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The Fabrication of an Amplifier Nonlinear Distortion Research Device

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Abstract

This paper mainly introduces a circuit amplifier nonlinear distortion experimental system which is used by students of electronic circuit and related majors. First of all, from the structure and function of the system, this paper introduces the basic structure and function of the system, the parameters and application scope of the system. Secondly, the paper introduces the design of the system and analyzes the reasons for selecting various types of devices. After that, this paper analyzes the principle of analog electronic technology based on the system and the calculation formula of related parameters, and gives the corresponding circuit design process and program design process of the system. Finally, this paper carries out the corresponding experimental test and result analysis of the system, and finally verifies that the device can measure various output conditions and corresponding parameters of the nonlinear distortion of the amplifier under the condition of ensuring a certain accuracy, so as to achieve the purpose of the system design.

Keywords

STM32; Amplifier Circuit; A/D; FFT; THD.

1. Introduction

This system uses STM32F103 as the core processor to make an amplifier nonlinear distortion research device: amplifier circuit module is composed of two-stage transistor common emitter amplifier circuit, one-stage circuit amplifies 10 times, two-stage amplifies 100 times, and the output voltage peak reaches 2V; the control module is composed of single-chip microcomputer and analog switch CD4051: through the external MCU I/O port to realize the control of analog switch, and then realize five conditions of amplifier circuit output; The indicator measurement module is mainly composed A/D and microprocessor: the output voltage Uo and sampling rate are measured, and the input signal is transformed by FFT function of 1024 points, and the THD calculation is calculated, and the result of THD is displayed in the final LCD.After the test, the system can realize four kinds of distortion and no obvious distortion of the amplifier circuit: The output voltage and THD calculated results of each distortion waveform accord with the corresponding circuit principle and the requirements of daily experimental equipment.

The main functions of the system are as follows:

(1) The circuit can realize the amplification output waveform including saturation distortion, cut-off distortion, bidirectional distortion, crossover distortion and normal amplification sine wave output waveform;

(2) The controller can make the output of the circuit present different output states according to different user input instructions; The five states of the output circuit can be switched back and forth;

(3) The controller can sample and FFT the amplified signal, and calculate the total harmonic distortion of different output waveforms.

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The parameters of the system are as follows:

(1) Input voltage peak to peak range: 0 ~ 0.3V

(2) Peak to peak range of output voltage: 0 ~ 3.0V

(3) The magnification of the first stage amplifier circuit: 10

(4) Amplification factor of the second stage amplification circuit: 10

(5) THD at normal amplification: 0

(6) THD when the output is cut-off distortion: 18 ~ 22

(7) THD when output is saturation distortion: 18 ~ 23

(8) THD when output is bidirectional distortion: 35 ~ 44

(9) THD when the output is crossover distortion: 10 ~ 14

2. System scheme

2.1 Technical Scheme Analysis

2.1.1 The Demonstration and Selection of the Design Scheme of the Amplifier Circuit Module

Plan 1: the signal passes through the two-stage amplifier circuit, by changing its resistance parameters to complete the output of the letter complete waveform, top distortion, bottom distortion, two-way distortion waveform, and the stage uses the power amplifier circuit to access and complete the cross-over distortion waveform output.

Plan 2: The signal passes through the three-stage amplifier circuit, and the effect of signal amplification is realized by changing the resistance, but the signal effect is not good due to too many series and the resistance adjustment is too complicated.

2.1.2 The Demonstration and Selection of the Design Scheme of the Index Measurement Module

Plan 1: STM32F103 realizes voltage acquisition, measurement and calculation through internal A/D

The STM32 chip comes with 2 12-bit ADCs, which control the sampling rate through the timer and ADC sampling cycle, and the THD can be displayed by the LCD of STM32 single chip. At the same time, each harmonic amplitude and simple signal spectrum can be calculated and displayed in real-time.

Advantages: easy to operate, good precision, can meet the basic requirements of this experiment.

Disadvantages: The sampling rate is low and only low frequency signals can be analyzed. When the first harmonic frequency is 1 KHz, only the amplitude value of the maximum fifth harmonic can be detected.

