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High Voltage Generation and Control Circuit for Silicon Drift Detectors

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***Abstract*- The work concentrates on the design of a high voltage supply for silicon drift detector which is a kind of semiconductor X-ray detector. A dc to dc converter is designed that can convert the low voltage of the raw bus to a value (-300V) high enough to make the detector work. It is optimized to have a low mass and power. The design also satisfies some stringent requirements such as corona proof, power bus protection, the automatic reduction of HV applied to the detector when satellite enters into high charge concentrated regions in the sky, in its trajectory. The HV unit is used in space applications so it has to be compact, light in weight and has to consume low power. It must be able to withstand the widely varying temperatures and the harsh radiation conditions of space. The design can produce voltages in the range ±200 to ±2000V with only slight modifications in the circuit thus can be used for any other kind of detector as well.**

1. INTRODUCTION

X-ray astronomy is an observational branch of astronomy which deals with the study of X-ray emission from celestial objects. It is one of the extensively growing branches of astronomy. X-ray radiation is absorbed by the Earth's atmosphere, so instruments for detection must be taken to high altitude by balloons, sounding rockets, and satellites. The X-rays emitted from a particular source interacts with the material of the detector producing signals that can be analyzed to study the X-ray source. X-ray detectors are of various types. Many conventional and new detector technologies require the application of intermediate to very high voltages. Example of the detectors requiring high voltage bias are gas filled chambers and scintillators coupled to photomultiplier tubes. Some special semiconductors such as Cadmium Telluride, Cadmium Zinc Telluride are operated at intermediate high voltages. Applications which include micro channel plate as the basic detector would require HV up to 3kv.

The project work concentrates on the design of a compact a high voltage bias for a kind of semiconductor x-ray detector know as silicon drift detector (SDD) used in X-ray astronomy and astrophysics. Here a dc to dc converter is designed that can convert the low voltage of the raw bus to a value high enough to make the detector work. The design is aimed to produce compact and efficient HV bias. With modifications it can produce voltages in the range ±200 to ±2000V, thus useful for other types of detectors.

The high voltage unit designed is used for space based experiments. An apt method for dc-dc conversion was designed based on the requirements. The paper design was made. The whole circuit was divided into various sub circuits for ease of design and simulation. Each sub circuit contained different parts. The software simulation of each part was done in the PSpice simulation tool.

2. DESIGN SPECIFICATIONS

The HV unit design is aimed to give a voltage in the range -200 to -300V. The range is given for different SDD detectors. The specifications that are given change with the type of detector used. Here we are taking SDD as an example. It stands for Silicon Drift Detector which is a type of semiconductor detector. The various design specifications for SDD are given below.

Electrical Specifications: These are the maximum values like current, voltage etc. that the detector can withstand without getting damaged. The specifications given below are for SDD detector. These values may change for different detector and the HV design can be modified accordingly.

Table 2 Electrical specifications

Parameter	Value	Unit
Output Voltage	-200 to -300	V
Load Current	+25	µA
Ripple	0.1	%
Regulation	0.1	%
Power consumption	<1	mW

Simulation tool: SPICE is the most suitable simulation tool for the implementation of this HV circuit. SPICE is a powerful general purpose analog and mixed-mode circuit simulator that is used to verify circuit designs and to predict the circuit behavior. This is of particular importance for integrated circuits.

3. EXPERIMENTAL SETUP

The high voltage bias circuit consists of mainly 3 sub circuits – HV generation unit, HV regulation unit and HV control unit.

Generation Unit: The HV generation consists of a transformer and a voltage multiplier. The transformer provides isolation and ac voltage step up. A saturable core transformer with primary, secondary and feedback winding is used here. The voltage multiplier converts the ac output from the transformer to a very high value dc. It consists of certain number of diode-capacitor stages that provides the required voltage multiplication. Its output is a pulsating dc thus VM also provides a rectification of the applied ac.

Regulation Unit: The HV regulator unit consists of a transistor series pass regulator. It consists of 2 transistors forming a Darlington pair. It provides a constant output voltage regardless of load and line variation.

