The high voltage supply power of portable nuclear instrument

Xiaowen Zhao\textsuperscript{1a}, Bin Yang\textsuperscript{1}, Yan Li\textsuperscript{1*}, Gang Li\textsuperscript{1}, Haixia Yan\textsuperscript{1} and Peng Wu\textsuperscript{2}

\textsuperscript{1}Technical Physics Institute of Heilongjiang Academy of Sciences, Haerbin, Heilongjiang, 150086, China
\textsuperscript{2}Nuclear and Radiation Safety Center of the Ministry of Ecological Environment, Beijing, 100000, China

\textsuperscript{a}zhaoxiaowen@hljas.cn \textsuperscript{*Corresponding author’s e-mail: 114790708@163.com}

Abstract. This paper introduces the basic demand of high supply power for portable nuclear instrument. The basic principle and practical application circuits of obtaining high voltage are introduced by self-excited oscillation mode and unself-excited oscillation mode.

1. Introduction

The basic detection component of nuclear instrument is nuclear detector. The work of nuclear detector needs DC high voltage power supply, and the performance of high voltage power supply varies greatly with different nuclear detectors. The basic requirements of portable nuclear instruments for high-voltage power supply are as follows: low power supply voltage, high conversion efficiency, low power consumption, small size and light weight. The traditional high-voltage power supply has high low-voltage, which is usually 12v-24v\textsuperscript{[1-3]}. Its low-voltage comes from alternating current, which has large power consumption, volume and weight, and is not suitable for portable nuclear instruments. Although the volume of the integrated high-voltage module has been reduced, the low-voltage power supply is still very high, and the power consumption is also very large. The traditional low-voltage power supply has a high low-voltage power supply, generally 12V～24V. Its low voltage comes from AC mains. It does not care about the large power consumption, large size, and light weight\textsuperscript{[4]}. Although the technical performance is high, it is basically not suitable for providing DC high voltage for detectors on portable nuclear instruments.

For different nuclear instruments and detectors, the basic requirements for high-pressure performance are quite different. For example, in the dose instrument, the detector commonly uses counter tube and ionization chamber, and the working high pressure is generally 300V～500V\textsuperscript{[5]}. As long as the high pressure works in the flat area of the detector, the requirements for high voltage are low, and the requirements for stability, the ripple and output current are not strict. The portable scintillation spectrometer has relatively strict requirements on high pressure, but it is allowed to have high pressure due to the low radioactivity measured the resistance value of resistance divider is set relatively high, and the requirement of high voltage ripple can be reduced by using negative high voltage power supply. High frequency AC and high voltage are usually produced by self-excited oscillation or unself-excitation oscillation. The step-up transformer is usually made of small-sized annular magnetic core. The way of high-voltage voltage stabilization is relatively simple, some do not need to stabilize voltage, and the simple negative feedback method is also used.
2. Self-excited oscillation produces high voltage

2.1. Single switch converter
Figure 1 is the simplest single switch converter circuit, which consists of a crystal triode, a high frequency and high voltage magnetic core transformer, a resistor and a capacitor.

![Figure 1. Single switch DC-AC converter](image)

High frequency and high voltage core transformer are composed of three windings $L_c$, $L_b$ and $L_G$ wound on the core frame. $L_G$ is the high-voltage winding with the largest number of turns, which is the output coil of the transformer, also known as the step-up winding; $L_c$ is the collector winding, called the main vibration coil, with less turns; $L_b$ is the base winding, also known as the feedback coil, with the least number of turns. The number of turns ratio between $L_G$ and $L_c$ is called boost ratio, which is determined by power supply low voltage and output high voltage; the number of turns ratio between $L_c$ and $L_b$ is called feedback ratio, which can be taken from 5:1 to 2:1. The base bias resistance $R$ provides the base current for the crystal triode, which is used to adjust the working state of the control circuit and improve the conversion efficiency. The capacitance $C$ provides the AC path for the base and emitter.

2.2. Double switch converter
Single switch converter is usually used in the situation of low power. When the power is large, the double switch push-pull converter is usually used. It has not only high output power, high efficiency, but also good output voltage stability. Figure 2 shows a double switch push-pull converter with common emitter connection. This connection has high efficiency and is easy to start vibration. It is suitable for low-voltage power supply.

![Figure 2. Two transistor push pull converter with common emitter connection](image)

2.3. Application circuit of self excited oscillation transformation
The high-frequency AC pulse voltage generated by self-excited oscillation is boosted and output by high-frequency transformer of magnetic ring, and then DC high voltage is generated by voltage
doubling rectification and filtering, which can directly provide working high voltage for counter. Figure 3 shows the high voltage power supply supplied by G-M counter, which is powered by DC low voltage 6.2V.

![Image of high voltage power supply for counter]

As a result of the long working area of the counter, the output pulse amplitude of the counter is large and has nothing to do with the type and energy of the incident radiation. The output pulse signal of the counter is only used for counting intensity measurement, so the required working high voltage is not strictly required. Therefore, the direct current high voltage after rectification and filtering can directly supply power to the counter without stabilizing the voltage. By adjusting the base bias resistance of the oscillator tube, the output high voltage is 380V, and the false load whose output resistance is 10mΩ is removed to ensure that the output high voltage remains unchanged. The power consumption of the circuit is very small, about 8 mA, which can be widely used in portable instruments and two-wire circuit of counter.

3. Unself-excited oscillation to produce high voltage
Unself-excited oscillation means that the external AC square wave signal is used to start the oscillation circuit to make it oscillate. Its output is also coupled and boosted by high-frequency transformer. The oscillation frequency is the frequency of the external square wave signal.