Plan 2: Measurement and calculation via ATT7022E of three-phase metering chip:

ATT7022E is a multi-functional and high-precision three-phase electric power metering chip, suitable for three-phase three-wire and three-phase four-wire applications. ATT7022E integrates seven-way second-order A/D, which can measure the active power, reactive power, apparent power and so on. It provides two kinds of apparent power and energy measurement methods, as well as the fundamental wave parameter measurement. ATT7022E also has an SPI communication interface.

2.1.3 Demonstration and Selection of Circuit Control Module Design Scheme

STM32F103 can realize high and low level switching through I/O port, and then realize the adjustment of analog switch CD4052 to the circuit.

CD4052 is A differential 4-channel digital control analog switch with A and B binary control inputs and INH inputs with low on-impedance and very low cut-off leakage current.

STM32 single chip microcomputer has dozens of I/O interfaces and four keys and can be configured, so that the operator can realize the I/O interface's high and low level switch through the operating button, and then make CD4052 change access circuit, in order to realize the waveform transformation.

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Advantages: The analog switch has the advantages of low power consumption, fast speed, no mechanical contact and small size. Single chip I/O port to the high and low level boundary is obvious, voltage stability, low level 0V, high level 3.3V, enough for CD4502 address selection.

Disadvantages: CD4052 when the signal amplitude or frequency between adjacent channels is too large, the signals between channels will form crosstalk, and the on resistance is large, about 80-180Ω. Single-chip I/O port can only output only 0V/3.3V fixed voltage, and the voltage adjustment range is narrow.

2.2 System overall scheme design

The amplifier nonlinear distortion research device system is a system which can amplify the small signal source, and can produce corresponding normal waveform and four corresponding distortion waveforms including crossover distortion and top distortion, and can generate the distortion waveform FFT transformation and THD calculation system. The system is mainly composed of two-stage transistor amplifier circuit module, an index measurement module composed of STM32F103 series CPU and its single-chip microcomputer with 12-bit AD, the control module composed of analog switch CD4052 and single-chip computer I/O port, and the result display module composed of a touch screen module. The research device uses STM32F103RCT6 of ST company as the general controller of the system; access to the analog switch CD4052 control circuit, the 12-bit ADC of STM32F103 is responsible for measuring the output voltage. After collecting data, the data can be displayed in real-time on the color touch screen after FFT and related calculation by single-chip. Because the internal AD of STM32 cannot collect negative voltage and cannot exceed 3.3V, the signal needs to contain DC component to realize the potential shift of the output voltage, so as to facilitate measurement. When studying the amplifying characteristics of transistor amplifier circuit, the personnel control the analog switch CD4052 by pressing the button to select different access circuits to output different waveforms, through the measurement and collection of output voltage by ADC and the calculation of data collection inside the single-chip. The system realizes the output of normal waveform and four kinds of distortion waveforms, and can carry out simple harmonic analysis, THD calculation, simple spectrum display and other functions.

2.3 Theoretical Analysis and Calculation

By calculating the following formula and combining with the equivalent circuit diagram to complete waveform---distortion-free amplification of theoretical calculation:

$$A_V = \frac{V_O}{V_i} = -\beta \frac{R_L'}{r_{be}}$$

The results of theoretical simulation are as follows:

(1) The type of related distortion can be changed by changing the relative resistance

(2) Access to different module circuits can change the type of related distortion.

(3) According to the formula of distortion waveform and common total harmonic distortion (THD: total harmonic distortion):

$$THD = \frac{\sqrt{U_{o2}^2 + U_{o3}^2 + U_{o4}^2 + L + U_{on}^2}}{U_{o1}} \times 100\% .$$

2.4 Circuit and Programming

2.4.1General Block Diagram of Circuit System

Demonstration of the overall design of the device see figure 1.

2.4.2 Core Circuit Design

(1) Two-stage amplifier circuit board

The circuit board adopts the two-stage co-emission amplifier circuit, and uses S9014NPN transistors and other components to realize the amplification function, the accumulative amplification is 100 times: Vpp20mv--2V, to realize normal amplification function, and to guarantee no distortion.

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(2) Replacement Resistance Board

The resistor board is composed of a plurality of different resistance resistors and CD4052 analog switches. By receiving the command of the controller's key address, the corresponding path is connected, which includes normal, top distortion, bottom distortion and bidirectional distortion.

