DEVELOPMENT OF A PRECISE TIMING SYSTEM FOR THE ISIR L-BAND LINAC AT OSAKA UNIVERSITY

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Abstract

We are developing a free electron laser (FEL) in the infrared region and also conducting Self-Amplified Spontaneous Emission (SASE) experiment in the same wavelength region using the L-band linear accelerator at the Institute of Scientific and Industrial Research (ISIR), Osaka University. In order to conduct such studies, a stable operation of the linac is critical, so that we have developed a highly precise and flexible timing system for a stable generation of the high intensity electron beam with the energy region of 10-30 MeV. In the timing system, a rubidium atomic clock producing 10 MHz rf signal is used as a time base for a synthesizer which is used as the master oscillator for generating the acceleration frequency of 1.3 GHz. The 1.3 GHz rf signal from the master oscillator is directly counted down to produce the clock signal of the timing system at 27 MHz and the four rf signals for the linac and laser used in the beam experiments. The start signal for the linac is precisely synchronized with the 27 MHz clock signal. To make an arbitrary delayed timing signal, a standard digital delay generator is used to make a gate signal for a GaAs rf switch, which slices out one of the 27 MHz clock pulses to generate the delayed timing signal. Any timing signal can be made at an interval of 37 ns and the timing jitter of the delayed signal is less than 2 ps (rms). We will report the new timing system and its performance in detail.

INTRODUCTION

The L-band electron linear accelerator is used for studies on nanotechnology and beam science as well as for basic studies in the related fields at the Radiation Laboratory of the Institute of Scientific and Industrial Research (ISIR), Osaka University. The L-band linac can produce electron beams of different time structures, like a single-bunch, multi-bunch with 9.1 ns spacing and so on, corresponding to various beam experiments. The high intensity single-bunch beam is the most characteristic beam of this L-band linac and it is very useful for radiation chemistry studies by means of pulse radiolysis

