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ELECTRONIC ENGINEERING

Construction of High Voltage Power Supply Unit for GM Counter

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***Abstract*— High Voltage Power Supply Unit is essential for nuclear radiation detection or counting system. A high voltage power supply unit that is suitable to use with GM (Geiger Muller) counter is constructed with locally available components. The constructed high voltage unit is based on push-pull mode and it is acceptable for low-level primary voltage (2V to 10.19V) and delivers it at high-level secondary voltage (105V to 514V) of transformer. To avoid the insulation problem at the transformer secondary coil, a voltage multiplying circuit is used. The desired voltage is rectified and multiplied by voltage multiplier unit provides 3055V (-3 kV) DC at approximately 1mA output current.**

***Keywords*— high voltage power supply unit, GM (Geiger Muller) counter, oscillator, frequency divider, push-pull mode, transformer, voltage multiplier**

I. INTRODUCTION

High Voltage (H.V) power supply is required by a nuclear instrumentation to produce an electrical signal when a radiation enters its detector. The signal can be in the form of pulse or current and its magnitude depends on the intensity of radiation around the detector. It also depends on the voltage across the positive and negative terminals of the detector. In both gaseous and solid counters, charged particles liberated by ionization can be collected at boundary electrodes under an applied High potential electric field. There are mainly two types of HVPS in the nuclear field: those for very low current (up to 100µA) used for biasing semiconductor detectors and gas-filled detectors and those able to deliver higher currents needed when working with photomultiplier tubes. Fig.1 shows HVPS system for GM counter, type of gas filled detector. The High Voltage Power Supply unit in present work is constructed with oscillator, JK flip-flop, push-pull driver transistors, step-up transformer, regulated voltage power supply, variable voltage regulator and voltage multiplier. A regulated power supply provides 12V DC to operate oscillator, flip-flop and driver transistors. Oscillator converts electrical energy in the form of DC to electrical energy in the form of AC. Flip-flop acts as alternator and frequency divider. Driver transistors switch the high current required to provide appreciable power to step-up transformer. Compact size, low power consumption and low cost are the major advantages over conventional E.H.T design. This unit can provide (~3kV) DC at 1mA output current by varying the High Voltage output control adjustment. The block diagram of the typical radiation detection for GM tube is as shown in Fig. 2.

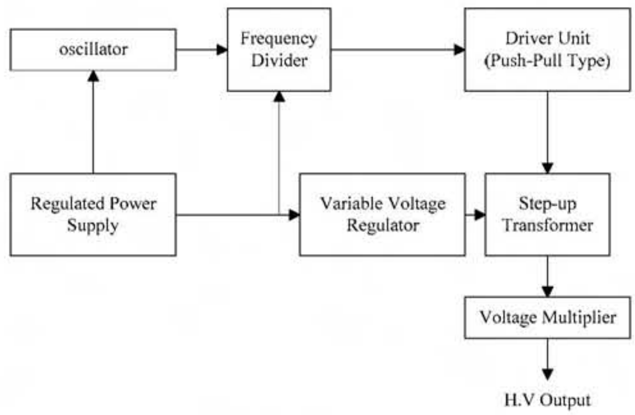

Fig. 1 Block diagram of high voltage unit

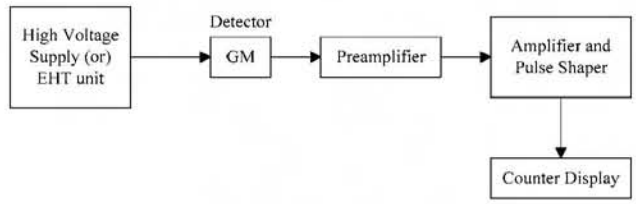

Fig. 2 Typical radiation detection system

II. INTRODUCTION OVERVIEW OF CONSTRUCTION OF HIGH VOLTAGE POWER SUPPLY UNIT

A. Oscillator

Oscillator is a circuit that produces a repetitive waveform on its output with only the DC supply voltage as an input. A repetitive input signal is not required. Oscillators are used to generate required frequencies and timing signals. Essentially an oscillator converts electrical energy in the form of DC to electrical energy in the form of AC. A basic oscillator consists of an amplifier for gain (either discrete transistor or operational amplifier) and a positive feedback circuit that produces phase shift and provide attenuation.

