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# Design and Development of Low-Cost, Highly Stable Regulated High-Voltage Power Supply for Radiation Detector

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**Abstract**

In this paper we design and develop a highly stable and low cost regulated DC power supply for Geiger Müller (GM) Counter/detector. A regulated high voltage power supply is an important power source to bias gas-discharge tubes, X-ray tubes, and radiation detectors etc. A highly stabilized regulated 575 volts DC power supply was developed using the pulse width modulation (PWM) control technique from a 5 volt supply. It is specially designed for biasing GM detector for the area radiation monitor. The output high voltage can be adjusted at any suitable value by adjusting the preset potentiometer.

**Index Terms:** Pulse Width Modulation, Geiger Müller (GM) Counter, multivibrator, regulated power supply.



## 1. Introduction

A regulated high-voltage power supply (HVPS) is an important power source in the field of scientific research, industry, communication, medicine, military, and agriculture. For example: in the field of medicine a high voltage power supply effectively used mainly for biasing of gas-discharge tubes, x-ray device, photo-multiplier tube and radiation detectors etc. [1-3]. In industry a HVPS is used to operate electro-beam welding [4], electro-static coating etc., and in the field of agriculture HVPS use in static-electric de-duster.

This paper is specially discussed on the designed HVPS for biasing Geiger Müller (GM) detector for the area radiation monitor or dosimeter. A GM detector is a device which consists of a pair of electrodes surrounded by gas (usually neon, argon, or helium, and sometimes krypton) and it is used to detect and measure all types of radiation such as: alpha, beta and gamma radiation [3]. Those radiations are very harmful to the human body as well as animals.

To operate a GM detector properly, one should have the acceptable voltage across the electrodes. If the voltage is just too low, the electrical field within the tube is just too weak to cause a current pulse. Similarly, if

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the operating voltage is just too high, the tube can endure continuous discharge, and also the tube may be broken [5]. Therefore, it is important to apply the correct operating voltage to the GM counter.

In a GM counter once a radiation particle enters the tube it will ionize the gas. The ions (and electrons) are collected by the electrodes and also the ensuing current pulse produces a fast-rising voltage pulse across the series resistance chain within the external circuit and pulse may be detected by a scale or counter. A lot of HVPS are available in the market and much research is going on until now, but most of the HVPS are expensive. In this paper, we have designed and developed a low cost and regulated HVPS mainly for biasing of GM detector which is based on the principle of pulse width modulation (PWM) technique. All components of the designed HVPS are available in the local electronic components market. Table 1 shows the specifications of the designed HVPS.

The remainder of this paper is organized as follows. Section 2 describes the block diagram of the designed HVPS system. In section 3, we have discussed in details step by step the design procedure, operation and experiment of the HVPS. To evaluate the performance of the system, a number of experimental results are presented in section 4. Finally, some conclusions are discussed in section 5.

Table 1. Specifications of the Designed High Voltage Power Supply

| **Parameter** | **Specification** |
|---|---|
| Input dc voltage | + 5 V |
| Output high voltage | + 575 V |
| Output current | 25 µA |
| Output resistance | 240 KΩ |
| Efficiency | 75% at Maximum load |
| Load regulation | 1.05 % |
| Ripple and noise | 12 mV |
| Output power | 14.37 mW |

## 2. Functional description

The simplified block diagram of the designed HVPS for radiation detector is shown in Fig. 1. The pulse generator is an astable multivibrator, it generates square waves of frequency (1 KHz). Its output is connected to the input of the monostable multivibrator. The monostable multivibrator produces one positive pulse for each negative clock edge of the triggering pulses. Its output is connected to the input of the driver circuit. The driver circuit drives i.e. turns on or off the pulse transformer according to applied input pulse. The output of the pulse transformer is connected to the voltage multiplier circuit and its output gives 575 volts DC. The voltage sampling circuit is placed in parallel to the output terminal. The output of the highly stable voltage reference circuit and the voltage sampling circuit are connected to the inputs of the error amplifier and its output is connected to the control input of the monostable multivibrator. If the sampling voltage increased due to increases of output terminal voltage than the output of the error amplifier change which corresponding to the change of the output pulse width of the monostable multivibrator, as a result the output voltage of the system remains constant.

