Design of programmable gain linear pulse amplifier based on energy spectrum analysis

Chunkai Chen, Xiaoguo Wan, Shuwei Wang

（*Tianjin Polytechnic University, School of electronic and Information Engineering,Tianjin,300387, China*）

Abstract：*The multichannel pulse amplitude analyzer as an important component of the spectrum measuring instrument, the performance of the linear pulse amplifier directly affects the final results of the energy spectrum measurement. Using the quasi-Gaussian CR-RC-CR shaping circuit structure, the non-volatile digital potentiometers and the precision operational amplifiers, that can greatly simplify the circuit structure, stronger anti-jamming ability, gain multistage changes smoothly, and system has characteristics like low temperature drift, good pulse linear, completed the nuclear detector output signal amplification and filtering the forming process.*

Keywords: *Programmable; linear pulse amplifier; Digital potentiometer; Multichannel spectrometer*

I.   Introduction

In nuclear measuring instruments, the amplifier is widely used, and occupies a very important position. In fact, the pulse shaping, amplification of linear, temperature drift, frequency response, and so on are affecting the counting rate and measurement accuracy. This paper gives a quasi-Gaussian CR-RC-CR shaping circuit structure, the use of non-volatile digital potentiometers and precision operational amplifier to achieve programmable gain linear pulse amplifier. All electronics circuits of the amplifier are packaged in a double-sided printed circuit board. This significantly improved the stability of the amplifier and anti-jamming capability, also make gain multistage continuous change smoothly, low temperature drift and with good pulse linearity. After the successful development of the amplifier, to use the multi-channel card that we developed can realize automatic spectrum stabilization. It has been used for more than two years, it is proved that the amplifier has good performance and has achieved the expected design requirements.
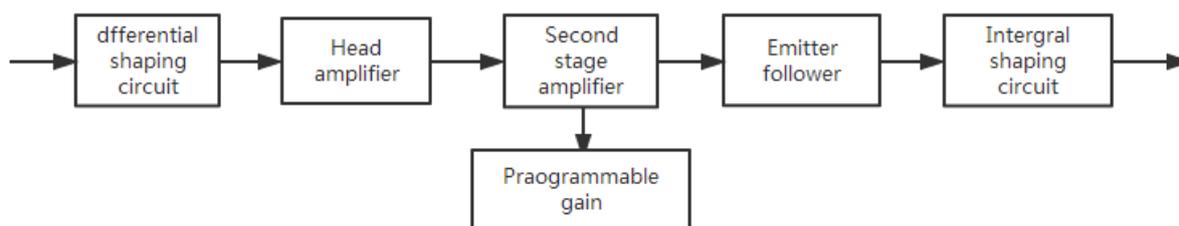
II. Pulse Amplifier Structure and Waveform Shaping

Fig.1 Function block diagram of programmable gain amplifier.

2.1   Overall Design

The nuclear detector output pulse signal amplitude is very small, its value is approximately between a few millivolts to hundreds of millivolts, and the pulse width is also very narrow. This signal cannot be used to analyze and deal with the follow-up of the circuit, so it is necessary to use a linear amplifier circuit for signal processing. The amplifying circuit consists of several amplifier stages having a feedback loop. Use AC negative feedback can further improve the performance of amplifier, including stable magnification, increase the input resistance, reduce the output resistance, broaden the bandwidth and reduce non-linear distortion. As shown in fig.1, the amplifier use two-stage amplification and one-stage follower circuit. For weak signals, the first-stage amplification is the key of three-stage amplification and need to suppress noise as much as possible, otherwise the first stage noise will into the behind amplifier with single and causing the noise to cover the useful signal in the final stage amplifier. So that needs to be done in the design of the circuit board layout is reasonable, the power supply noise and ripple suppression strength is big, the first stage amplifier have a good shielding and anti-jamming performance. With direct coupling mode between the first and second stages can improve the stability of transistor static working point, making the output of the preamplifier is distortion-free amplification

and significantly broadened the frequency range of the amplifier. After two stage amplification of the signal has certain amplitude, the influence of the working points can be avoided by using the resistance capacitance coupling. The third stage emitter follower amplification quantity is 1; its main function is increasing the input impedance and reducing the output impedance to enhance the driving ability.