1) 4011 NAND Gate as an Oscillator: The phase shift I.C oscillator produces a frequency of 3kHz and it consists of two NAND gates. The function of the phase shift oscillator (or) square wave oscillator is as follows: First, assume logic "1" at point a. Therefore, logic "0" will be obtained at point b and time constant is $T_1 = R_1C_1$. Similarly, point c will be "1" with the time constant $T_2=R_2C_2$ respectively. Therefore, point a and point b, point b and point c are 180 out of phase of $R_1C_1 = R_2C_2 = RC$, the frequency of oscillation is

$$f = \frac{1}{2RC}$$

In this design, R = 150k and C=1nF

$$f = \frac{1}{2 \times 150k \times 1n}$$

f = 3.33 kHz (~3kHz)

B. 4027 JK Flip-Flop used as Frequency Divider

There are two modes in a dual JK flip-flop, clocked and direct. In the clocked mode, the direct set and clear inputs remain at ground. The inputs to the J and K lines decide what the flip-flop is going to do. If the J and K remain grounded, the clocking does nothing. If J is positive and K grounded, the clocking forces Q positive and to ground. If J is grounded and K positive, the clocking forces Q to ground positive. If both J and K are positive, the clocking alternates the Q and states. In the direct mode, a positive set input forces Q positive and to ground. A positive reset input forces Q to ground and positive. Both set and reset inputs simultaneously go positive, both Q and will also go positive. This is usually a disallowed state. The actual operation doesn't happen until the positive edge ground to positive transition of the clock. The output signals will change state while the input signal is going positive since it is used a positive edge triggered JK flip-flop. The output Q and are out-of-phase. Since it takes two input clock pulses to produce one output cycle, the output signal frequency is the half of the input signal frequency. Therefore, it can be used as a frequency divider and is also called a T (or) Toggle flip-flop.

C. Push-Pull Driver Transistor

The function of the driver transistor is to deliver a specified amount of power to its load.

In this high voltage supply, the two transistors (C1383) are used as driver transistors. C1383 transistor is NPN Si, AF power amplifier. Its rating should not be exceeded above the following data.

- Collector to emitter voltage BV_{CE}= 50V
- Collector to base voltage BV_{CB}= 60V
- Base to emitter voltage BV_{EB} = 5V
- Maximum collector current I_C = 1A
- Maximum Device power dissipation PD watts = 1W (Heat sink) (or) 0.75W
- Frequency in MHz f = 200 MHz
- Current gain h_{FE} = 120 min

These two transistors are connected in push-pull amplifier form. By connecting two transistors in push-pull, it is possible to increase the power output that obtainable from a single stage. The two input signals applied to the base terminals of the two transistors must be equal in magnitude but of the positive phase. Each transistor conducts at all times and, as a result of the input signals, the collector current in one transistor increases when thata in the other decreases. Each transistor supplies one half of the power output delivered to the load. A push-pull amplifier has the added advantage of reduced non-linear distortion. If one of these transistors would have a better h_{FE} it would take over the whole current and it would burn. To avoid this problem, a resistor is to be inserted in series with base.

D. Selection of Constructed H.V Transformer

To avoid the insulation problem at the transformer secondary coil, voltage multiplying circuit will be used. For safe operation, the transformer secondary voltage should not exceed 600V. The specification of constructed transformer parameters is as follows:

Specification of Constructed Transformer Design

Iron core size in inches

- Width -0.65inch
- Stack height -1.006inch
- Cross-sectional area - 0.654inch
- Core-type -EI type
- Primary winding
- Current -800mA
- Voltage -12V AC
- Power -9.6 W
- Number of turns -288turns
- SWG -23

