A LOW-POWER RF SYSTEM WITH ACCURATE SYNCHRONIZATION FOR AN S-BAND RF-GUN USING A LASER-TRIGGERED PHOTOCATHODE

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Abstract

An S-band RF-gun using a laser-triggered photocathode and its low-power RF system have been constructed. The main elements of the low-power RF system comprise a 600-W amplifier, an amplitude modulator, a phase detector, a phase shifter and a frequency-divider module. Synchronization between the RF fields for acceleration and the mode-locked laser pulses for beam triggering are among the important points concerning the RF-gun. The frequency divider module which down converts from 2856 MHz(RF) to 89.25 MHz(laser), and the electrical phase-shifter were specially developed for stable phase control.

The phase jitter of the frequency divider should be less than 10 ps to satisfy our present requirements. The first experiments in order to trigger and accelerate beams with the above-mentioned system were carried out in January, 1992.

1, Introduction

The electron source of the Japan Linear Collider (JLC) must produce 80 intense electron bunches with a spacing of 2.8 or 5.6 ns for each cycle of operation with a repetition rate of 50 or 150 Hz in order to obtain high luminosity. The S-band RF-gun using a laser-triggered photocathode[1,2] is a candidate to realize these specifications, since the laser pulses which are synchronized with RF fields could trigger the above-mentioned bunch structure directly on the cathode. In the present experiment a frequency-doubled mode-locked Nd:YAG laser is used in which an acoust-optical(AO-) modulator is fed with an RF signal of 89.25 MHz to produce laser pulses of 178.5 MHz. One of the key issues of the RF-gun is phase stability (the synchronization between two RF signals of 2856 MHz for acceleration and 89.25 MHz for the laser), since its accuracy mainly determines the beam quality.

At the JLC, the phase jitter for a short time(<10 ps) and the phase drift for a long time(~ days) should be as small as possible. On the other hand, the accuracy of their measurements and the phase-related performance of solid-state devices are around 5 ps and ± 1 degrees using present-day technologies. In addition, the pulse width of the laser light is 10 - 20 ps in the present experiment. Consequently, as a first step, the targets of the phase jitter and phase stability of the low-power RF system are set at 10 ps and ± 1 degrees, respectively.

A fast feedback system of the phase within an RF pulse duration of a few μs is also effective for obtaining good phase stability. In order to realize such a fast phase-locked system and simple control, only solid-state devices, such as diodes and transistors, are used in the low-power RF system.

In the following sections we will describe the system and the performance obtained by the experiment.

2, Low-Power RF system

The low-power RF system for the RF-gun (Fig. 1) should drive a high-power klystron, the laser system and a trigger system for the various pulsed circuits. It generates four frequencies which are 2856 MHz for RF acceleration, 89.25 MHz for the AO-modulator and a coarse-timing system (TD-1 trigger delay module), and 375 MHz for a fine-timing system (TD-2 trigger delay module).

The signal flow of the system for driving the klystron is as follows. An acceleration frequency of 2856 MHz is generated with a signal source which is a frequency synthesizer (HP-8665A); it is modulated with a PIN diode modulator (HP-11720A) so as to have a pulse width of 3 μs.