2.2 Shaping circuit

The output voltage pulse of the detector is not the ideal step signal, this single's waveform is a kind of the front edge rise rapidly and after edge exponential decay with time. When a high pulse count rate, resulting in a large number of pulses stacked tail, which can cause significant baseline drift, the peak position from moving and reduce the energy of energy spectrometer. Due to the output signal of the preamplifier in Fig. 2 (a) show, the tail decay time constant typically tens of microseconds or more, and its rise time is usually tens of nanoseconds, this "stacked signal" easily clog the amplifier and loss of amplification, so that the pulse shaping circuit is essential. First, the main amplifier input signal is narrowed, but after a simple CR filter circuit, the tail of the signal appeared "recoil" in Fig.2 (b), it can be removed by pole-zero cancellation circuit show in Fig.2(c).
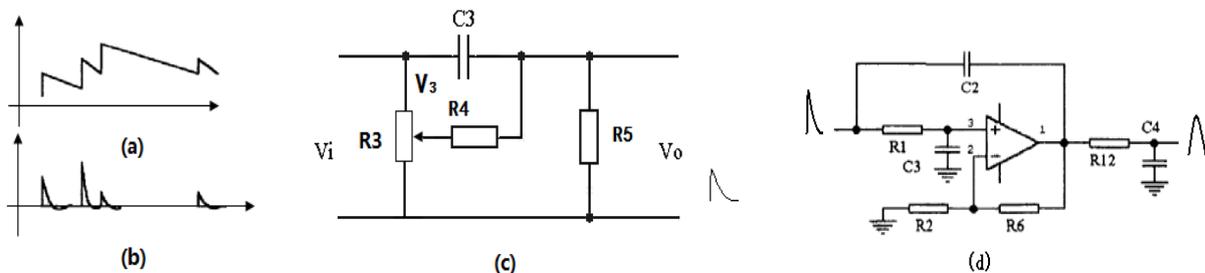
In the pole - zero cancellation circuit, the relationship between the input $F(S)$ and output $Y(S)$ signals and transfer function $H(S)$ is:

$$Y(S) = F(S) \cdot H(S)$$

In Fig.2(c)，the value of resistance $R4$ is relatively large, so the current in the resistance $R3$ is far less than that of the $R4$. By $V_3 = KV_i$, can calculate that：

$$H(S) = \frac{S + \dfrac{1}{\tau_1}}{S + \dfrac{1}{\tau_2}} \quad \text{Among them} \begin{cases} \tau_1 = \dfrac{R4 \cdot C3}{K} \\ \tau_2 = \dfrac{R4 \cdot R5}{R4 + R5} \cdot C3 \end{cases}$$

By adjusting potentiometer R3, so as to achieve pole - zero cancellation purposes. This circuit is especially suitable for in shaping with pulse signal of the overload pulse of high count rate. After this shaping circuit added with two-stage corresponding integral circuit in Fig.2 (d), the first stage is the second-order active shaping integral filtering circuit. The pulse signal from the same phase input and it has a high input impedance for the following passive RC integrator. Nuclear pulse signal after two-stage integral filter shaping circuit can be a "quasi Gaussian wave" signal of single polarity, top rounder and high signal noise ratio (SNR)

（a）Front output signal （b）Simple CR output waveform （c）Differential and pole-zero cancellation circuit （d）Two stages of integral circuit

Fig.2 Differential, integral circuit and wave

2.3 power supply design

The ±12V power supply of the amplifier is provided by the city power that after power transformer, three terminal voltage regulator and the filter, but there is a lot of AC interference and ripple coefficient, the noise introduced belong to the machine noise. So the power need to further processing and filtering. The low-pass filter can suppress high frequency noise on the power line. At the same time there is a single DC power supply to the plurality of circuit problems, this can generate a self-excited oscillation of noise and so on. So the design of the π-type low-pass filter between each unit circuit of the DC power supply line and ground for that filter and prevent the inter-stage coupling. The actual circuit uses a 18mH inductor, it has a certain resistance value of approximately 100 ohms, so DC on the inductor has certain partial pressure，just reduce the voltage that due to the filtering to improved，but also save a few resistors.

2.4 Integrated operational amplifier selection and amplification circuit

Band width is an important indicator, the Op37 is a wideband precision，low temperature drift amplifier and having unit gain bandwidth of 63 MHZ, by three-stage amplifier, this band get greatly widened. The main features of this type of this kind of amplifier is that gain and CMRR are very high (above 100dB), offset, temperature drift and noise are particularly small. It not only uses ultra-β and low noise transistors, but also adopted a strict thermal matching design and introduction of high precision resistor manufacturing technology in order to obtain the lowest offset voltage and offset current.