- Secondary winding
- Current -17.4mA
- Voltage -500V AC
- Power -8.7 W
- Number of turns -6000 turns
- SWG -43

E. Regulated Power Supply

The block diagram of a regulated power supply is shown in Fig. 3. The secondary voltage (18V) of the transformer is connected to the Bridge rectifiers. Rectifiers convert the AC input voltage to a pulsating DC voltage. Thus, rectifier is also called converter circuit. Filter eliminates the fluctuations in the rectified voltage and produces a relatively smooth DC voltage. The filter capacitor 1000μF/25V and 0.1μF/50V are provided in unregulated portion of the circuit. The function of a regulated power supply is to provide the necessary DC voltage and current with low level of ripple and with regulation. It must provide a stable DC output voltage, irrespective of changes in the main input voltage and of changes in the load current. A +12V, 1A regulated power supply unit requires in this system. The three-terminal IC regulator LM 7812 is used for positive voltage output.

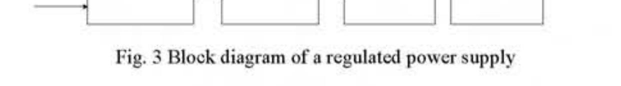

Fig. 3 Block diagram of a regulated power supply

1) 78×× Series Three-terminal Voltage Regulator IC

A simple three-terminal IC regulator, such as 78×× series, can be configured in many ways for varies requirements. These 78×× series are designed to stabilize a positive supply. The input voltage (V_{in}) must be at least 2V above the output voltage in order to maintain regulation. For application hints of such a regulator, C_1 and C_2 are required to be situated nearly the regulator IC. Due to high open-loop gain of such a regulator it should oscillate without these capacitors near the terminals. The value of C_1 is 100μF and C_2 is 10μF. C_1 is used to prevent unwanted oscillations when the regulator is some distance from the power supply filter such that the line has significant inductance. C_2 acts basically as a line filter to improve transient response. The 7812 is a 12V linear regulator and therefore it must be mounted on a heat sink due to the power dissipation in it 7812 can produce output current in excess of 1A when used with an adequate heat sink.

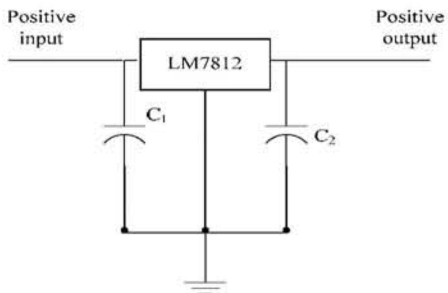

Fig. 4 Basic fixed-voltage regulator

2) Three-terminal Adjustable Voltage Positive Regulator of LM 317 IC: LM 317 is an excellent example of a three-terminal positive regulator with an adjustable output voltage. There is an input, an output, and an adjustment terminal. The external fixed resistor R_1 and the external variable resistor R_2 provide the output voltage adjustment. The output voltage can be varied from 1.2V to 37V depending on the resistor values. The LM 317 can provide over 1.5A of output current to load. The LM 317 is operated as a "floating" regulator because the adjustment terminal is not connected to ground, but floats to whatever voltage is across R_2. This allows the output voltage to be much higher than that of a fixed-voltage regulator. The LM 317 provides an internal reference voltage of 1.25V between the output and adjustment terminals. The device was designed to minimize the term I_{adj} (100μA Max:) and to maintain it very constant with line and load change. Usually, the error term, $I_{adj} R_2$ can be neglected. The output voltage is a function of both R_1 and R_2. Once when the value of R_1 is set, the output voltage is adjusted by varying R_2. In order to optimize the load regulation, the current-set resistor R_1 should be tied as close as possible to the regulator while the ground terminal of R_2 should be near the ground of the load. Normally, no external capacitors are required, but performance may be improved with addded capacitors as follows:

(a) input bypass capacitor, C_1 of 100nF,

(b) a 10μF capacitor is grounded at the adjustment terminal to improve the ripple rejection of about 15dB,

(c) a 1μF tantalum capacitor is grounded at the output to improve transient response. In addition to external capacitors, it is good practice to add protection diodes, D_1 and D_2. D_1 protects the device against input short circuit, while D_2 protects against output short circuit for capacitor discharging.

