

## DEVELOPMENT OF A THERMIONIC ELECTRON GUN OF THE L-BAND LINAC FOR FEL OPERATION

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### Abstract

We are developing an electron gun system using a high-repetition-rate grid pulser with FET to generate a multi-bunch electron beam for FEL based on the L band linac at Osaka University. A test bench is set up for evaluating the performance of the electron gun system. The multi-bunch electron beam at a 27 MHz repetition-rate is successfully generated though an irregular part appeared at the beginning of the pulse train produced in the grid pulser.

### INTRODUCTION

We are conducting FEL experiments in the far-infrared region with the L band electron linac at the Institution of Scientific and Industrial Research (ISIR), Osaka University. The linac is equipped with a thermionic electron gun and the three-stage sub-harmonic buncher (SHB) system consisting of two 108 MHz cavities and one 216 MHz cavity. In FEL experiments an 8  $\mu$ s long electron pulse is injected from the gun and the SHB system is turned on for generating a multi-bunch electron beam of an 8  $\mu$ s duration with 2 nC charge per bunch and 9.2 ns intervals between bunches [1]. It repeatedly amplifies light pulses stored in the optical resonator of the FEL and lasing begins and develops up to a saturation power levels. The roundtrip time of light pulse is 37 ns, so that four light pulses are stored in the resonator. The higher FEL gain has a significant impact on improving performance of FEL and the gain becomes higher with increasing peak current in the bunch or charge per bunch. The present value of charge per bunch, 2 nC, is limited by the high beam loading in the acceleration tube of the linac, exceeding a half of the input RF power. If the bunch intervals can be extended to 37 ns, the charge per bunch can be made four times higher for the same beam loading, resulting in significant increase of the FEL gain.

The grid pulser for the electron gun currently used is one developed and made at ISIR. It uses avalanche diodes for generating the fast high-voltage pulse, so that it can generate a single pulse as short as 5 ns but cannot generate a series of pulses owing to the characteristics of the avalanche diode. To generate such a multi-bunch electron beam, we are developing an electron gun system with a new grid-pulser using FET. We will report progress of the study.

### TEST BENCH

We have set up a test bench for measurement of

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characteristics of the electron beam with the new grid pulser. Figure 1 schematically shows the layout of the test bench.

The high-voltage power supply is a Cockcroft-Walton generator with the maximum voltage of 250 kV. The grid pulser, a bias power supply, and a heater power supply are installed on the high-voltage deck for a thermionic cathode (EIMAC, YU-156). Some other components for generating trigger signals to the grid-pulser are also put on the deck, details of which will be described in the next chapter. The cathode was used for operation of the L band linac until October 2009. It worked normally when it was replaced with a new one.

When we began conditioning of the electron gun assembly, the vacuum was  $6.7 \times 10^{-7}$  Pa. The nominal operation voltage of the electron gun is 100 kV DC but we have not reached it. The maximum voltage so far obtained is 85 kV and we will continue the conditioning.

### GRID PULSER

Figure 2 shows a schematic drawing of the grid pulser circuit with an FET. The working principle of the grid pulser is as follows. The input signal is a positive pulse of  $\sim 2$  V and the pulser is triggered at the leading edge of the pulse. The pulse duration must be longer than the output pulse duration, 5 ns, but shorter than the time between the input pulses. The input pulse is first amplified and then divided into two signals. One is sent through a capacitor to the FET gate. The other is delayed using a coaxial cable and sent through a capacitor to the gate of the transistor. The drain of the FET is pulled up to 100~150 V. When the leading edge of the first signal turns on the FEL, the negative pulse is generated through the output capacitor at the output. Sometime later, the delayed second signal turns on the transistor, so that the FET

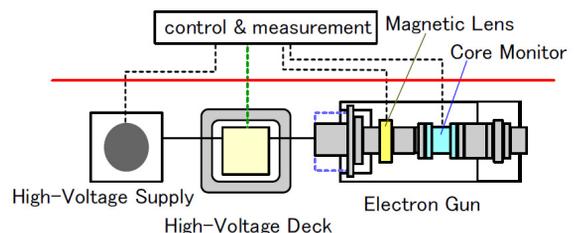


Figure 1: Schematic layout of the test bench for the electron gun system.

