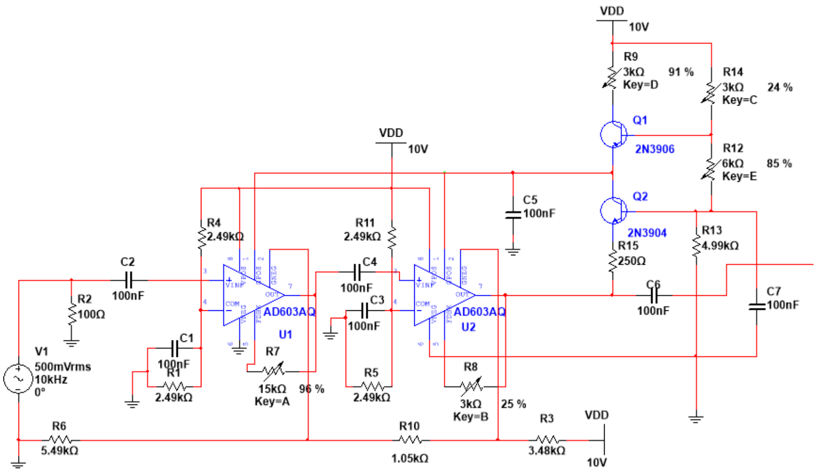

Fig. 4. Automatic Gain Amplifier Circuit Simulation Diagram.

To increase the load capacity of the output amplifier, an emitter follower is added to the output of the AGC circuit (see Fig. 5). A Darlington tube was used in the emitter follower to boost the input impedance to prevent the negative half-axis of the output waveform from being truncated, which would result in distortion. In the initial solution, the authors chose a single transistor (2N3903, a silicon NPN transistor designed for general-purpose amplifier and switching applications [9]) to enhance the input impedance, but after simulation and physical circuit experiments, the authors found that the input impedance provided by a single transistor was not sufficient to drive a 200Ω load, so the authors chose a Darlington with a larger input impedance as the final solution. An emitter follower, like a cathode follower, is essentially a feedback device. At low frequencies, the feedback is usually reduced. Under certain conditions, usually in the presence of a drive inductor and load capacitance, the feedback is regenerated at high frequencies, resulting in damped oscillations or sustained oscillations [10]. The co-emitter amplifier circuit of the transistor inside the emitter follower connects the input signal to the emitter port of the transistor, where the signal is amplified and followed inside the transistor and output from the collector port of the transistor. The high gain characteristic of the transistor allows the input signal to accurately track the output signal, thus keeping the signal stable and distortion free. Due to the limitation of the effective operating frequency of the AD603 chip (the lowest effective operating frequency is 16kHz), a constant output of about 800mVpp can only be achieved with a 200 Ω load. With the addition of a follower stage, a stable output of approximately 1.50V can be achieved. Under all other conditions, a stable output of 2Vpp can be achieved.

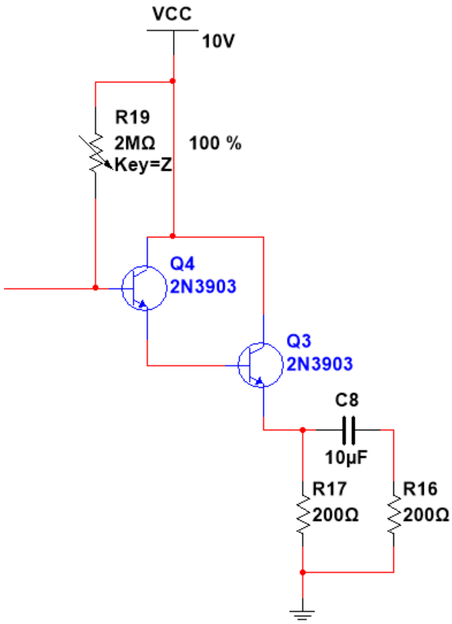

Fig. 5. Simulation of the emitter follower circuit.