3) Voltage Regulation: Regulation is term to define variation of voltage and current subject to load. There are two basic categories of voltage regulations: line regulation and load regulation. Line regulation maintains a nearly constant voltage when the input voltage varies. Load regulation maintains a nearly constant output voltage when the load varies. The voltage regulation is an important measure of transformer performance.

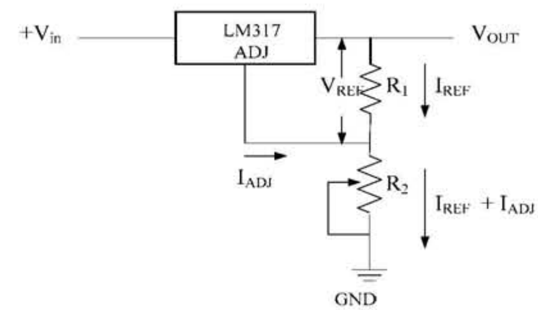

Fig. 5 Basic adjustable regulator using LM317IC

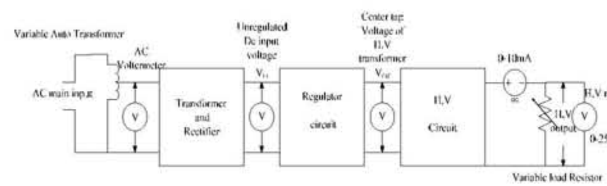

Fig. 6 A hook-up for measuring load and line regulation of H.V Unit

F. Voltage Multipliers (×5Times)

Voltage multipliers use clamping action to increase peak rectified voltage without the necessity of increasing the input transformer's voltage rating. Multiplication factor of two, three and four are common. Voltage multipliers are used in high-voltage, low current applications such as supplying cathode ray tubes (the picture tube in TV receiver, oscilloscopes and computers displays). On the positive half cycle of the secondary voltage, C_1 charges to V_p through D_1. During the negative half cycle, C_2 charges to $2V_p$ through D_2. During the next positive half cycle, C_3 charges to $2V_p$ through D_3. The tripler output is taken across C_1 and C_3. C_4 charges to $2V_p$ through D_4 on a negative half-cycle. The $4V_p$ output is taken across C_2 and C_4. C_5 charges to $2V_p$ through D_5 on a positive half-cycle. The $5V_p$ output is taken across C_1, C_3 and C_5. Theoretically, it could be continue adding more peak rectifiers to get higher multiples of input peak voltage. But the output ripple keeps getting worse because the discharge between peak gets larger.

III. PRESULT AND DISCUSSION

The output data of present work are measured and results is shown in Table I, Table II and Table III are shown line regulation and load regulation for 3055(~3kV).

TABLE I
HIGH VOLTAGE DC OUTPUT AT 3kHz OSCILLATOR FREQUENCY

Regulated primary centre DC Voltage of the H.V transformer (V)	Seccondary Voltage of the H.V transformer (V)	High voltage DC output (V)
2	105	970
4	213	1685
6	315	2069
8	401	2693
10	492	2990
10.19	514	3055

TABLE II
HIGH VOLTAGE DC OUTPUT VARIATION DUE TO LINE VOLTAGE CHANGING AT LOAD CURRENT OF 1mA

AC Line voltage (V)	Unregulated DC voltage (V)	Centre voltage of H.V transformer (V)	High voltage DC output (V)
(rms)	(V_{in})	(V_{out})	(V_{out})
180	13.51	10.09	2995
190	14.37	10.17	3020
200	15.59	10.18	3030
210	16.33	10.19	3035
220	17.45	10.19	3055
230	18.19	10.19	3055
240	19.36	10.19	3055

$$\text{Line regulation} = \frac{\frac{\Delta Vout}{Vout}}{\Delta Vin} \times 100\%$$

$$= \frac{\frac{(3055-2995)}{2995}}{(17.45-13.51)} \times 100\%$$

$$= 0.5\%$$

Centre tap DC voltage of H.V transformer = 10.19 V
Maximum output voltage of H.V meter = 3055V (~3kV)