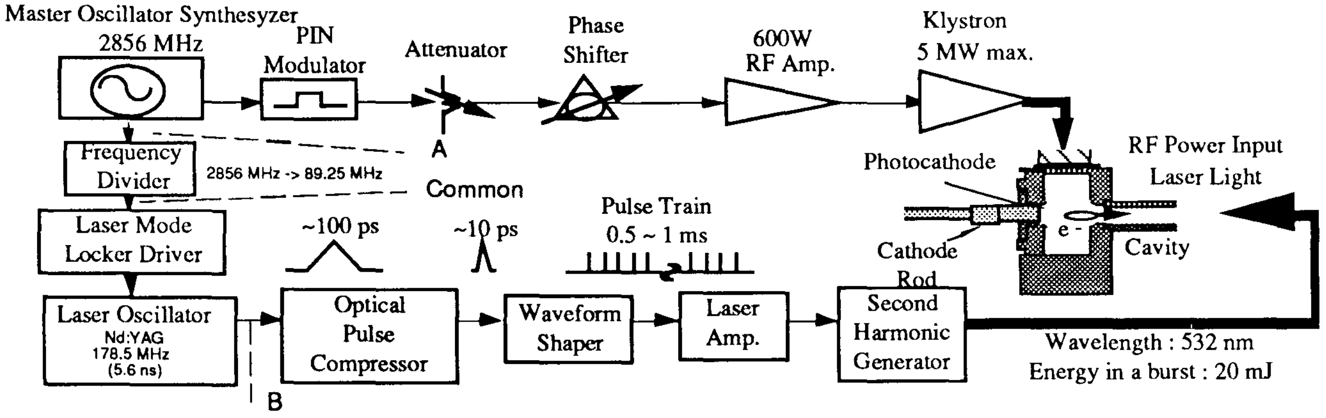

Fig. 1 Block diagram of the RF-gun system: the upper side is the RF system and the lower side is the laser system

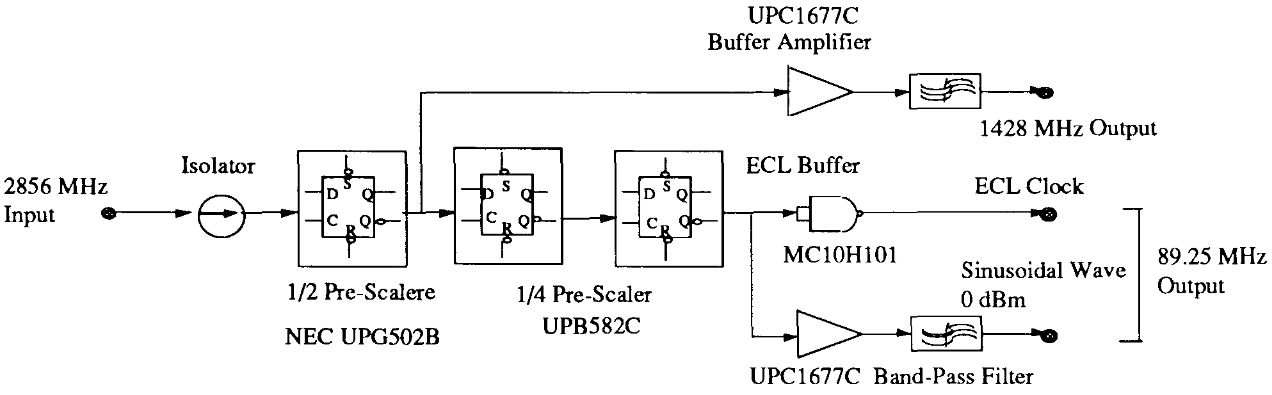

Fig. 2 Block diagram of the frequency divider module for making 89.25 MHz from 2856 MHz

The RF phase and the amplitude of the pulse are controlled by the phase shifter using varactor diodes and the amplitude modulator using double-balanced mixers. The pulsed RF is then amplified by a 600-W solid-state amplifier for driving the klystron.

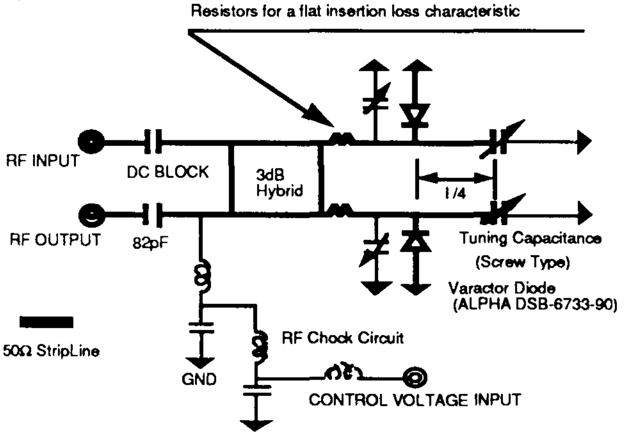

Fig. 3 Circuit diagram of the voltage-controlled phase shifter

2-1, Frequency divider modules[3]

The following two frequency divider modules have been fabricated for the low-power RF system.