4 Circuits and Programming

Based on the circuit simulation results of Multisim software, the schematic diagram of the circuit is drawn with the PCB board. Fig. 6 is the schematic diagram drawn based on the analogue circuit showing the VCC network, GND network, input ports, and output ports.

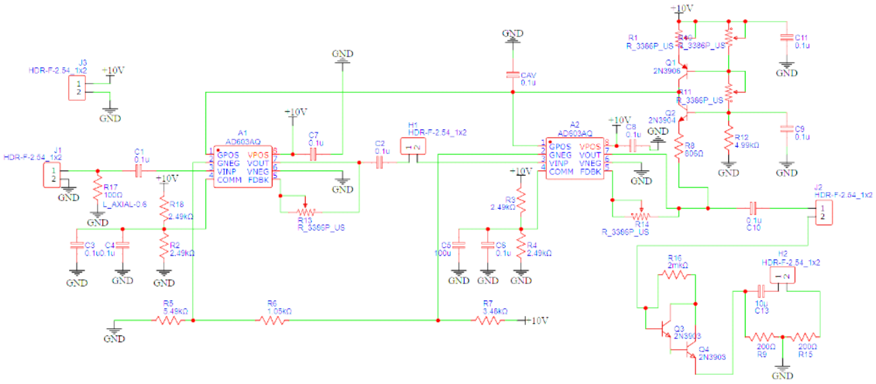

Fig. 6. Simulation Circuit Schematic.

Fig. 7 shows the printed circuit board drawn based on the schematic diagram of Fig. 6. The wiring is done using the proximity principle to reduce flying wires. From left to right, the VGN circuit, the automatic gain control circuit, and the driver circuit are shown.

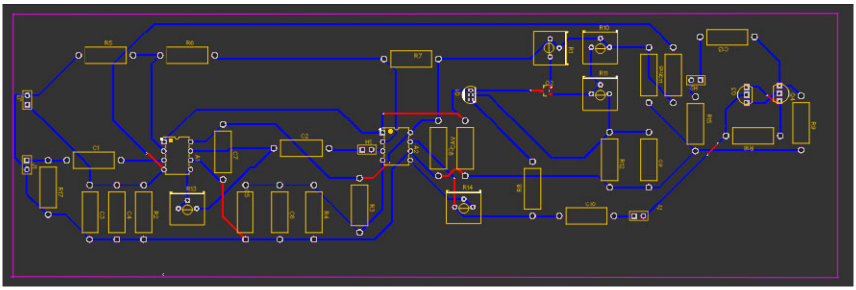

Fig. 7. PCB diagram.

In order to check whether the designed circuit can meet the requirements, the authors chose to solder the physical analogue circuit for testing. The physical drop circuit adopts a double-layer circuit board structure, the upper circuit is the AGC circuit (see Fig. 8), and the lower circuit is the AC/DC voltage conversion module (see Fig. 9).

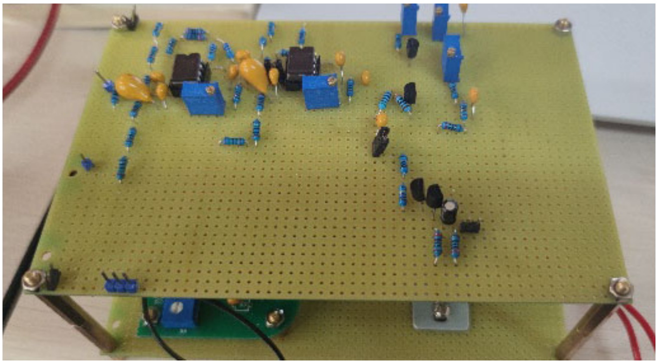

Fig. 8. Gain Control Amplifier Circuit Physical Diagram (Positive).