TABLE III
HIGH VOLTAGE OUTPUT VARIATION DUE TO CHANGING LOAD CURRENT

Load current (mA)	High voltage DC output (V)
No load 0.0	3160
0.5	3135
Full load 1	3055
1.0	3035

$$\text{Load regulation} = \frac{V_{NL} - V_{FL}}{\Delta V_{FL}} \times 100\%$$

$$= \frac{3160-3055}{3055} \times 100\%$$

Load regulation = 3.44% (or) 34.4 mV per Volt

The constructed High Voltage Power Supply can be used for G.M Counter DC 3055 (~3kV) at 1mA.

As a discussion, to get higher DC output voltage, voltage multiplier can be extended into six times, seven times, etc. In this design, five time voltage multiplier is constructed to get ~3kV DC output voltage from 10.19 VDC primary centre tap of H.V transformer tension. High Voltage Power Supply Unit is essential for nuclear radiation detection system. As a further work, the more stable high voltage DC power supply (low current) unit can be constructed for the scintillation detector and semiconductor detector.

Fig. 7 Photo of constructed high voltage power supply unit

Fig. 8 Photo of the scope output characteristics for GM counter

IV. CONCLUSION

Fig. 7 shows the photo of constructed high voltage power supply unit. Voltage regulator provides 10.19V DC to operate the square wave oscillator. The square wave oscillator of 3kHz clock pulses are fed at the clock input of 4027 JK flip-flop. J input and K input is attached with +12V V_{CC} line to get toggle action at output Q and which are connected to the base of the push-pull converter transistor TR_1 and TR_2. The centre tap of the primary winding is connected to a DC supply coming from a variable voltage regulator. The voltage regulator samples high voltage and adjust the potential of the centre tap to compensate for possible variations of the high voltage. Potentiometer or variable resistor VR permits the final adjustment of the high voltage. The primary windings of the transformer receive power from two transistor's collectors with output voltage of opposite phase. Under these circumstances 105V to 514V square wave is developed in the secondary winding of the transformer. This step-up voltage on the secondary side of the transformer is rectified and multiplied by a factor of five by using voltage tripler nework. In this way, the regulated high voltage 3055 V (~3kV) DC output at approximately 1mA output current. This system is constructed with locally available components and useful for not only G.M Counter but also for other high voltage low current applications. Figure 8 shows the photo of the scope output characteristics curve for GM counter.

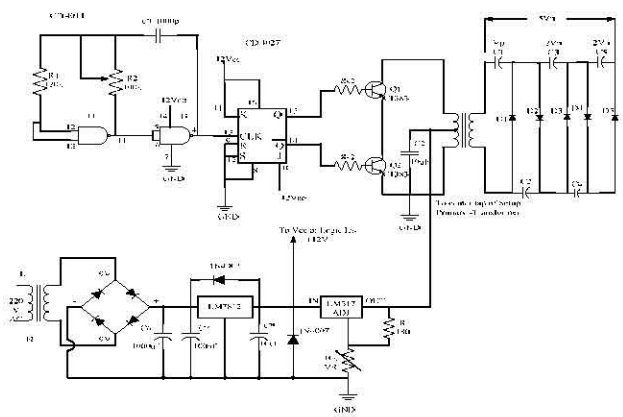

Fig. 6 Circuit diagram of the high voltage unit

Technical data for constructed high voltage is as follows:

- Output voltage -3055 V (~3kV) DC
- Load current - 1mA
- Ripple at output -75mV
- Line regulation -0.5%
- Load regulation -3.44% (or) 34.4 mV per Volt

This system can also provide negative output voltage approximately -3055(~ -3kV) by reversing the polarity of diode. To get more stable and low ripple output voltage, transformer type design, frequency, transformer driver stage and filter should be considered.

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