2.5 Main technical parameters:

Input noise: At 0.1 Hz-10Hz, the typical value is 0.08μVp-p, the maximum is 0.08μVp-p,
At 1000Hz, the typical value is 3.2nVp-p, the maximum is 4.5nVp-p;

Speed: Minimum: 11V/μs, typical: 11.9V/μs;

Bandwidth: 63MHz;   Power supply: $\pm$ 4V ~ $\pm$ 18V;

Output resistance: 700;   input resistance: RIN typical value of 5 MΩ;

Short circuit current: 25mA;   low temperature drift: 0.2uv/oC;
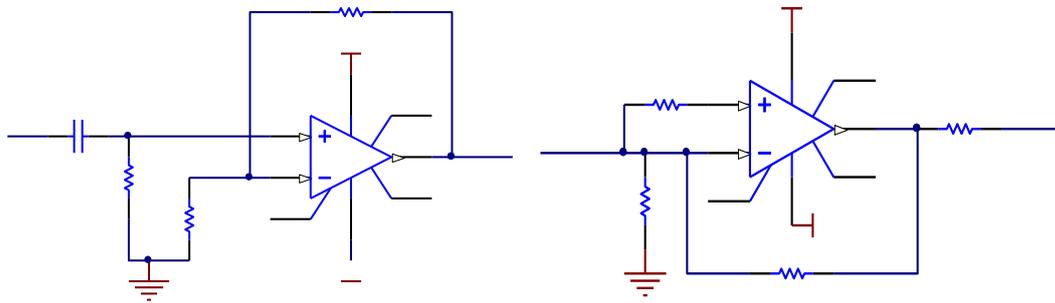

Fig.3 The primary and final amplifier circuit.

III. Realize The Digital Control Of Linear Pulse Amplifier

Digital potentiometer and operational amplifier easily constitute programmable gain amplifier. It features not only to achieve range multi-level change and high gain resolution, but also the line is very simple. Use digital potentiometer can adjust the parameters of intelligent instrumentation fast, precise, stable and better than the mechanical potentiometer.

The interface circuit of programmable gain amplifier is composed of X9221 potentiometer (Fig.4). PC machine connected with MCU by serial port through the MAX2323 level converter. Not only through the PC serial communication to get signal acquisition data, but also can dynamically control the resistance of X9221 according to the actual situation of signal acquisition and processing. Thus, the gain control is realized in the signal acquisition and automatic spectrum stabilization. The controller selected a single 89C51 microcontroller, with the P1.0 and P1.1 two ports connected with X9221's SDA and SCL. The SDA and SCL lines provided pull-up resistor 10K.
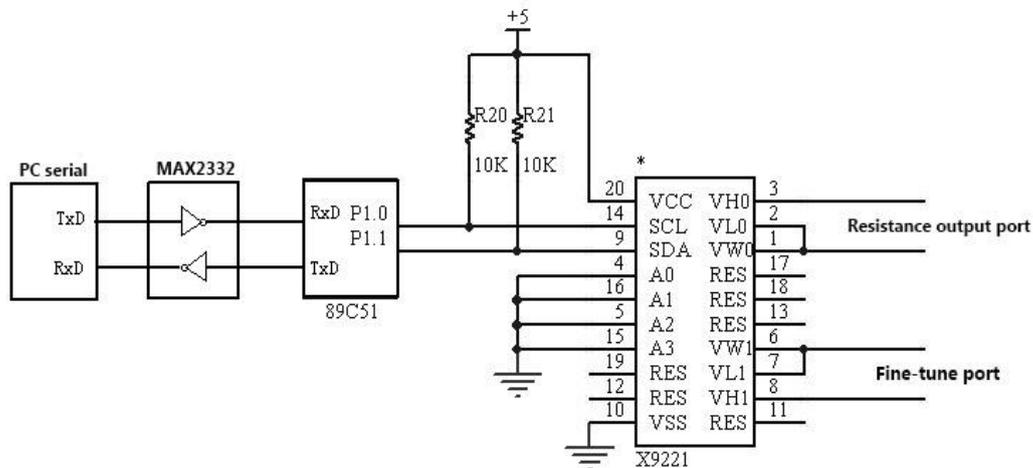

Fig.4 Programmable gain interface circuit

Due to the limited X9221 sliding side tap number, the resolution is seven, so the digital potentiometer resistance range and resolution is not enough for the fine-tuning's required. It's need to be extended. We make potentiometer W1 and W2 in series(W1 is a mechanical precision potentiometer, W2 is a X9221 digital potentiometer resistance 10K), W1 sliding end with one end shorted and the values of R1, W2 as the output end of the sliding. Resistance is R2 and R3（R2+R3=10K）. The input voltage signal is Ui and the output signal is Uo, then $U_o = \dfrac{R3}{R1 + R2 + R3} U_i$, since the denominator in the formula becomes large, the 10K into R1 + 10K, so adjust the step N allows the output resolution increases.