Control Unit: The HV control unit consists of a voltage divider circuit, a multiplexer and an error amplifier. The voltage divider provides a small portion of the HV output for feedback. The multiplexer gives a provision for applying a variable input as reference. The error amplifier compares the output with the reference signal and rectifies the errors. Other important sub circuits include – low voltage dc-dc converter, oscillator and filter. The LV dc-dc converts the raw bus voltage (about 26-42V) into a low dc value of around 7V. The oscillator circuit is used to provide a proper ac signal (square wave) to the transformer primary from the input dc. It mainly uses the push pull action of 2 transistors. Filter circuit consists of 3 resistors and capacitors that provide a proper dc. The overall action consists of converting a low dc voltage (around 26-42V dc) into a high value (-200 to -300V dc). Here dc to ac conversion, step up of ac, and ac to dc back conversion actions take place. The following block diagram illustrates the circuit:

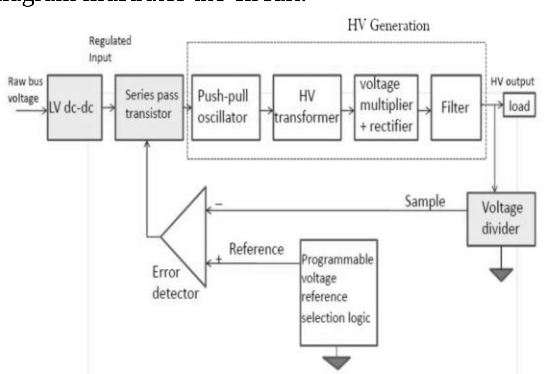

Figure 1 Basic block diagram

4. PSPICE SIMULATION CIRCUITS AND RESULTS

The various circuits that have been created and simulated in the PSpice simulation tool are shown below.

Voltage multiplier: Figure 2 shows a voltage multiplier (VM) circuit. This type of circuit is called a Cockroft Walton voltage multiplier. It is a multistage diode-capacitor device that can give a high voltage at low current and low cost. Voltage multiplier can be a doubler, tripler, quadripler etc producing twice, thrice or 4 times the input peak voltage. The output can be odd or even multiples of the input depending on the number of stages. The output can be positive or negative voltage depending on the connection of the diodes. The number of stage of the VM is decided according to the voltage multiplication required. In figure is a 1.5 stage VM consisting of 3 Capacitor and 3 diodes. A 3rd order filter is also used to filter out the ripples in the voltage multiplier output and give a smooth dc. In the actual circuit input to VM is the secondary voltage of transformer. For the PSpice simulation a pulse producing source has been used.

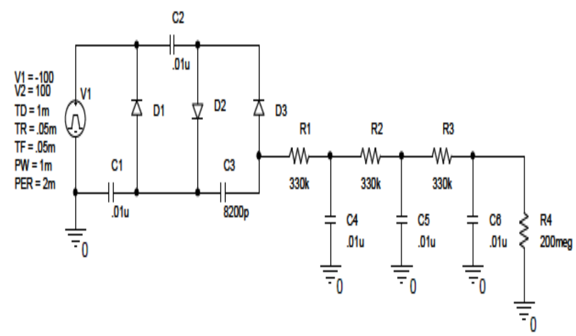

Figure 2 Voltage multiplier and filter circuit

Working: During the negative of the 1st cycle C1 is charge to the peak value of the supply voltage through the forward biased diode D1. In the positive half of the cycle C2 is charged to Vc1+Vpeak=2Vin. In a similar fashion all the capacitors are charged to 2Vin through the diodes. Vout is obtained as the sum of the voltage across the capacitors and the ground. Thus we can get the desired dc output across the load. A filter circuit can be used to further remove the output voltage ripple.

Design Equations:

- $E_{out}=2n\times Epk$
- $I_{load}=E_{out}/R$
- $C_1=C_2=nC$
- $C_3=(n-1)C$

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- $V_{drop}=n^2I_{load}/fC$
- $V_{ripple}=nI_{load}/fC$

Where,
n= number of stages (2 capacitors and 2 diodes form 1 stage)
E_{out}= output voltage
E_{pk}= peak input voltage
I_{load}= load current
C= capacitance value
C_1, C_2, C_3, are the stage capacitances
R= load resistance
f= input frequency
V_{drop}= drop in output voltage
V_{ripple}= output voltage ripple

Figure 3 is the result obtained while simulating a 1.5 stage voltage multiplier (figure 2). In figure blue graph shows the input ac signal. Its value is 100V (rms). The green line shows pulsating output dc. The red line shows dc after filtering. Its value is -300V dc. The connection of the diodes is such that the output is negative. Thus voltage multiplication has taken place.