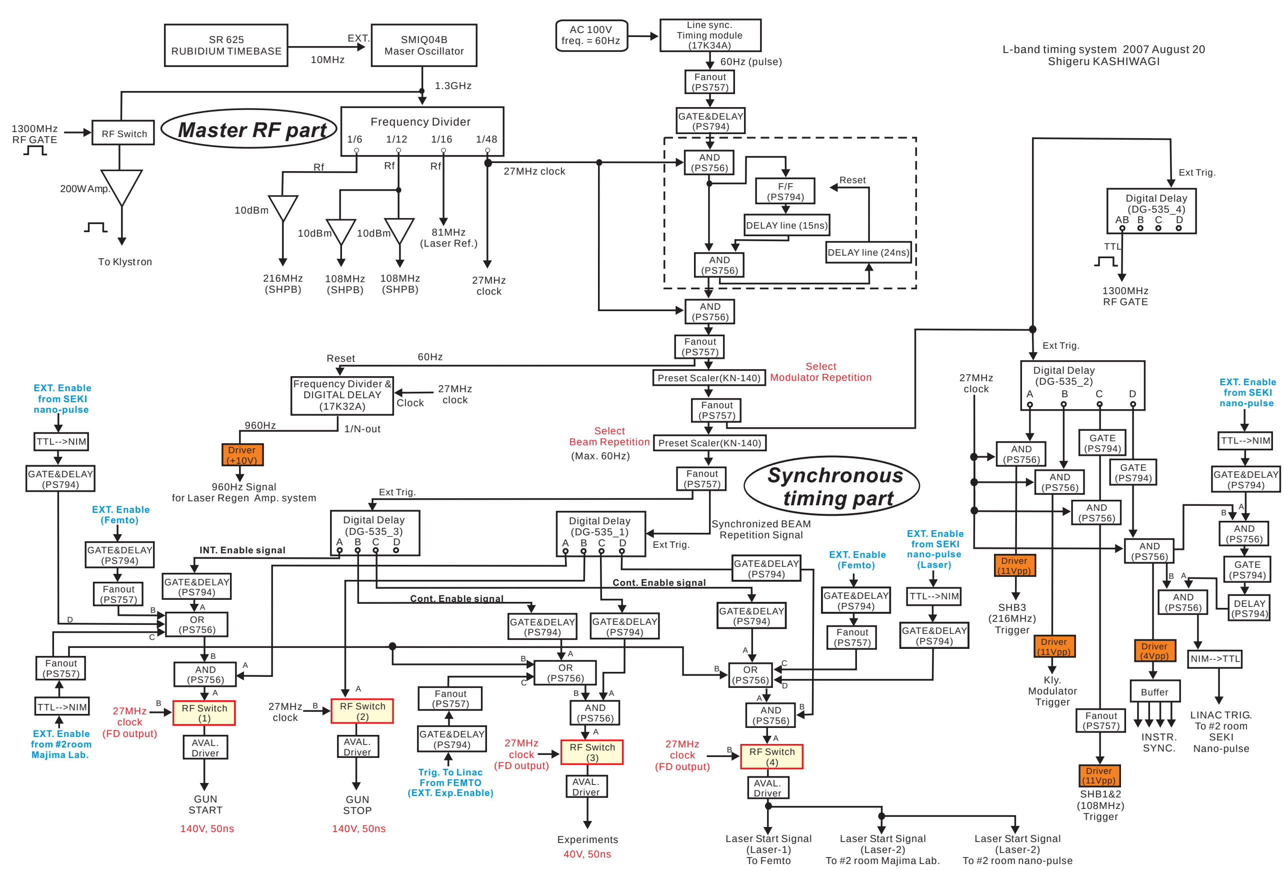

Fig. 1: Block diagram of the new timing system for the L-band linac at ISIR, Osaka University.

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in the time range down to sub-picoseconds [1,2] and basic study of SASE in the far-infrared region [3,4].

The timing system of the linac plays a very important role in generating a high quality and stable electron beam. The timing jitter between a trigger signal for the electron gun and a reference rf signal of accelerator system directly affects the stability of the electron beam in terms of intensity and energy. Experiments using the L-band linac require synchronized trigger pulse for their data acquisition, and rf signals for laser oscillator. In order to enhance the stability of the linac, we have developed a new highly precise and flexible timing system for the L-band linac at ISIR, Osaka University.

CONFIGURATION OF L-BAND LINAC AND LASER SYSTEM

The fundamental accelerating frequency of the L-band linac at ISIR is 1.3 GHz. The linac has been optimized for generating the high-intensity single-bunch beam. The L-band linac is consisted of a high-current triode electron gun, three stage sub-harmonic bunchers (two operate at 108 MHz, which is a 12th subharmonic of the fundamental frequency and one at 216 MHz, a 6th of 1.3GHz), two fundamental traversing wave bunchers and 3m-long main accelerating structure. The SHB system is used mainly for single-bunch operation. The timing system is required to generate three rf signals for these rf components.

Two grid pulser circuits of the electron gun are used for generating single-bunch and multi-bunch beam. The trigger pulse for the gun grid has to be synchronized with 1.3 GHz rf signals precisely. In single-bunch operation, one trigger pulse for the gun grid with 120V height and 50ns duration is distributed from the timing system at the control room. In multi-bunch operation, two triggers for a start and a stop of pulse are necessary to decide the pulse length of multi-bunch beam in the grid pulser circuit. The trigger pulse for single-bunch and the start trigger of multi-bunch generation are common, and the input trigger pulse for the trigger circuit of the gun is switched by operation mode of the linac.

The laser system for a sub-picosecond pulse radiolysis experiment consists of a CW green laser, a femtosecond Ti:sapphire laser operated at 81 MHz, Nd: YLF laser with a regenerative amplifier operated at 960 Hz, an optical parametric amplifier (OPA) and a pulse generator. Thus, the laser system requires the 81 MHz rf signal and thre960 Hz and 60Hz trigger pulses to the timing system of the linac [1].