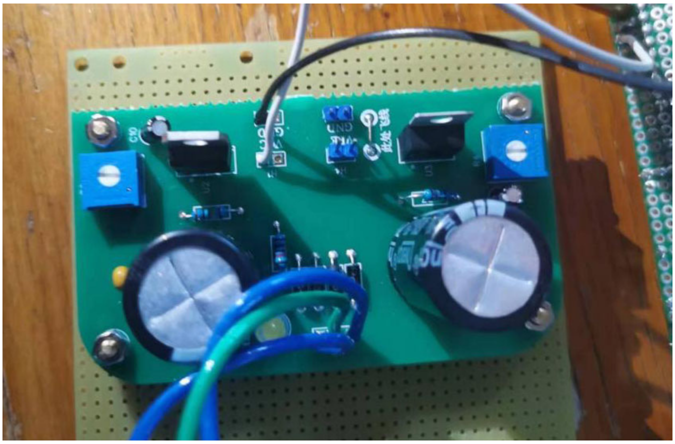

Fig. 9. AC-DC Voltage Conversion Modules.

5 Test Methods and Data

The circuit was tested using a function generator, an oscilloscope, a multimeter, and a 10-volt DC power supply as test instruments.

The circuit was tested by connecting a function generator to the three-pin probe of the A1 chip and an oscilloscope to the probe of the radio level follower and supplying it with a +10V DC power supply. Use the generator to output a pulse with an amplitude of 500mVpp and a frequency of 10kHz, observe Vpp and record the result. Output a pulse with an amplitude of 500mVPP using a signal generator and increase the frequency from 100Hz to 1MHz (10 times each), observe Vpp and record the result. The generator outputs a pulse with a signal frequency of 10kHz. Use the knob to change the amplitude from 100mVpp to 900mV by increasing the frequency from 100mVpp to 1MHz (100mV each time), observe the Vpp and record the result. The generator outputs a pulse with an amplitude of 100mVpp, and the frequency is increased from 100Hz to 1MHz sequentially (by 10 each time), Vpp is recorded and the result is displayed. The generator outputs a pulse with an amplitude of 1Vpp, and the frequency is increased from 100Hz to 1MHz (10 increases each time), observe Vpp and record the displayed result.

According to the project objectives, the authors conducted simulation tests using Multisim. The test results are shown in Table 1, Table 2 and Table 3.

Table 1. Simulation results for input signal amplitude of 500mVpp and 100mVpp

Input Frequency	Output Voltage (input signal amplitude fixed at 500mVpp)	Output Voltage (input signal amplitude fixed at 500mVpp)
100Hz	467.774mV	303mV
1kHz	2.075V	2.085V
10kHz	2.141V	2.103V
100kHz	2.144V	2.129V
1MHz	2.145V	2.085V

Table 2. Simulation results with input signal frequency fixed at 10kHz

Input Amplitude	Output Voltage
100mVpp	2.137V
200mVpp	2.137V
300mVpp	2.132V
400mVpp	2.131V
500mVpp	2.124V
600mVpp	2.115V
700mVpp	2.136V
800mVpp	2.136V
900mVpp	2.131V

Table 3. Simulation results with input signal frequency fixed at 10kHz

Input Frequency	Output Voltage
100Hz	2.604V
1kHz	2.169V
10kHz	2.142V
100kHz	2.610V
1MHz	2.546V

In order to compare with the simulation results, the authors tested the actual circuit and recorded the data. The data results are shown in Tables 4, 5 and 6.

Table 4. Input signal amplitude 500mVpp and 100mVpp

Input Frequency	Output voltage (input signal amplitude fixed at	Output voltage (input signal amplitude fixed at

	500mVpp)	100mVpp)
100Hz	(signal) distortion	(signal) distortion
1kHz	(signal) distortion	(signal) distortion
10kHz	2.017V	2.050V
100kHz	2.000V	2.000V
1MHz	1.933V	1.933V

Table 5. Input signal frequency fixed at 10kHz

Input Amplitude	output voltage
100mVpp	2.050V
200mVpp	2.033V
300mVpp	2.033V
400mVpp	2.033V
500mVpp	2.017V
600mVpp	2.033V
700mVpp	2.050V
800mVpp	2.033V
900mVpp	2.017V