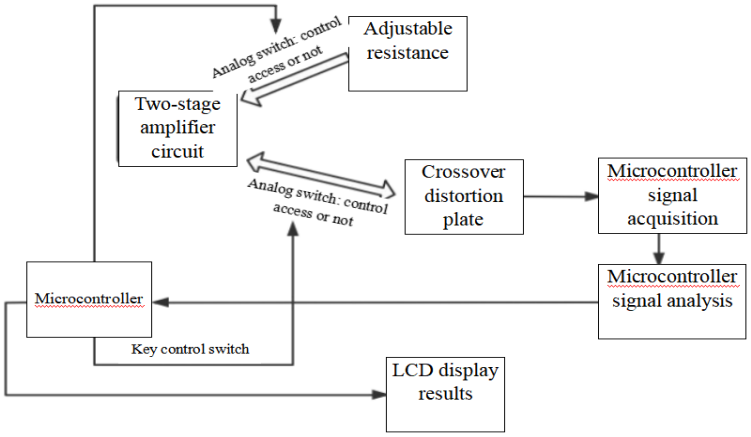

Figure 1. Demonstration of the overall design of the device

(3) Crossover Distortion Module Board

The module is composed of crossover distortion related NPN, PNP transistor and other components, and is connected with CD4052 analog switch for access.

(4) Microcontroller Data Processing Board & Key Control Panel

This system uses STM32F103 single-chip microcomputer as the microcontroller, LCD screen for data processing feedback display, can carry out the calculation results of the display, very convenient; and the key is used as the input path to control the analog switch. By inputting different addresses, the THD results of different distortion waveforms are displayed on the LCD, and the external oscilloscope can monitor the circuit generated by the relevant amplifier signal and distortion signal.

The circuit schematic diagram is as follows:

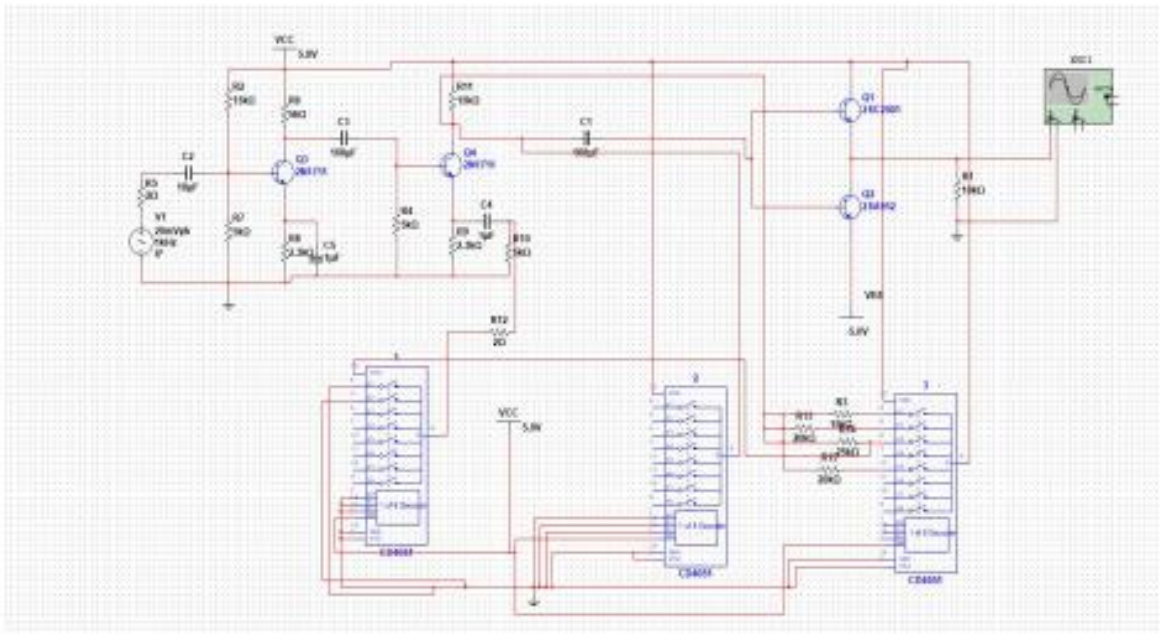

Figure 2. Device Circuit Diagram

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(Note: The abc terminal of CD4051 No. 3 is controlled by a single chip microcomputer. Because the simulation software does not have some functions of CD4051 module, other methods are used to realize the simulation. The circuit diagram is the concept diagram, and other methods are not shown.)