- Vout=2×1.5×Vin i.e. 3×100=300V(-dc)

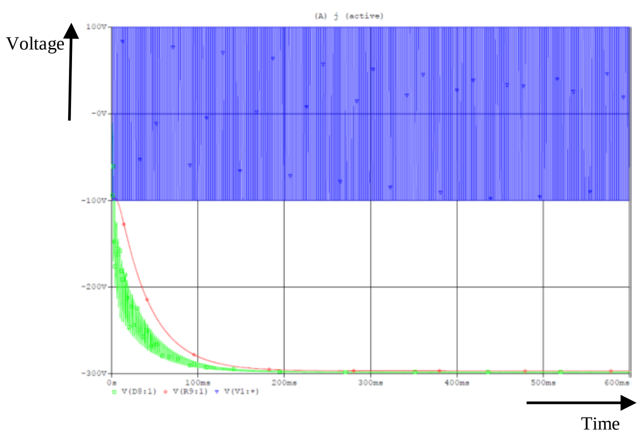

Figure 3 Output of voltage multiplier and filter

HV Transformer: Figure 4 shows a transformer (step up). The transformer used here has a saturable core with the primary, secondary and feedback windings wound on it. The primary and feedback windings are bifilar. The primary input is provided by a pair of transistors called Royer oscillator. The turns-ratio is designed such that it can provide the required input to the voltage multiplier for further multiplication.

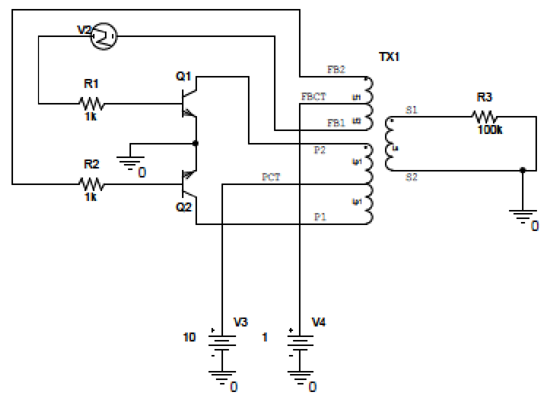

Figure 4 Transformer working

Working: A dc supply connected to the transformer primary center tap (PCT). Another smaller dc voltage is given to the center tap of the feedback winding. The starting and ending of the feedback winding is connected to one of the bases of the 2 transistors through an appropriate resistance value. Practically no two transistors are alike also there will be some inherent noise in the circuit. Due to these reasons one of the transistors will be driven to saturation causing the other to go to cut-off. Say Q_1 goes to saturation first. This allows current to flow in the 1^{st} half of the primary winding through P_2 to Q_2 to ground. During the next moment Q_1 goes to cutoff causing Q_2 to go to saturation. So now the power flow is through the 2^{nd} half of the primary winding. Thus the transistors undergo a push pull action causing the voltage at the 2 halves of the primary winding to oscillate. Now by the transformer action the secondary voltage is generated (red graph) (figure 5). Here in simulation the transistors are identical and no noise is present therefore an external pulse is used to provide the initial trigger to 1 of the transistors. [5]

Major Transformer Equations

- $n= N_s/N_p=V_{out}/V_{in}$
- $N_p= V_{in}\times10^8/(2\times B\times f\times A_c)$
- $N_s = V_{out}\times10^8/(2\times B\times f\times A_c)$
- $R= \rho\times l\times N/A_w$
- $A_c= H\times(OD-ID)\times SF/2$ (for toroidal core)

Where,
N_p= number of turns of primary winding
N_s= number of turns of secondary winding
n= turns ratio
V_{in}= input voltage
V_{out}= output voltage
B= flux density
f= frequency

A_c= core area
R= Resistance of winding
A_w= area of wire
l= path length
ρ= resistivity
H= height of core
OD= outer diameter
ID= inner diameter
SF= stacking factor