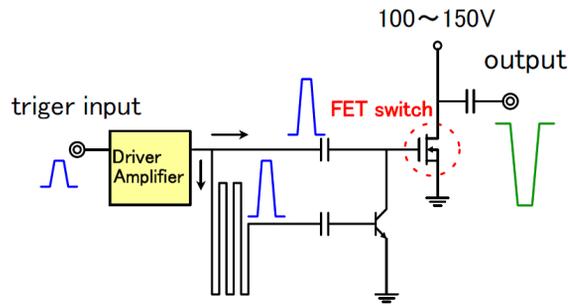


Figure 2: Schematic diagram of the grid pulser circuit.

switch is forcibly turned off and the output pulse is terminated. The negative output pulse is thus generated. The pulse height is equal to the voltage applied to the drain of the FET and the duration is determined by the delay time of the second signal. The FET for switching is a key component of the grid pulser. We use 2SK408 (Hitachi), which is designed for power amplifier in the VHF band. We have adopted it for switching because the maximum drain-to-source voltage is high (180 V) and it works relatively fast.

First we have conducted operation test of the grid pulser. Figure 3 shows the block diagram of the trigger system for the grid pulser. It is a tentative arrangement for the present experiment. A 1.3 GHz CW RF signal is generated with a synthesized signal generator and it is converted to 27 MHz clock signal using a frequency divider. Then the signal is amplified and sent to the high voltage deck through an optical fiber. An 8  $\mu$ s long pulse train signal is generated with an RF switch and an arbitrary function generator; the pulse train is sliced out from the CW signal with the RF switch using a square-wave gate signal from the function generator. As the signal is negative up to this point, the polarity is converted with an RF transformer so that the positive trigger is sent to the grid pulser. Note that the first and the last pulse signals in the pulse train may be clipped off because the gate signal for the RF switch is not synchronized with the 27 MHz clock signal.

Figure 4 shows the output signal of the grid pulser for 8

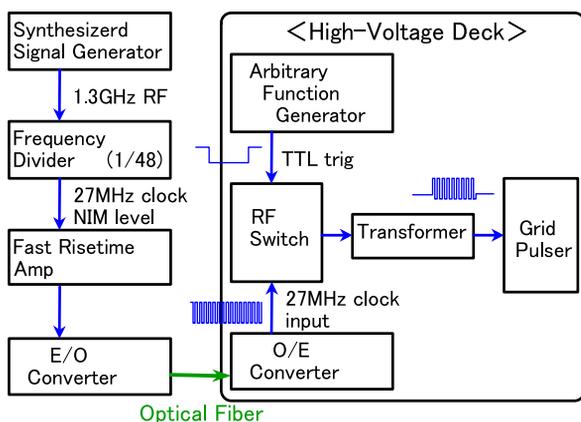


Figure 3: Block diagram of the trigger system.

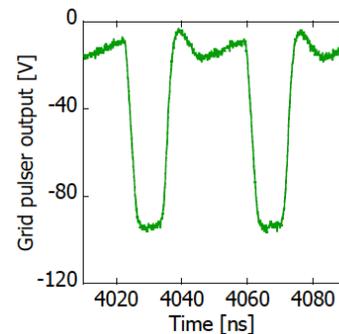
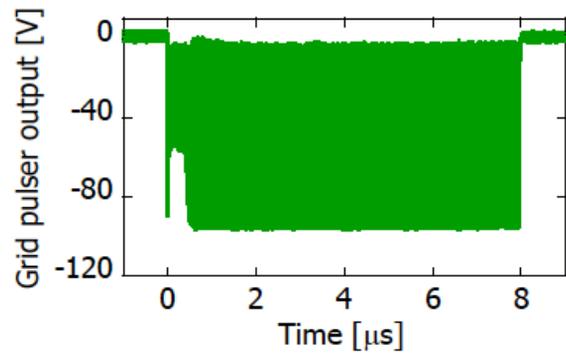


Figure 4: Output signal of the grid pulser. (a) Whole pulse train and (b) its expansion.