## 3. Circuit description and experiment

The complete circuit diagram of the designed low cost HVPS is shown in Fig. 2. In this section, we have discussed step by step the operation and calculation of the different units of the HVPS for radiation detector as given below:

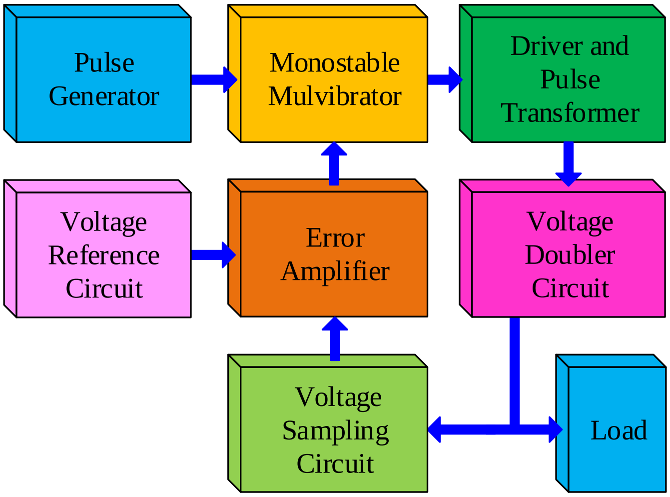


Fig.1. Simplified Block Diagram of the High Voltage Power Supply.

### *3.1. Pulse generator*

The pulse generator circuit is a combination circuit of a square wave oscillator and a T flip-flop [6, 7]. The square wave oscillator circuit consists of R1, R2, C1, and IC1. The oscillator circuit is based on a standard NE 555 timer and it is connected as an astable multivibrator mode. This oscillator circuit generates square waves of frequency 2 KHz.

The free running frequency f and duty cycle D are accurately controlled with two external resistors R1, R2 and one capacitor C1. The frequency of oscillation can be calculated with the following formula [8, 9]:

$$f = \frac{1.44}{(R1+2R2)C1}, \tag{1}$$

and the duty cycle can be written by the following mathematical equation:

$$D = \frac{R1}{R1+2R2}. \tag{2}$$

Now considering, the supply voltage $V_{CC} = 5V$, frequency f = 2 KHz, R1 = 5 KΩ and C1 = 50 nf. Then from *(1)* and *(2)* we get,

R2 = 4.3 KΩ and
Duty cycle, D = 68.38%

Since the duty cycle of the signal is not 50%, so, we feed this signal to the clock (CLK) input of the toggle (T) flip-flop to obtain 1 KHz of frequency with 50% duty cycle. The T flip-flop changes its output on each clock edge, giving an output which is half the frequency of the signal to the T input. We use a CD4027 J-K flip-flop to make a T flip-flop. To do this, the J input pin 6 and K input pin 5 are connected to logic HIGH (i.e. $V_{DD}$), and the set S input pin 4 and reset R input pin 4 are connected to logic LOW (i.e. $V_{SS}$). The output pin 3 of the timer 555 IC1 is connected to the CLK input pin 3 of the flip-flop. The CD4027 is a positive edge sensitive flip-flop and the output Q pin 1 of the flip-flop change its logic state during the positive-going transition of the clock pulses.

