STUDY ON THE CHARACTERISTICS OF THE SUB-NANO SECOND PULSE GENERATOR FOR A PLS ELECTRON GUN

Y. G. Son, S. D. Jang, J. S. Oh, S. J. Park, PAL/POSTECH, Pohang, Kyungbuk 790-784, Korea

Abstract

A PLS (Pohang Light Source) electron gun has a grid pulse generator providing a pulse voltage of –500 V with 2-ns pulse width into a 50-ohm load to generate 2-A electron beams. To make a short pulse width, a coaxial PFL (Pulse Forming Line) that can reduce the stray inductance and an avalanche transistor switch that enables rapid switching are essential. Sub-nano second electron beams can increase an injection efficiency of the PLS storage ring. Pulse specifications and characteristics are reviewed for the sub-nano second pulse generation. The switching characteristics of an avalanche transistor switch are examined in detail. This paper shows the experimental result and the detail of the development of sub-nano second pulse generator

INTRODUCTION

The electron gun of the PLS injector linac generates electron beams with 2-ns pulse width by a grid trigger pulse. Considering the 2-ns period of 500-MHz RF of PLS storage ring, the pulse width shorter than 2 ns is favourable.

NPN transistors and a coaxial cable are used to make a nano-second pulse. The pulse width is proportional to the length of the coaxial cable and the pulse amplitude is determined by the charging voltage of the coaxial cable and the impedance ratio between the coaxial cable and a load.

The main switch is a series-connected NPN transistor. It is operating at the avalanche breakdown region. The switching speed of the transistor is dominant factor in the short pulse generator. This paper shows the design details and experimental results of a sub-nano pulse generator.

ELECTRON GUN SYSTEM

The electron gun of the PLS injector linac is a triode-type gun. It is consisted of an anode, cathode, and grid. The acceleration voltage is – 80 kV and maximum extraction current is 5 A with minimum pulse width of less than 1.0 ns, and maximum pulse repetition rate of 100 Hz. The vacuum pressure is kept less than five nano-Torr.

Figure 1 shows the circuit diagram of the electron gun system. The electron beam is generated at the dispenser-type cathode and the beam trajectory to the anode is controlled by a focusing electrode. The negative high voltage is applied to the cathode to accelerate the electron beam. The grid is negatively biased to suppress the electron emission from the cathode. The electron beam is extracted by adding a short positive pulse on this bias voltage. Table 1 shows the main parameters of the electron gun. [1]

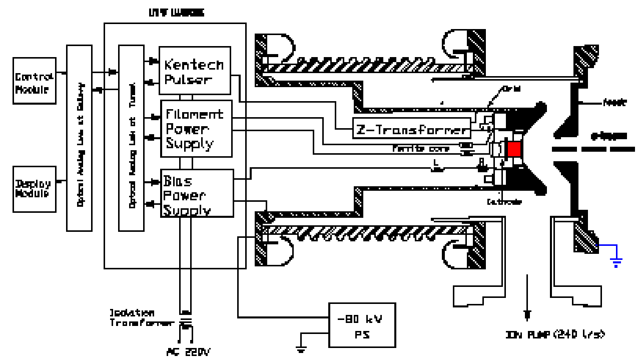

Figure 1: Circuit diagram of the electron gun

Table 1: Main parameters of the electron gun

Parameter	Unit	Value
Peak beam current	A	> 2
Beam voltage	kV	- 80
Pulse width (FWHM)	ns	2
Repetition rate	Hz	10
Time jitter	ps	< 40
Cathode diameter	mm	16
Grid bias voltage	V	50-500
High voltage insulation	Air	
Grid driver	Line type pulser with avalanche Tr.	
Cathode material	Dispenser	

Table 2: Specifications of a grid pulser

Parameter	Symbol	Valve
Pulse output voltage	kV	1.0 @50 Ω
Rise time	ns	0.7
Pulse length	ns	< 1, 1, 2, 5, 10
Polarity		Negative
Trigger	V	5.0 @50 Ω
Jitter	ps (RMS)	10
Trigger delay	ns	20
Input power supply	Vac	230

SUB-NANO SECOND PULSER

Table 2 shows the specifications of a grid pulser for a PLS electron gun. The pulse amplitude is 1 kV into 50-Ohm load with a rise time of 0.7 ns. The pulse width can be adjustable and the timing jitter is 10 ps.

The grid trigger pulser has a coaxial cable as an energy storage and pulse shaping device, and a transistor as a discharging switch. The collector of a NPN transistor is positively biased, and the emitter is grounded together with the base. There is primary breakdown region due to conventional avalanche breakdown and the attendant large flow of current. Applying a fast rising voltage, there is secondary breakdown region that appears as a steep voltage drop in the collector-emitter voltage at large collector currents.