3.1. Method of generating square wave signal
The most commonly used method of generating square pulse signal is multi-vibrator. In radiation dose monitoring, a simple pulse signal generator is usually used to check whether the instrument can work normally (i.e. self-test). The self-test signal is generated by a multi-vibrator. The main types of multi-vibrator are as follows:
- Transistor multi-vibrator, composed of two triodes, has simple circuit and wide frequency regulation range.
- If CMOS devices are used in the multi-vibrator composed of integrated circuit, it will save more power.
- The required frequency can be obtained by proper frequency division.

3.2. The applied circuit of the other oscillation transformation
It has the advantages of stable frequency, good waveform, short transition process, low power consumption and high conversion efficiency. Figure 4 is the high voltage power supply for the high-pressure ionization chamber of α radon detector.
Figure 4. The high voltage power supply for high pressure ionization chamber of α radon detector

In this way, an alternating voltage is generated on the primary winding of the transformer on the collector. After coupling and boosting by the transformer, an alternating voltage of about 200V can be generated on the output winding, and -1000V DC high voltage can be obtained through quadruple voltage rectification and filtering to supply power for the high voltage ionization chamber. The negative feedback principle is adopted in high voltage stabilization. The square wave trigger signal is generated and suspended by controlling the reset end of NE555 oscillator.

When the output voltage increases, the feedback sampling voltage signal also increases, which makes the comparator output low level and controls the reset end of NE555 oscillator, so that the oscillator stops working. When the output voltage drops to a stable value, the comparator outputs high level, NE555 oscillates again and outputs square wave pulse signal, and triggers the triode oscillator again to stabilize the output high voltage.

At the same time, the low-voltage power supply of the circuit is +5V, and the input voltage supplies power to the converter through the forward diode, and has two main functions: one is to isolate the coupling oscillation signal between the +5V power supply and the transformer, so that the +5V power supply can maintain a clean voltage without interfering with the work of other unit circuits; the other is to prevent the wrong connection of +5V power supply, even if the reverse circuit does not work, it will not damage the original.

Figure 5 shows the high voltage power supply for the counter, which adopts double tube push-pull single end trigger oscillation mode. The power supply voltage is +5V, the output high voltage is +400V, +5V, the working current is 10mA, and the power consumption is 50MW. As a push-pull circuit, the complementary follower composed of two transistor T1 and T2 can effectively reduce the working loss and improve the conversion efficiency.

Figure 5. Single ended flip-flop converter
4. Selection of high voltage module
The integrated high-voltage module has the advantages of small volume, light weight, stable and reliable performance, easy to use and so on. There are many types of high-voltage modules. The module with low power consumption can also be used in portable nuclear measurement instruments. Figure 6 is a practical test circuit of high voltage output mode with resistance adjustment.

![Figure 6. Application circuit of high voltage module](image)

The relationship between +12V power consumption and high voltage is very complex. Under high-voltage output 700V, the power consumption is 50mA when the high-voltage load is 3.3m, 20mA when the load is 11M, and 8.5mA when the load is no-load. In the first two cases, power is supplied to scintillation detector, while no-load is equivalent to power supply for counter and ionization chamber. If a small photomultiplier tube and a high value resistance voltage divider are used, it is equivalent to the no-load condition, and the power consumption of the scintillation detector will be greatly reduced.

5. The way to reduce energy consumption

5.1. Choose the appropriate type of high voltage circuit
According to the type of detector used, on the premise of meeting the performance requirements, the most simple and power-saving high-voltage circuit is selected and the low-voltage power supply is reduced as far as possible.

5.2. Reduce the oscillation frequency as much as possible
The oscillation tube works in the switch state, either saturated conduction or cut-off. Although the current is large at saturation, the voltage drop is small and the power consumption is very low; at the cut-off time, the tube current is very small and the power consumption is very low. Only in the transition from saturation to cut-off or from cut-off to saturation can the power consumption be increased. Improving the oscillation waveform and reducing the oscillation frequency can effectively reduce the time of the transition process.

5.3. Select appropriate working state and power saving components.
Adjust the circuit parameters so that the oscillator does not have deep saturation, try to take high resistance load circuit and voltage divider resistance, and select low power consumption components under the same functional conditions.

6. Conclusion
This paper describes the method and structure circuit of high voltage generated by self-excited oscillation and unself-excited oscillation, and lists the advantages of different modes. At the same time, it discusses the selection of high-voltage module and typical circuit structure, finally, introduces the method suitable for portable and detector to reduce energy consumption.

References
[1] Yin S. (2018) A novel PMT test system based on waveform sampling. Journal of Instrumentation, 13: 1005.
[2] Chirikov Z. I. (2001) Method for precise analysis of the metal package photomultiplier single photomultiplier single photoelectron spectra. Nuclear Instruments & Methods in Physics Research, 456:310-324.

[3] Rajibur R. K., Shin W. K. (2015) Design and Development of Low-Cost, Highly Stable Regulated High-Voltage Power Supply for Radiation Detector. International Journal of Engineering and Manufacturing(IJEM), 5:1-10.

[4] Shchagin, A. V., Shul'ga, N. F., Trofymenko, S. V. (2016) Semiconductor detector with smoothly tunable effective thickness for the study of ionization loss by moderately relativistic electrons. Nuclear Instruments and Methods in Physics Research, Section B, 387:29-33.

[5] Kim H., Sergeev S., Vankov I. (2007) High voltage system for the CMS forward calorimeter. Nuclear Instruments and Methods in Physics Research, Section A, 572:618-623.