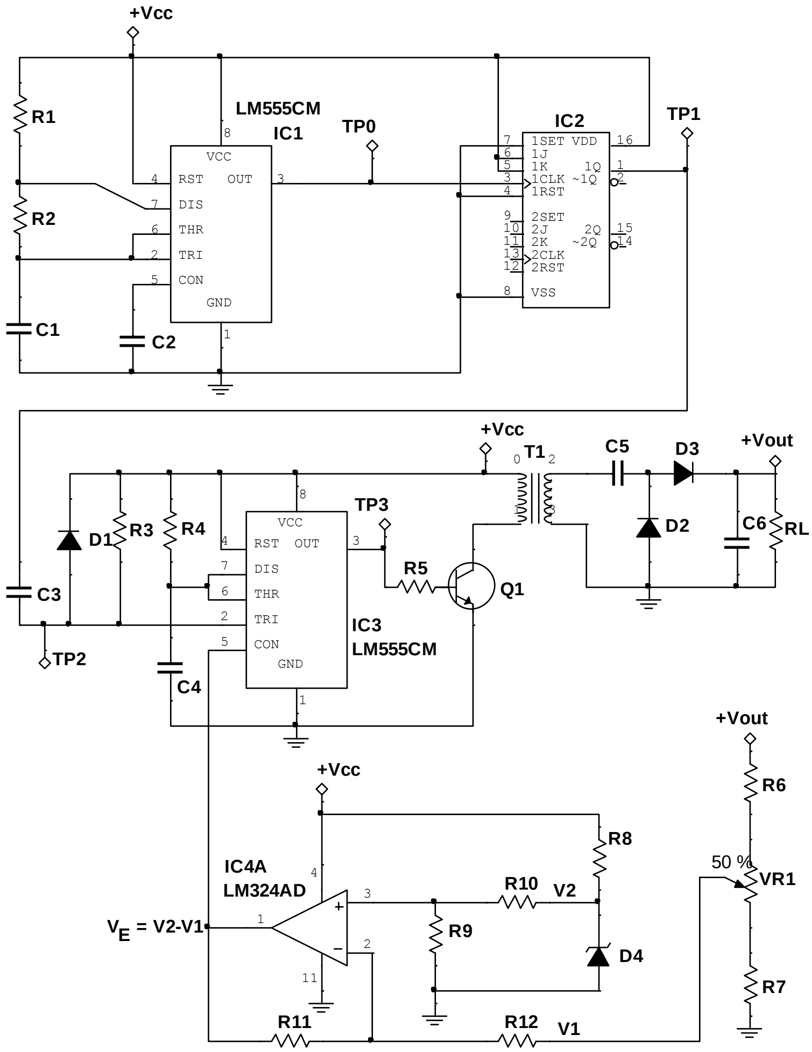


Fig.2. Complete Circuit Diagram of Designed High Voltage Power Supply.

### *3.2. Monostable multivibrator*

The monostable multivibrator consists of R3, R4, C3, C4, D1, and IC3. Its function is to provide a uniform current pulse output for each input pulse. IC3 is connected as a falling edge monostable multivibrator. In this mode the output is LOW (0V) when there is no triggering, when it is triggered via trigger input pin 2, then, the output goes HIGH ( $V_{CC}$ ) for some time. The external timing components R4 and C4 determines the duration of the output pulse width. The trigger is applied via a differentiator circuit to make sharp pulses and the differentiator circuit consists of R3, C3 and D1. The resistor R3 of the differentiator is connected to $V_{CC}$ to generate negative trigger pulses and the diode D1 is used to avoid positive spikes. The output pin 3 of IC3 is connected to the base of the transistor, Q1 via R5. The duration of the high state of the output pulse width of the monostable multivibrator is given by [8]

$$T_H = 1.11 R4C4, \tag{3}$$

### *3.3. Driver and pulse transformer circuit*

The driver [10] and pulse transformer circuit consists of R5, Q1 and a pulse transformer T1. The primary turns of the pulse transformer are $N_P$ = 50 turns with 32 SWG and secondary $N_S$ = 240 turns with 36 SWG. The output pin 3 of IC3 connected to the base of Q1 via a resistor, R5. When the output pin 3 of IC3 is at high state, transistor Q1 goes into saturation, i.e. turns on and a high voltage developed across the secondary of the transformer T1. Similarly, when the output pin 3 of IC3 is at LOW state, transistor Q1 goes into cutoff condition, i.e. turns off and the output voltage across the secondary terminal of the transformer becomes is zero.

### *3.4. Voltage multiplier circuit*

The voltage multiplier circuit consists of C5, C6, D2 and D3. The voltage doubler is a rectifier capable of delivering a DC voltage almost twice the peak value of applied AC voltage [11]. The voltage doubler circuit multiplies the secondary voltage and gives the desired high voltage output. Its output is connected to the voltage sampling circuit.

### *3.5. Voltage sampling circuit*

The voltage sampling circuit consists of R6, R7, VR1. It samples the output voltage continuously to monitor the variation of output voltage. A resistive path parallel to the load will act as a voltage sampling circuit. The sampler output voltage is compared with a stable reference voltage. The output of the sampling circuit is connected to the input of the error amplifier circuit. The variable resistor VR1 can be used to select the sampling voltage.

### *3.6. Voltage reference circuit*

The voltage reference circuit [3] consists of R8 and a zener diode D4. The highly stable reference voltage is required to compare with the sampling voltage. The reference voltage 3.3 V is derived from the resistor R8 and D4. Its output is connected to the one input of the error amplifier.