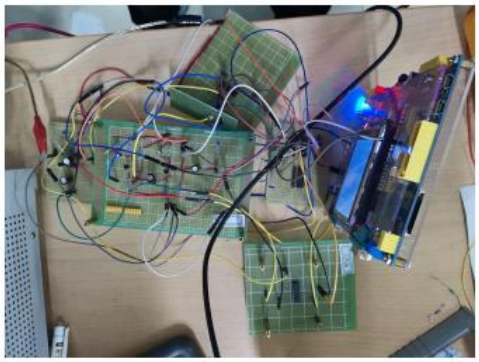

Figure 3. Physical device diagram

(5) Software programming

The three functions of the whole software are as follows:

(1) STM32F103 single-chip microcomputer through its key control to achieve high and low level conversion, control CD4052's enable end, make it choose different circuit, to realize the control of output waveform;

(2) The output voltage of amplifier circuit is collected in real time through the STM32F103 single chip microcomputer with 12-bit AD, the data is collected by 1024-bit FFT, and the simple spectrum image and THD result are shown.

The program flow chart is as follows:

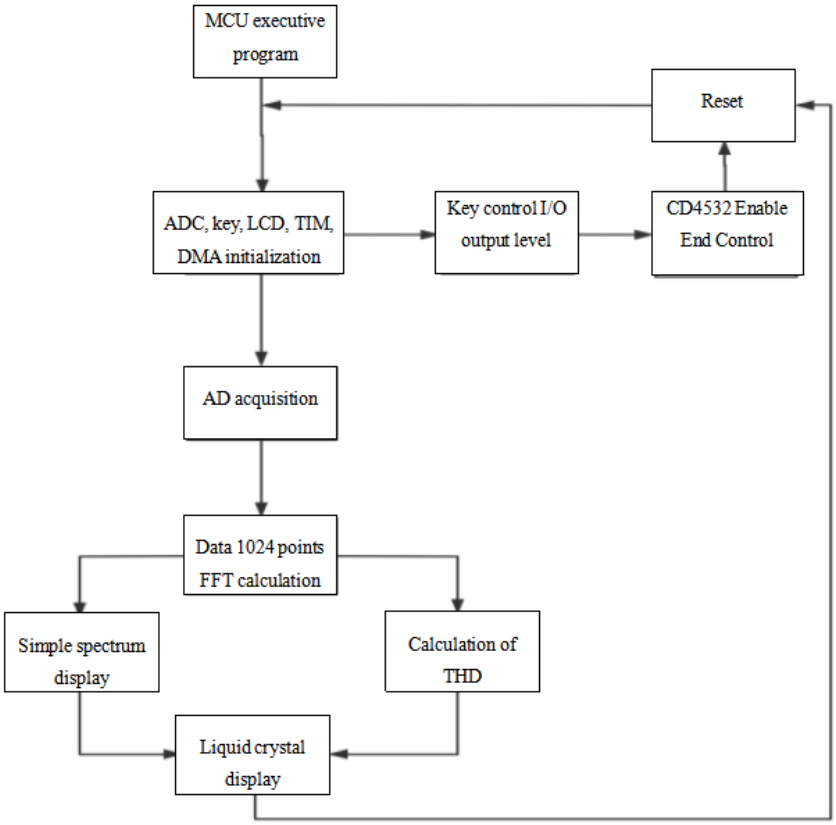

Figure 4. Single chip microcomputer code design ideas

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3. Test plan and test result

3.1 Test plan

Firstly, the theoretical value of the index to be measured is calculated, and the beta of the triode S9014 in the amplifier circuit is obtained by measurement as 276. After calculating the theoretical value, the system is used to measure the output voltage and other indexes; and then the accurate value of "total harmonic distortion" is obtained according to the FFT algorithm of 1024 bits and THD calculation formula, and the signal processing unit of the microcontroller produces the approximate value. The theoretical and practical magnification index & approximate value compared with the accurate value and observe the results.