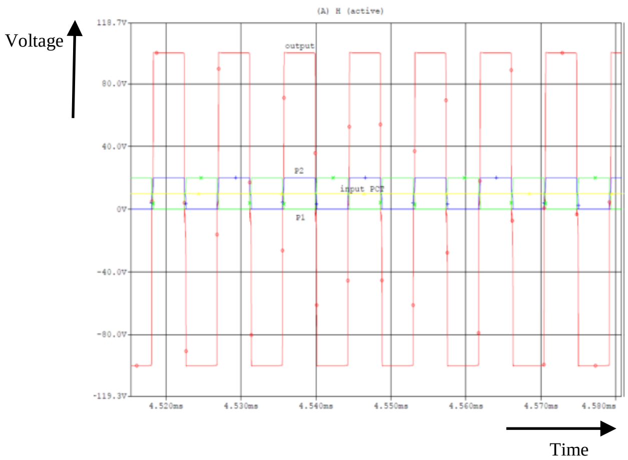

Figure 5 Voltages at transformer primary and secondary windings

HV Generation circuit: Figure 6 shows the generation circuit consisting of voltage multiplier, transformer, oscillator and filter. The transistor base is connected to the feedback winding. [4] The input dc appears as square pulse which is out of phase at the base of the 2 transistors. Thus 1 of the 2 transistors goes to saturation and the other to cut off. Hence the push-pull action starts, giving square pulses to transformer primary. By transformer action voltage is stepped up at the secondary. The output of transformer secondary acts as input to the voltage multiplier. The voltage multiplier multiplies and rectifies the input giving a pulsating dc at its output. This dc is then filtered to give the HV bias. A part of this HV can be used for feed back if control action needs to be performed.

The simulation result of the entire circuit is shown in figure 7. A 7V dc (green) is converted into -300V dc (red). Numbers of turns of the primary and secondary winding are 70 and 1000 respectively. Thus the turns ratio is around 14.28 and hence we get a secondary voltage is around 100V (rms) (blue). This is input to the voltage multiplier. It gives a voltage 3 times its input so we get 300V as the final output. The diodes are connected such that we get a negative voltage. Thus -300V HV bias is generated and it is used for the powering of SDD detectors.

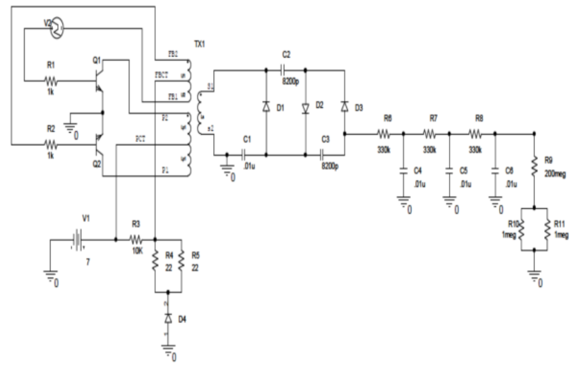

Figure 6 Circuit consisting of oscillator, transformer, voltage multiplier and filter

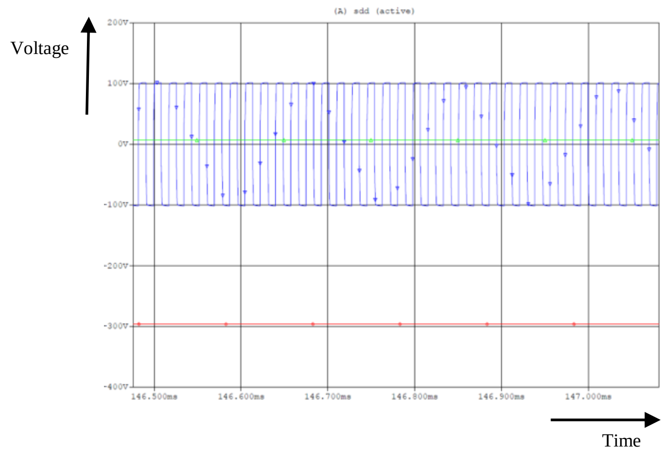

Figure 7 Entire circuit output

6. CONCLUSOION

X-ray study is carried out with the help of detectors. There are various types of detectors, each having its own advantages and disadvantage. Many of the detectors need a high voltage bias for their working. In a spacecraft the main source of power is the solar panel or battery. The magnitude of voltage from these sources lies in the lower range; say between 28V to 43 V. Hence it is essential to convert this value to the required HV value (for biasing the x-ray detectors referred earlier) using dc-dc converters. The high voltage unit must work at a low power, must be compact and light in weight. It must also be space qualified to withstand the variations in temperature, pressure and radiation conditions of the outer space. An HV bias unit providing a voltage around -300V dc has been designed to power silicon drift detector. In the circuit transformer serves as an isolator in addition to stepping up the voltage. The voltage multiplier further multiplies and rectifies the voltage. The turns ratio of the transformer and the number of stages in the voltage multiplier can be adjusted according to the required voltage. Thus the same circuit can be used for other detector types as well. All the components used in the circuit are designed for high reliability and compactness. Thus this design can deliver a high voltage for space applications.

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