PULSE DESIGN AND TEST

The circuit diagram of the pulse generator is shown in Fig. 2. The switch is a series-stacked avalanche transistor. The coaxial cable, energy storage device, is connected to the end of the switch. The pulse width is determined by a length of the coaxial cable.

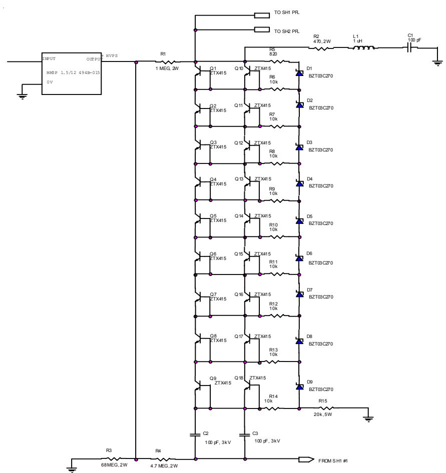

Figure 2: Circuit diagram of the grid pulser

The output voltage, V_o of the grid pulser is given by

$$V_o = n \times V_a \qquad (1)$$

$$Q_{COAX} = C_{COAX} \times V_{av} \qquad (2)$$

$$\frac{dQ_{COAX}}{dt} = -I_p \qquad (3)$$

$$V_P = I_P \times Z_L \qquad (4)$$

where n is the number of transistor, V_a is the applied voltage to each avalanche transistor, C_{COAX} is the capacitance of the coaxial cable, Q_{COAX} is the total charge of the coaxial cable, V_P is a output voltage, I_P is a output current, Z_L is a load impedance.

The ZETEX avalanche transistor, ZTX415 and ZTX300 is used in the pulser. The PFL (pulse forming line) is made by a RG-178B/U coaxial cable. The characteristic impedance of the coaxial cable, Z_o is given by

$$Z_o = \sqrt{\frac{L}{C}} = \sqrt{60\varepsilon_r}\,\ln\left[\frac{b}{a}\right] \quad [\Omega] \qquad (5)$$

where L is the inductance of a coaxial cable in Henry, C is the capacitance of a coaxial cable in Farad, ε_r is the relative permittivity of a dielectric material in the coaxial cable, b is the inner radius of the outer shield and a is the outer radius of the center conductor.

The pulse width, t_w is given by

$$t_w = 2\sqrt{LC} = 2CZ_o = \frac{2L}{Z_o} \quad [\mu s] \qquad (6)$$

The coaxial cables are prepared with different length matched to the pulse width of 10-ns, 5-ns, 2-ns, less than 1-ns. The output waveform according to different cable length is shown in Fig. 3. The length is changed from 5 cm to 50 cm. The polarity of the a grid pulse is negative.

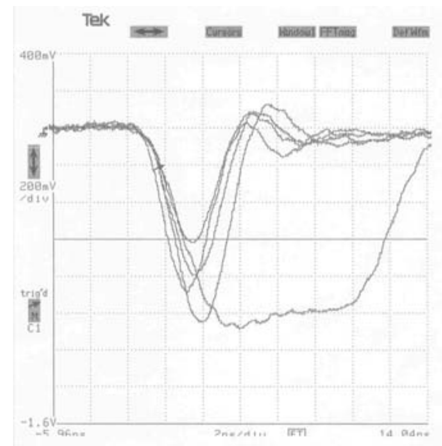

Figure 3: Grid pulser waveform (200V/div)

Increasing the length of a coaxial cable, total capacitance of the cable is increasing. It results low load impedance. The measured load impedance at the load current of 10 A is 12 Ohm but it is 50 Ohm at 1 A load current. Due to the stray inductance and distributed capacitance near the components and PCB, the waveform is similar to triangular when the PFL length is very short. This is equivalent to LC circuit as shown in Fig. 4 instead of a coaxial cable. L and C are the inductance and the capacitance of a coaxial cable, respectively. The choke coil inductance, L_c and the voltage-grading resistance, R_d are large values so that their effect on the pulse characteristics is negligible. The internal inductance and turn-on resistance of a switch is relatively large in case of short pulser generator with the pulse length less than 2-ns.