(1) A frequency divider used to produce 89.25 MHz for the laser: It uses GaAs(Gallium Arsenic) high-speed pre-scaler devices which are compatible to an ECL circuit. The module comprises a 1/2 pre-scaler device (NEC, UPG502B) at a 1st stage for dividing 2856 MHz, two 1/4 pre-scaler devices at the following stages for making 89.25 MHz and microwave passive devices like a band-pass filter which converts a square waveform to a sinusoidal waveform. A block diagram of the frequency divider is shown in Fig. 2.

(2) A 1/4 divider module to produce 375 MHz: It produces 375 MHz from the output at the 1st stage of the above-mentioned divider in order to make an accurate timing clock of 357 MHz with TD-2 modules.

In the circuit design for the above-mentioned dividers, microwave stripline technology was employed in order to adjust the impedance to 50 ohm; the thickness and material of the dielectric part of the circuit board are carefully chosen. Also, the stripline width in the circuit board using Duroid (Rogers Corp., $\varepsilon_r = 6$, thickness = 0.3 mm) was adjusted to 50 ohm system in order to prevent signal reflection.

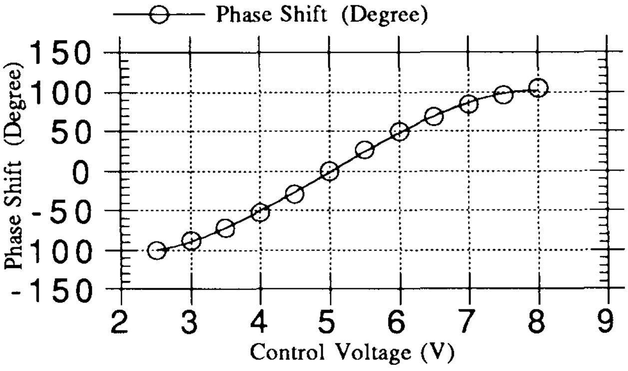

Fig. 4 Phase shift of the voltage-controlled phase shifter, phase shift vs control voltage

2-2, Voltage-controlled phase shifter[4]

The voltage-controlled phase shifter was designed based on a method developed at SLAC, which is basically one port circuit (Fig. 3). It comprises a rectangular 3 dB hybrid, two one-port phase shifter circuits with varactor diodes, tuning capacitances and a bias voltage circuit. The phase shifter controlled by the bias voltage has the necessary characteristics to be a phase variation according to a tangent function and a pulse response of 10 ns. Fig. 4 shows the phase shift as a function of the control voltage. If we look at the central part of the tangent function in Fig. 4, it is almost a quasi-linear characteristic, which is important for a control device.

3, Measurements of the synchronization and long-term phase stability.

3-1, Synchronization

Measurements of the phase jitter are performed at two points (A and B) with respect to a common point, as indicated in Fig. 1. For measurements, a 50 GHz digital sampling oscilloscope (HP-54124T) triggered by 89.25 MHz at the common point was used; a PIN photodiode with a rise time of 65 ps was used to receive the laser light. As the results of measurements shows in Fig. 5, the synchronization values at points A and B are about 8 ps and 50 - 100 ps, respectively. The large phase jitter at point B was caused by mechanical vibration of the AO-modulator and the laser rod in the oscillator due to cooling water. The low-power RF system, itself, has worked quit well.

3-2, Long-term stability

The long-term phase stability between the synthesizer and a monitor signal of the klystron output through a 40 dB directional coupler was measured using the RF-phase detector[5] for pulsed operation and the oscilloscope. For about 8 hours we could not observe any significant phase change between them on the oscilloscope display.

It has been confirmed that the phase drift is proportional to the room temperature, (± 1 degree per 1 °C) by individual tests for the devices.

After the tests the performance of the low-power RF devices was tuned so as be sufficiently stable for the present experiment. The first experiment concerning the beam acceleration of the RF-gun using the above-mentioned devices was successfully made. Fig. 6 shows the waveform of the extracted beam synchronized with RF fields.

4, Conclusion

The low-power RF system for the RF-gun has worked well. Synchronization and the long-term phase drift are sufficiently small for the present experiments. Furthermore, the pulse responses of the low-power devices are to be a couple of ten ns; this value allows great possibility to obtain a successful result for the fast-feedback system, which will be soon tested.