Table 1: RF signals and triggers for the L-band linac

RF signal	
1300 MHz	Main accelerating frequency
216 MHz	6th subharmonic buncher
108 MHz	12th subharmonic buncher
81MHz	Laser system (seed resonator)
Clock signal	
27 MHz	Main clock of accelerator
960 MHz	Laser system (Regen Amp)
Trigger pulse	
	Electron gun trigger (STARt/ STOP)
	Experimental trigger
	Laser trigger
	Others (kly. modulator, SHB amplifiers)

NEW SYNCHRONOUS TIMING SYSTEM

To achieve the stable and precise synchronization between RF signals and trigger pulses for the accelerator system, the timing system has been replaced with a new one completely. The new timing system of the linac comprises of a master rf part and a synchronous timing part. It provides four synchronous rf signals and a 27 MHz clock signal as well as various timing signals for operation of the linac and for the experiments. Figure 1 shows a block diagram of new timing system for the L-band linac.

Master RF part

In new timing system, some necessarily harmonic frequencies for the linac operation are produced by dividing a master frequency of 1.3 GHz, because the phase fluctuation of the dividing frequency is much smaller than the multiplied one [5]. The master RF of 1.3 GHz is generated by a frequency synthesizer (Rohde &

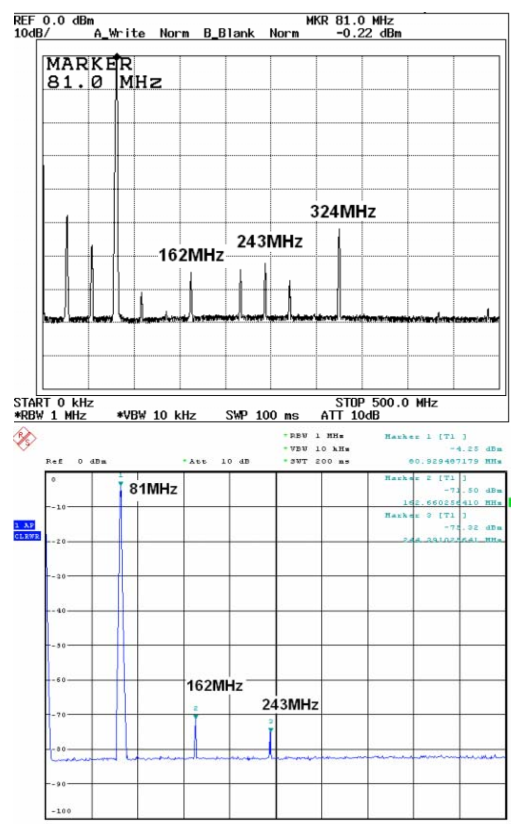

Fig. 2: Frequency spectrum of 81MHz rf signal without band-pass filter (upper) and with crystal narrow-band pass filter (lower).

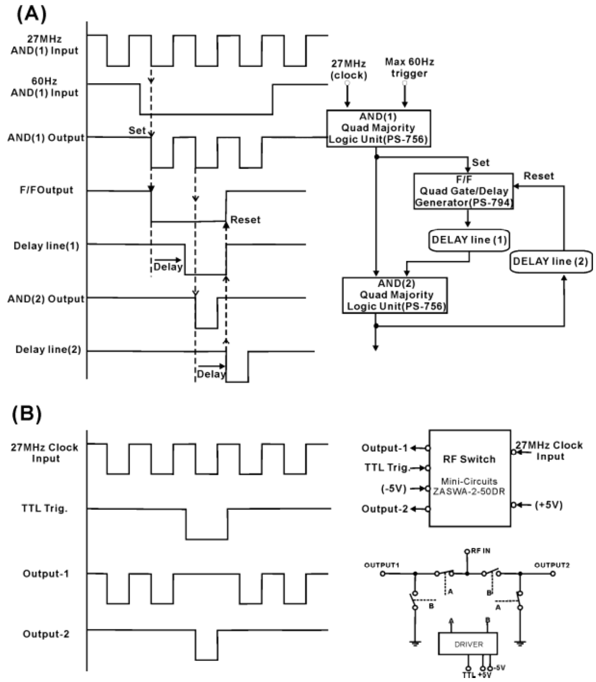

Fig. 3: Timing chart and block diagram of synchronizing system using (A) a logic circuit (Phillips-756) and flip-flop circuit (Phillips-794) and (B) a fast GaAs rf switch.