IV. Whole Test

4.1 Signal source test

As shown in Fig.4 is that waveform measured by dual trace oscilloscope and standard signal source. The signal source output 200K pulse signal, after differential and integral shaping, the input and output reverse, such signal is in accordance with the multi-channel analyzer requirements. From Table 1 and Table 2, can know that the linearity of the amplifier is good and the bandwidth can up to 300 KHz

Table 1: linear test.

Vin	14mv	56mv	106mv	157mv	208mv	258mv
Vout	280.0mv	1125.6mv	2120.0mv	3108.6mv	4160.0mv	5185.8
A(v)	20.0	20.1	20.0	19.8	20.0	20.1

Table 2: Test band (input voltage is 304mv, magnification is 10)

Hz(in)	50 kHz	80kHz	150kHz	250kHz	350kHz	400kHz	500kHz	550kHz
Vout	3.10v	3.05v	3.04v	3.04v	3.04v	3.04v	3.02v	3.00v

4.2 Standard source measured spectrum shape

Using BGO detector, 4096 channel multi-channel spectrometer, 1 kV High Voltage DC stable power measurement Co^{60} standard source, measurement conditions are the same. In Fig.5, the spectrum shape 1 is measure by new designed pulse amplifier and the spectrum shape 2 is original. The peak shift in the measurement is caused by the temperature variation of BGO detector. On the basis of this, with the heat preservation device and the temperature controller can remain the peak stable. As can be seen from Figure 5 the spectrum shape of the peak accurate, high resolution, and the count rate and dead time are good.
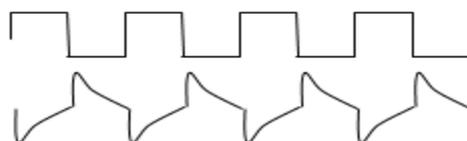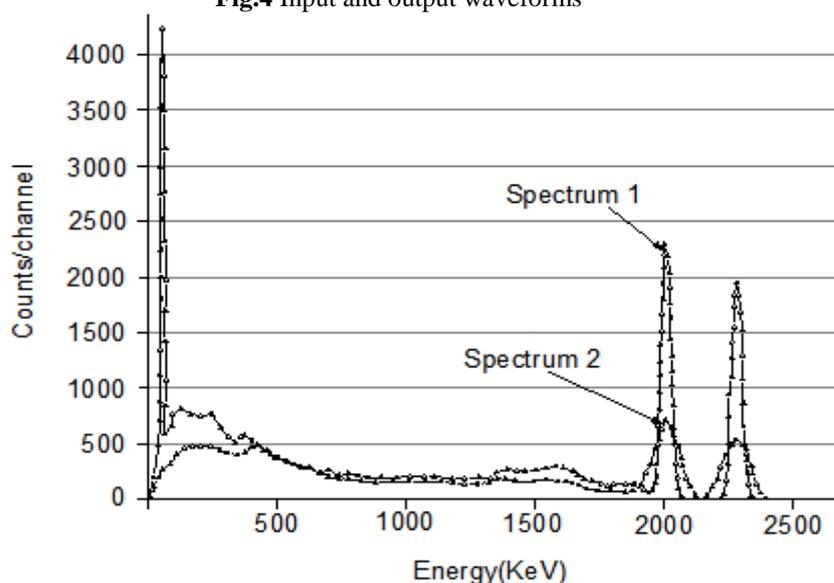
Fig.4 Input and output waveforms

Fig.5 Comparison of Co^{60} measured in two amplifier

V. Conclusion

The high precision and low temperature drift of the amplifier OP37 is applied to linear pulse amplifier and with appropriate peripheral circuit can make the temperature drift better and the overall linearity of the amplifier is good. Use digital potentiometer X9221 realized to gain adjustment digital, impact resistance, low noise, and laid a foundation for future intelligent amplifier design.

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