3.2 Test Conditions and Instruments

Test conditions: check many times, the simulation circuit and hardware circuit must be exactly the same as the system schematic diagram, and check correctly, the hardware circuit to ensure no welding leakage.

Test instrument: digital oscilloscope, analog oscilloscope, digital multimeter, student power supply.

3.3 Test Results and Analysis

We use Multisim14 software to simulate and compare the results with actual values, as shown in the table.

Output sinusoidal voltage without obvious distortion:

Table 1. Undistorted output voltage results

(β=276, f=1kHz)	Theoretical value	Experimental value
Input voltage Ui peak value	0.02V	0.02V
Output voltage Uo peak value	2V	2.48V
THD	0	1

Output Bottom Distortion Voltage:

Table 2. Bottom distortion output voltage results

(β=276, f=1kHz)	Theoretical value	Experimental value
Input voltage Ui peak value	0.02V	0.02V
Output voltage Uo peak value	2.583V	1.84V
THD	18	20

Output top distortion voltage:

Table 3. Top distortion output voltage results

(β=276, f=1kHz)	Theoretical value	Experimental value
Input voltage Ui peak value	0.02V	0.02V
Output voltage Uo peak value	2.583V	2.24V
THD	20	22

Output Bidirectional Distortion Voltage:

Table 4. Bidirectional distortion output voltage results

(β=276, f=1kHz)	Theoretical value	Experimental value
Input voltage Ui peak value	0.02V	0.02V
Output voltage Uo peak value	4.38V	3.44V
THD	35	40

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Output Crossover Distortion Voltage:

Table 5. Crossover distortion output voltage results

(β=276, f=1kHz)	Theoretical value	Experimental value
Input voltage Ui peak value	0.02V	0.02V
Output voltage Uo peak value	2.02V	2.24V
THD	10	14

Based on the above test data, the following conclusions can be drawn:

1. There is little difference between the actual value measured by the system and the theory of simulation software.

2. The error of THD calculation is small and the displayed waveform meets the requirements of the question.

3.4 Related images and analysis

Bidirectional distortion:

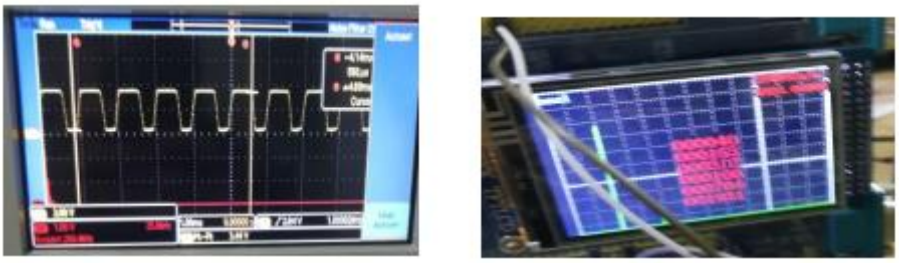

Figure 5. Experimental results of bidirectional distortion device

Sinusoidal voltage without obvious distortion:

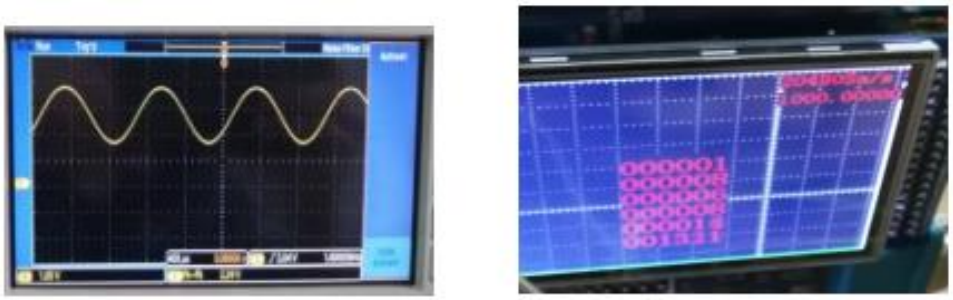

Figure 6. Experimental results of no obvious distortion device

Crossover Distortion:

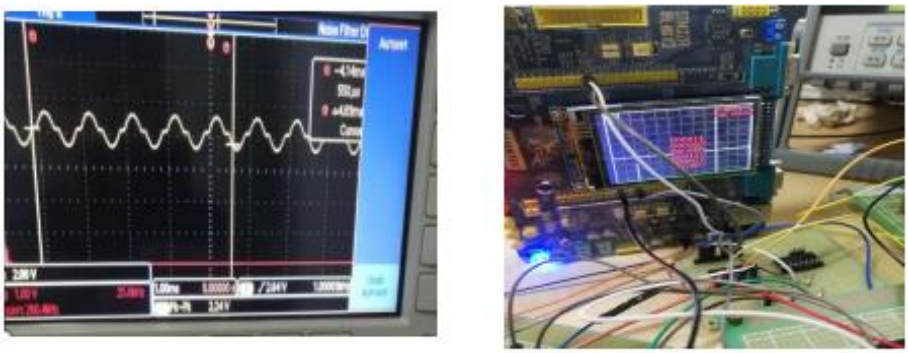

Figure 7. Experimental results of crossover d istortion device

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Bottom Distortion:

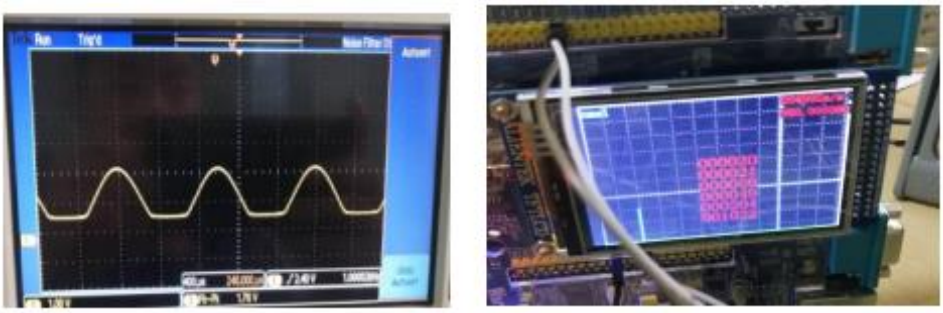

Figure 8. Experimental results of bottom distortion device

Top Distortion:

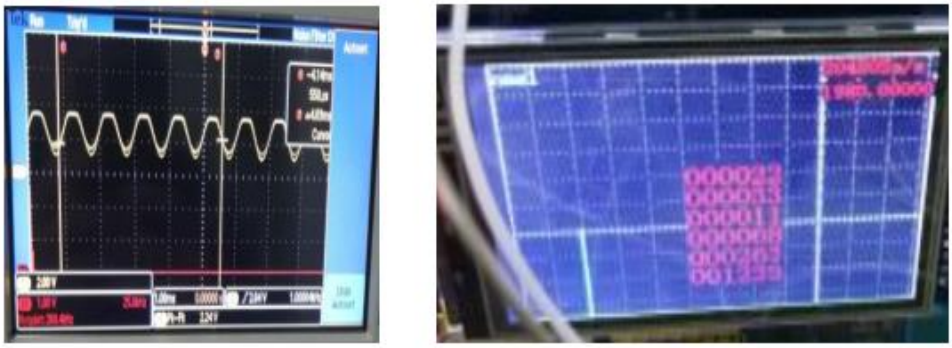

Figure 9. Experimental results of top distortion device

4. Conclusion

Analog electronic circuit is a very important subject for students majoring in electronic information engineering, and the triode amplifier circuit is a very important part of it. The system is portable and accurate, After careful design and experimental verification, it is confirmed that it can be used to measure and observe the five forms of output signal and calculate their total harmonic distortion parameters. It can be used as a portable amplifier nonlinear distortion research device for daily undergraduate students to study nonlinear amplifier circuit.

Acknowledgments

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References

[1] (Japan) Suzuki Yachen, transistor circuit design (top), Zhou Nansheng, translation, 2004.

[2] Xie Zhiyuan, Shang Qiufeng, Foundation of Analog Electronics Technology, 2011.

[3] Dong Yu & Wang Lina. (2021). Study on nonlinear amplification distortion characteristics of triode. Electronic measurement (02), 48-50. Doi: 10.16520/j.cnki.1000-8519.2021.02.015.