Schwarz: SMIQ04B) and a rubidium atomic clock producing 10 MHz rf signal is used as an external time base for the frequency synthesizer to realize long term stability. The 1.3 GHz rf signal is directly counted and frequency-divided using a ripple counter circuit to produce rf signals of a 6th and 12th sub-harmonics at 108 MHz and 216 MHz, and a 16th sub-harmonic at 81 MHz together with the NIM-level clock signal of a 48th sub-harmonic signal at 27 MHz. This synchronized 27MHz clock pulses are used as timing step of trigger pulses. The sub-harmonic rf frequencies are amplified to +10dBm level and sent to the SHB main amplifiers and the laser system. The pulse width of 1.3 GHz driving rf pulse for the klystron can be control using a fast rf switch with a synchronized trigger pulse. The width is typically 15 μs in linac operation.

Band-pass filters are introduced at the frequency divider output to suppress the unnecessary higher and lower harmonic frequencies. Figure 2 shows the frequency spectrum of 81 MHz rf signal, which is used as a reference signal for the Ti:Sapphire laser system, without a band-pass filter (upper figure) and with a narrow-band crystal filter (lower figure) at the output of the frequency divider. The generated rf signals are distributed to the laser system or an rf components.

Synchronous timing part

The synchronous timing part was fabricated using commercially available components and devices, such as standard NIM logic modules and digital delay generators, so that it is flexible for future expansion and development. The linac must be operated synchronously with the AC line frequency, which is 60 Hz in the western half of Japan, and the maximum repetition rate of the linac operation is also 60 Hz. In the synchronous timing part, the start signal is produced from the AC line voltage synchronized with the 27 MHz clock signal. Fig. 3(A) shows the timing chart and block diagram of synchronizing system using standard NIM modules and delay lines. The repetition rates of rf pulses and the beam are determined with two preset counter modules, respectively as shown in Fig. 1. The 960 Hz clock for the laser system is generated using synchronous universal counter, which counts the 27 MHz clock pulse and divides the clock frequency by 28212 [6].

To make an arbitrary delayed timing signal, the start signal is sent to standard digital delay generator (Stanford Research Systems: DG535) as the external trigger and it produces preset delayed signals. One of their delayed signals is used for producing a gate signal to slice out one of the 27 MHz clock pulses. Since the gun (start and stop), the experimental and the laser triggers, have to be synchronized with the reference rf signal precisely, we therefore use a fast GaAs RF switch (Mini-Circuits: ZASWA-2-50-DR) to slice out the timing pulses from the 27MHz clock as shown in Fig. 3 (B). The fast RF switch is a passive device, thus the time jitter of the sliced out timing pulse is determined by stability of the 27MHz clock. This is expected the timing jitter to be smaller than a few ps. Any timing signal can be generated at an integer multiple of 37 ns, which is a period of 27 MHz clock. The timing jitter of the delayed pulse does not depend on the delay time by using this delay method. To make other trigger pulses, such as the klystron modulator trigger, the delayed signals are made to be coincident with the 27 MHz clock using a logic module (Phillips-756). The time jitter of the logic module is expected to be about 5 ps.

Avalanche pulser

The avalanche pulser circuit is used to make high voltage pulse with less than a nanosecond rise time at the output part of the timing system. The timing jitter of the arbitrary delayed timing signal for triggering each component is mainly determined by a time jitter of the avalanche pulser. The required avalanche pulser outputs are 140 V for the Gun-start and stop triggers and the 50 V for the Experimental and Laser triggers, respectively. The synchronized timing pulse, which is sliced out by the fast GaAs rf switch, is applied to the avalanche pulser circuit as a trigger. The time jitter of avalanche pulser is strongly dependent on the leading-edge and the voltage of the drive pulse for the avalanche transistor. To get good leading-edge of the drive pulse, a transistor is used as a pre-amplifier with gain 5 (the output voltage: ~3V) and an emitter follower circuit is used for the last pre-amplifying stage of the circuit to provide low output impedance. In this circuit, two transistors are used to provide the drive pulse with good leading-edge for avalanche transistor. The timing jitter of this circuit was smaller than that of the circuit, which uses only one transistor in emitter ground circuit.