There was a noise problem from the high-voltage pulser of the klystron during the early stage of the experiment. To prevent any effects of noise, the location and installation method of the low-power devices to the high-voltage pulser were rearranged.

In the future, however, better synchronization and phase stability will be required for practical use at the JLC. We should therefore develop a more accurate synchronization method and stabler phase-control method. A large phase-jitter of 50 - 100 ps caused at the laser oscillator can be overcome by improving the cooling-water system, which is now under way. Furthermore, we must also reduce the variation in the environmental temperature around the low-power RF system.

Acknowledgment

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Reference

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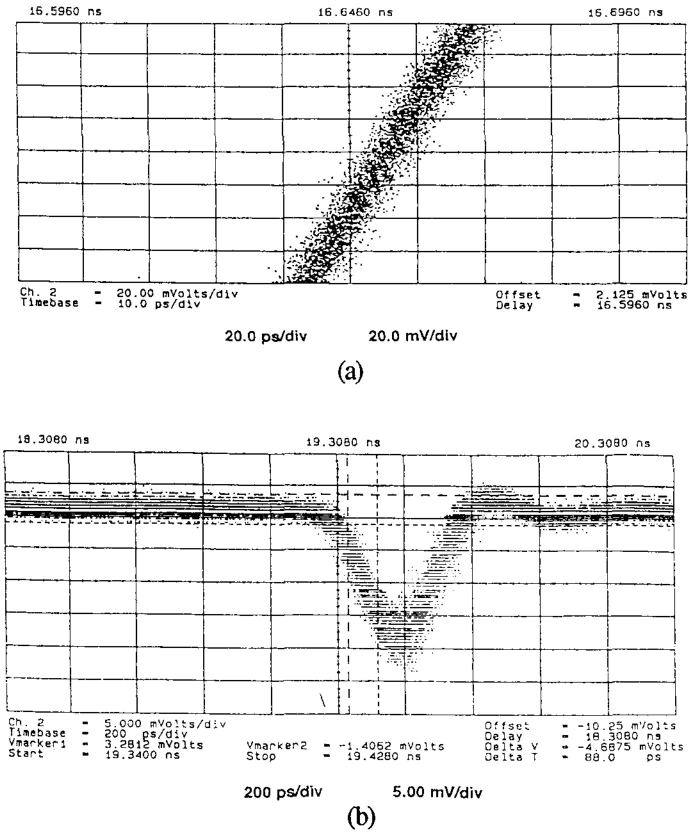

(a)

(b)

Fig. 5 The results of synchronization between (a) point A and common and (b) point B and common

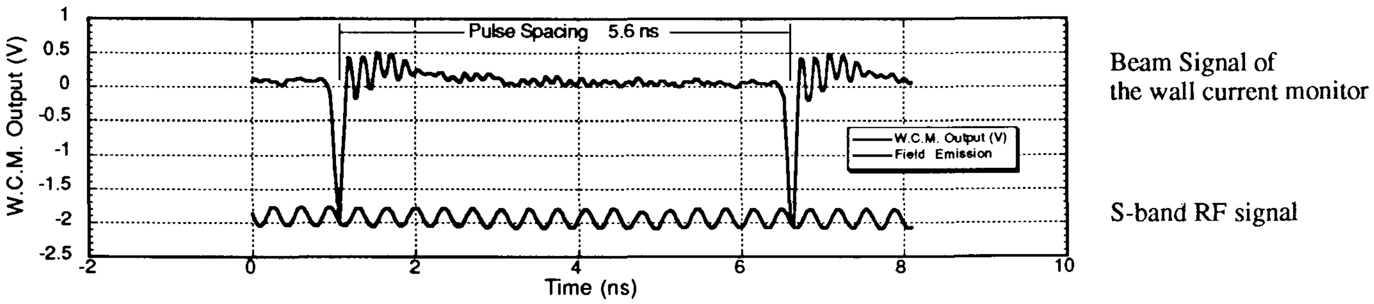

Fig. 6 Extracted beam of the RF-gun with reference S-band RF signal