### *3.7. Error amplifier circuit*

The error amplifier is a differential amplifier [12] and it consists of R9 to R12 and IC4. It continuously compares the sampled output voltage with the highly stable reference voltage. The output pin 1 of IC4 is connected to the control input pin 5 of IC3. If the output terminal voltage increases at any reason, then the sampling voltage also increased. This means that, the sampling voltage exceeds than the highly stable reference voltage. As a results the output of the error amplifier change, which change the output pulse width of IC4 as a result the output voltage remain constant. The output voltage of the differential amplifier can be written by the following mathematical equation:

$$V_E = V_2 - V_1. \tag{4}$$

## 4. Results and discussion

Fig. 3 shows the different waveforms of the pulse generator circuit. From Fig. 3(a) it is found that the free running frequency of the oscillator is about 2 kHz and the duty cycle is 68.38%. Fig. 3(b) shows the output waveform of the T flip-flop and it is found that the frequency of oscillation is 1 kHz and duty cycle is 50%. The input and output waveform of differentiator circuit are shown in Fig. 4.

In our experiment, we used a NE555 timer as a monostable multivibrator. The 555 timer works as a negative edge triggering monostable multivibrator such as when it's triggering input going to the LOW state, then it gives a positive pulse output for a certain time and this fact is shown in Fig. 5. From Fig. 5 it is found that the output pulse width of the monostable multivibrator is about 187.6 µs for our desire 575V DC output. This pulse is applied to the base of the transistor via a resistor R5. Fig. 6 shows the waveforms of the base-to-emitter voltage and flyback pulse amplitude. From Fig. 6 it is found that when the base-to-emitter voltage goes LOW state, then a high voltage pulse is developed at the primary terminal of the pulse transformer and this occurs due magnetic energy stored into the pulse transformer. The pulse width of the base-to-emitter voltage and the flyback voltage pulse were about 187.6 µs and 18.52 µs, respectively.

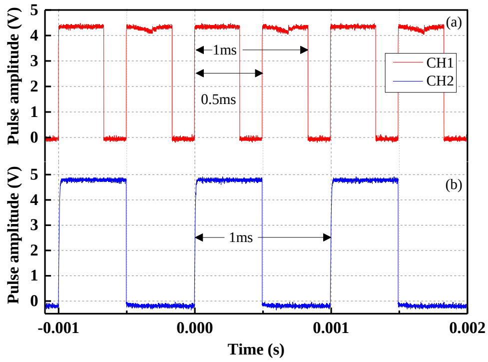


Fig.3. Waveforms of the Pulse Generator Circuit: (a) Waveform At The Output Of The Oscillator And (b) Waveform at the Output of the T Flip-Flop.

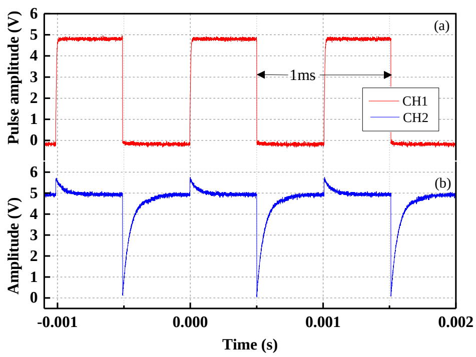


Fig.4. Waveforms of the Differential Circuit: (a) Input Waveform of the RC Differential Circuit and (b) Output Waveform of the Differential Circuit.

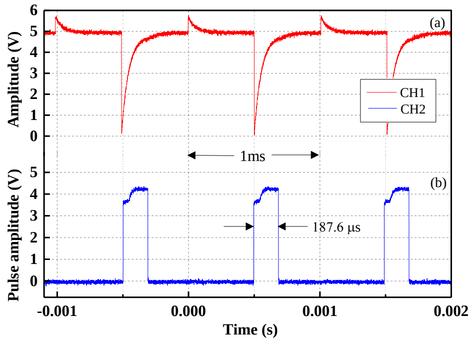


Fig.5. Waveforms of the Monostable Multivibrator: (a) Triggering Input Waveform and (b) Output Pulse Waveform.

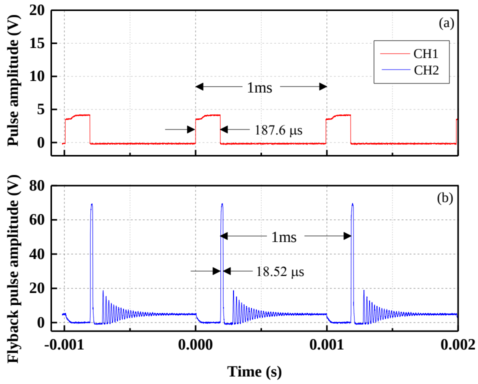


Fig.6. Waveforms of the Driver and Pulse Transformer Circuit: (a) Input Waveform of the Base-To-Emitter Terminal and (b) Flyback Voltage Waveform.