TIMING JITTER MEASUREMENT AND RESULT

The timing jitter measurement have been performed for the produced subharmonic RF signals and the synchronous trigger pulses relative to the master reference RF of 1.3 GHz using the Tektronix Communication Analyzer (Tektronix CSA8000B with 80E03 sampling module). In the measurement, the subharmonic RF signals or the timing pulses are used as a trigger of the oscilloscope. Absolute timing jitters of subharmonic frequencies relative to the 1.3 GHz master reference RF are approximately 1.3-2.0 ps (rms) with bandpass filter and the jitter of 27 MHz clock was 0.96 ps (rms). The timing jitter of the arbitrary delay timing signals sliced out by the fast RF switch from the 27 MHz clock pulses were also measured, and they are approximately 1.1-1.6 ps (rms).

A rise-time (10-90%) of amplified trigger pulse was measured using the sampling module with 20 GHz frequency bandwidth. The measured leading-edge of the 50V trigger pulse with -46 dB attenuator is shown in Fig.

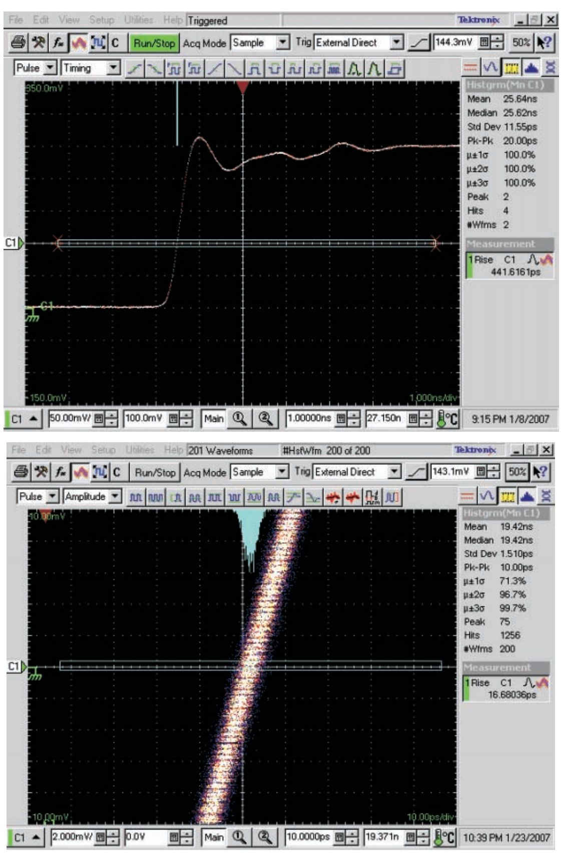

Fig. 4: Measured leading-edge and timing jitter of 50 V trigger pulse. The rise time of one was 0.44 ns and the timing jitter was 1.51 ps (rms) and 10.0 ps (pk-pk) in 1 hour measurement.

4 (upper) and the rise-time of the 140 and 50 V trigger pulses were 1.86 ns and 0.44 ns, respectively. Absolute timing jitter (rms) of the 140 and 50 V trigger pulses relative to the master RF were 2.7 ps (pk-pk = 16.4 ps) and 1.5 ps (pk-pk = 10.0 ps) in 1 hour measurement, respectively.

SUMMARY

The new highly precise and flexible timing system has been developed for the L-band linac and now it is used in real beam operation. Performance of new timing system exceedingly improved than a former one. In the timing jitter measurement, the jitter of the 50 V trigger pulse relative to the master reference RF was 1.5 ps using new synchronizing technique with the fast GaAs rf switch, before installation of new timing system it was about 7 ps. About other signals such as the subharmonic rf signals, their performances were also improved than before. In the present new timing system, the absolute timing jitter of the arbitrary delayed trigger pulse is mainly determined the stability of the 27 MHz clock pulse. To improve the precision of the 27MHz clock, we are planning to use the limiting amplifier for the 27 MHz clock generation.

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