Table 6. Input signal amplitude fixed at 1Vpp

Input frequency	output voltage
100Hz	(signal) distortion
1kHz	(signal) distortion
10kHz	2.067V
100kHz	1.983V
1MHz	1.917V

By comparing the simulation data with the actual circuit data, it is found that at a fixed input signal frequency of 10kHz, the physical circuit matches the simulation circuit data and performs well overall. Under the premise of fixing the input signal amplitude, the output voltage waveform shows different degrees of distortion when the input frequency is 100Hz or 1kHz. Through further control variable testing the authors found that the input frequency between 100Hz and 1600Hz, the input frequency of 100Hz, the waveform distortion is the most serious. And the higher the input frequency the smaller the waveform distortion. The distortion is not reproduced after the input frequency is greater than or equal to 1600Hz.

Except for the two frequencies of 100Hz and 1kHz, the performance of the rest of the frequencies matches the simulation data and performs well.

6 Conclusion

In this paper, an automatic gain amplification system is designed and implemented. The AGC system design in this paper is based on the AD603 chip, and after physical testing, the system is able to sense the signal between 16k Hz~1M Hz for automatic gain amplification. The gain control circuit can provide signals to the AD603 according to the difference between Q1 and Q2, so that the r-2r resistor network inside the AD603 can adjust the gain size by itself, and accurately output 2 Vpp. The driver circuit is a radio stage follower equipped with Darlington tubes, which can increase the input impedance, prevent the distortion of the output signal, and at the same time, improve the bandwidth capacity. In the actual measurement stage, the actual data and the simulation data are distorted in the range of 100Hz~1000Hz, and the waveform shown in the simulation does not appear. After checking the chip manual, it was found that the minimum effective operating frequency of the chip is 16kHz, and it does not support the 100Hz~1000Hz operating frequency. If the chip is replaced with a chip with a larger operating frequency range, it may be improved. AGC systems have a wide range of applications and high research value, which deserves continued in-depth research. It can be expected that its broader intermingling development with other fields.

References

1. Liang,Y., Zhao,L. and Tang,Q.: Design of High Dynamic AGC Control Model and Signal Processing Algorithm For Software Radio Receivers. 2020 IEEE 9th Joint International Information Technology and Artificial Intelligence Conference (ITAIC),1442-1446(2020) .
2. Xiang,X., Wang,Z.,Shen,D.,Chen,G. and Pham,K.: A Smart Hybrid AGC Scheme for Satellite System. 2020 IEEE Aerospace Conference,1-6(2020).
3. Chopra,P., Kumar,N. and Paily,R.: Ultra wideband AGC and VGA designs for software radio applications. TENCON 2008 - 2008 IEEE Region 10 Conference,1-5(2008).
4. Hernandez,J.,Garcia,D. E. and Mann,S.: HDR AGC Signal Optimization Applied to Audio.2020 IEEE SENSORS,1-4(2020).
5. Chopra,P.,Kumar,N. and Paily,R.: Ultra wideband AGC and VGA designs for software radio applications. TENCON 2008 - 2008 IEEE Region 10 Conference, 1-5 (2008).
6. Xia,G., Zhang,Q. and YangZ.: Design and implementation of an efficient and large dynamic range hybrid digital AGC for burst communication systems. 2012 IEEE 11th International Conference on Signal Processing,1373-1377 (2012).
7. Zhou,S.H.,Wang,D.C.,Ma,J.Z.: Variable Gain Amplifier Implementation. Instrumentation technology and sensors(07), 32-34(2001).
8. Analog Devices.: AD603: Low Noise, 90 MHz Variable Gain Amplifier Data Sheet (Rev.k).(2008).https://www.analog.com/media/en/technical-documentation/data-sheets/AD603.pdf
9. Central Semiconductor Crop,: 2N3903 2N3904 SILICON NPN TRANSISTORS.(2021).https://my.centralsemi.com/datasheets/2N3903.PDF
10. Kozikowski,J.: Analysis and Design of Emitter Followers at High Frequencies. in IEEE Transactions on Circuit Theory,11(1),129-136,(1964).