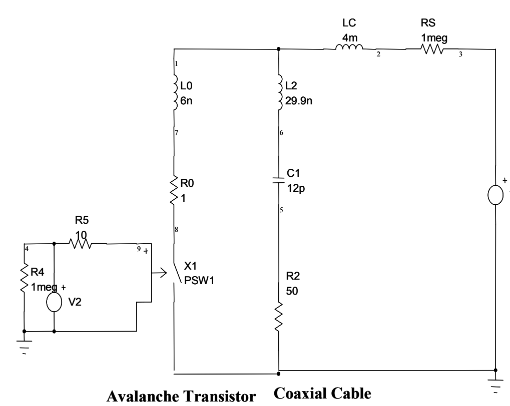

Figure 4: Equivalent circuit for a short pulse generator

The equivalent inductance of an avalanche transistor is 2 nH including a lead inductance. The equivalent turn-on resistance of an avalanche transistor is 1 Ohm including a PCB pattern resistance. [3][4]

The long pulse generator can be simulated by a 10-stage LC circuit. Figure 5 shows the simulated waveform that is well reproducing a measured waveform. It is assumed that the lead inductance, L_o and the internal resistance R_o of a transistor is constant so that it is not depend on the level of a current.

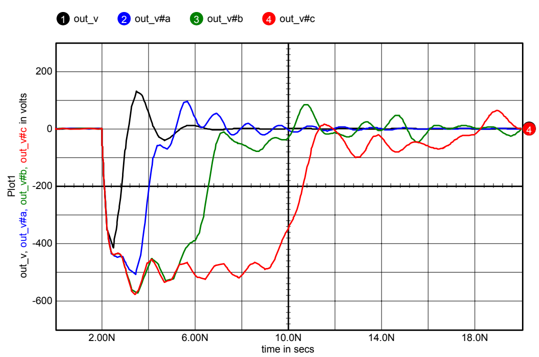

Figure 5: Simulated waveform for a long pulse generator

Figure. 6 shows the measured beam current extracted from the electron gun. The beam current is measured by a current transformer. The measured grid-cathode impedance of Y-824 assembly is 12 Ohm. The output impedance of the pulser is 50 Ohm. Therefore, it is necessary to put an impedance transformer between the pulser and the grid of the electron gun for an impedance matching.

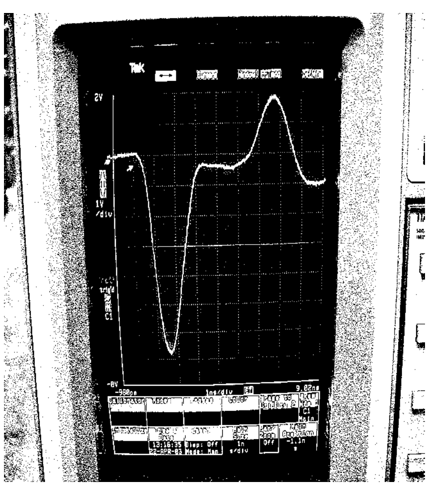

Figure 6: Electron beam current

Figure 7 is the photograph of the fabricated grid pulser. The experimental test circuit is composed of series-connected NPN transistors and a coaxial cable mounted on a PCB. The switch is composed of 4-6 avalanche transistors connected in series. The switch mode DC power supply with 1 kV output voltage is used to charge the PFL. The simulated load is a 50 Ohm, 2 W non-inductive resistor.

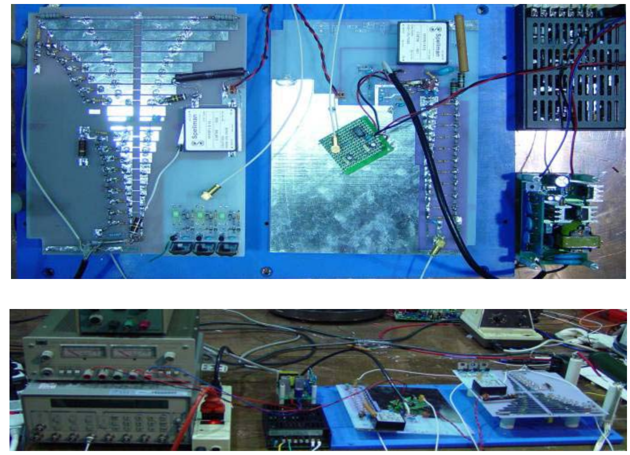

Figure 7: Photograph of the grid pulser

SUMMARY

The fast rising pulse with a short pulse width less than 1-ns is required for the grid pulser of the electron gun. The turn-on speed of an avalanche transistor is fast enough to match the rise time requirement. The measured rise time of the test circuit is confirmed to be 1-ns. The pulse width is controlled by adjusting the length of a coaxial cable. The performance of the pulser is sensitive to circuit parameters such as the inductance and capacitance of PCB pattern, impedance matching condition. Proper instruments and correct measurement are also important.

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