$\mu$ s operation. Figure 4(a) shows the whole shape of the pulse train. The peak voltage is 95 V when the drain voltage is 110 V and it is constant over the whole time spectrum except for the first 500 ns, where the pulse height drops to a half of the other part. This drop appears stably and reproducibly, but the cause of this unexpected irregularity is not clear. One possibility is that it may be caused by stray capacitance in the circuit substrate of the grid pulser. Figure 4(b) shows an expansion of the time profile shown in Fig. 4(a) in the regular part. The pulse interval is 37 ns, which is the reciprocal number of 27 MHz, the rise time of the negative pulse is 4 ns, the FWHM of the pulse is approximately 10 ns, and the fall time is 4.5 ns.

## MULTI-BUNCH GENERATION

We conducted experiments to generate a multi-bunch electron beam using the grid pulser. The experimental conditions for the cathode assembly (EIMAC, YU-156) are as follows. The heater voltage is 6 V, the cathode voltage is 50 kV, and the bias voltage for the grid is 50 V. We use the 2  $\mu$ s duration input for the grid pulser in order to avoid vacuum getting worse. The upper panel of Fig. 5 (a) shows the time structure of the electron beam measured with the core monitor shown in Fig. 1. An irregular structure appears in the beginning of the electron pulse train, which is similar to that of the grid voltage, but the drop is slightly smoothed. Figure 5 (b) shows their expansions in the regular part. The grid voltage is shown with the green line and the beam current with the red one.

**REFERENCE**

- [1] R. Kato, S. Okuda, Y. Nakajima, G. Kondo, Y. Iwase, H. Kobayashi, S. Suemine, G. Isoyama, Nucl. Instr. and Meth. A 407 (1998) 157

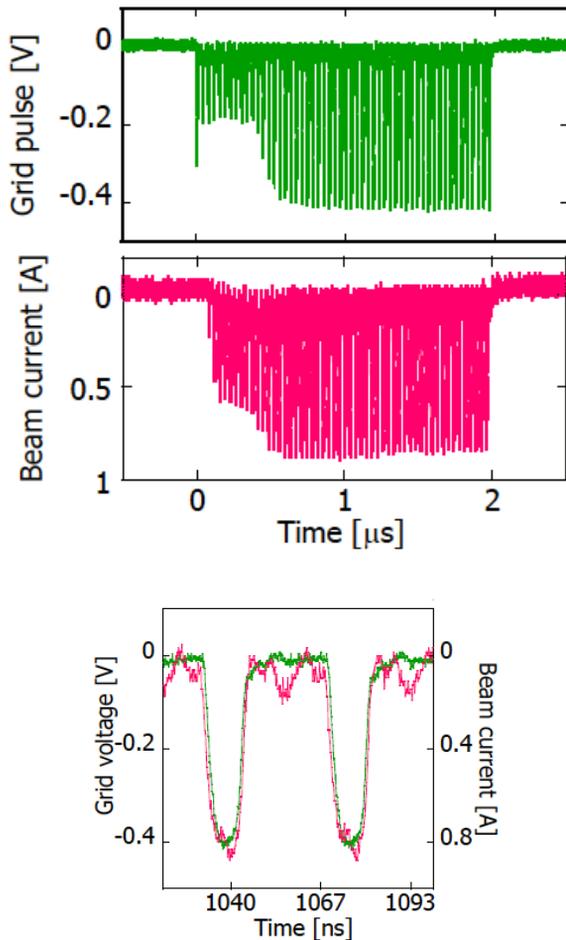


Figure 5: Time structures of the electron beam and the grid voltage for 2  $\mu\text{s}$  long pulse train. (a) Whole and (b) expansion. The green lines are grid voltage and the red lines are electron current from the cathode.

These pulse shapes agree quite well with each other, though the pulse width of the electron beam is slightly larger than that of the grid pulse. The pulse width of the electron beam is 11 ns and the interval is 37 ns. The peak current is 880 mA in the regular part.

**CONCLUSIONS**

We conducted experiments to evaluate the performance of the electron gun system using the grid pulser with FET being developed for the L-band linac to generate the multi-bunch electron beam for FEL. The multi-bunch electron beam at the 27 MHz repetition rate was successfully generated though the irregular part appeared at the beginning of the pulse train due to the grid pulser. We will continue the development of the electron gun system for generating a multi-bunch beam with arbitrary intervals.