The waveform of the primary and secondary terminal voltage pulse of the pulse transformer is shown in Fig. 7. We can find from Fig. 7 that the pulse amplitude of the primary and secondary winding was 69.8 V and 316 V, respectively, and its ratio was about 4.5. The relationship between the pulse width of the base-to-emitter voltage and the DC output voltage of the HVPS is represented in Fig. 8. From Fig. 8 it is found that the output DC voltage is directly proportional to the base-to-emitter voltage-pulse.

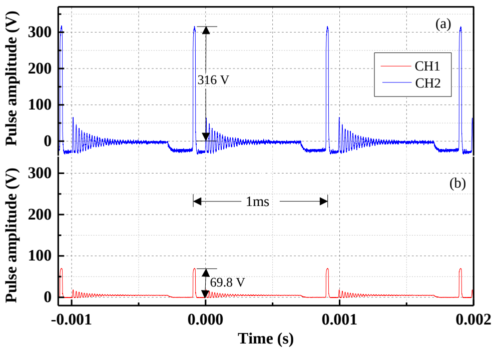


Fig.7. Waveforms of the Pulse Transformer Circuit: (a) Secondary Pulse Waveform and (b) Primary Voltage Waveform.

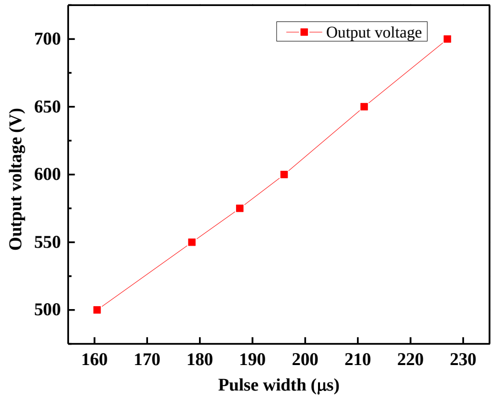


Fig.8. Relationship between the Pulse Width of Base-To-Emitter Voltage and the Output DC Voltage.

The variation of the flyback pulse amplitude and the pulse width of the flyback voltage with respect to the pulse width of base-to-emitter voltage is shown in Fig. 9 and it is found that as the pulse width of the base-to-emitter voltage increase than the amplitude of the flyback voltage increase, but the pulse width of the flyback voltage is decreased and vice versa. In our experiment we changed the base-to-emitter voltage pulse width from 160.5 μs to 227 μs and we obtained the output DC voltage from 500 V to 700 V. The output current of the designed HVPS was about 25 μA and the output power was about 14.37 mW.

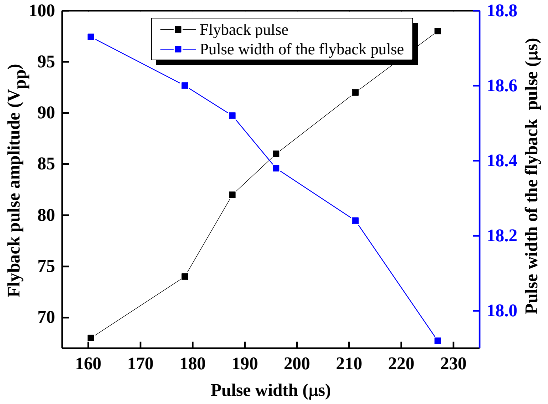


Fig.9. Variation of the Flyback Pulse Amplitude and Pulse Width of Flyback Voltage with Respect to the Change in the Pulse Width of Base-To-Emitter Voltage.

## 5. Conclusion

We designed and developed a low cost, highly stable, regulated high voltage DC power supply for radiation detector which is based on the pulse width modulation principle. The design 575Vd.c high voltage power supply was put under a series of test and its performance was very satisfactory. Its output was compared with the standard power supply Euro card module (NIM). This device is reliable in operation and it costs approximately U$ 100 for its fabrication, whereas the price of the similar instrument in the international market is not less than U$ 500. In future studies, we will use new technique to design HVPS with overload and short circuit protection system. We also plan to design HVPS for multi-channel area radiation monitoring system.

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