LOW-LEVEL RF SYSTEM FOR THE SUPERKEKB INJECTOR LINAC

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Abstract

The low-level RF system of the KEKB injector linac has been upgraded for the SuperKEKB. To satisfy the operational requirement for the SuperKEKB that is 40-times higher in luminosity compared with the KEKB, the main drive system in the low-level RF system of the KEKB injector linac was reconstructed. With recent technical developments in the solid-state amplifier, the configuration of the sub-booster system is expected to change. An outline of the low-level RF system for the SuperKEKB injector linac is described herein.

INTRODUCTION

After approximately 10 years of operation of the KEKB, the KEKB injector linac has been upgraded for use in the SuperKEKB (Figure 1). To archive 40-times higher luminosity compared with the KEKB, the electron/positron beam intensities and their emittances required for the linac must be upgraded [1]. To satisfy these requirements at the linac, a photo-cathode RF gun is added for the electron injection to the high energy ring (HER), and a damping ring (DR) is introduced for the positron injection to the low energy ring (LER).

The KEKB injector linac is used as a multi-purpose injector not only for the KEKB HER/LER, but also for the photon factory (PF), and the photon factory advanced ring for pulse X-rays (PF-AR). During the KEKB operation period, simultaneous top-up injection into the three storage rings (HER, LER, and PF) was established. In the simultaneous top-up injection, the beam injection parameter of each ring is controlled with an event-based system and switched pulse to pulse at 50-Hz repetition [2].

To satisfy the requirements of the SuperKEKB and synchronize with the event-based system for top-up injection, new RF sources for the photo-cathode RF gun, energy compensation system at the DR, and bunch compensation system for the DR are installed. Furthermore, various developments and changes have been planned and implemented for the low-level RF (LLRF) system compared with that of the KEKB injector linac [3]:

- LLRF control unit and rf monitor system based on digital system [4, 5],
- Main drive system for compatibility between laser oscillation for RF gun and HER/LER beam injection,
- Sub-booster system based on 600-W solid-state amplifiers.

The main drive system and the sub-booster system are described herein.

MAIN DRIVE SYSTEM

The main drive system is equipped with a frequency multiplier/divider and two-frequency (571 MHz and 2856 MHz) phase shifters. The master frequency of the SuperKEKB injector linac is 571.2 MHz. The signal is generated with a signal generator (Keysight; E8663D-HY2), which is synchronized with the SuperKEKB master oscillator via a 10-MHz reference signal.

571-MHz Phase Shifter

For laser oscillation of the RF gun, a supply of clock

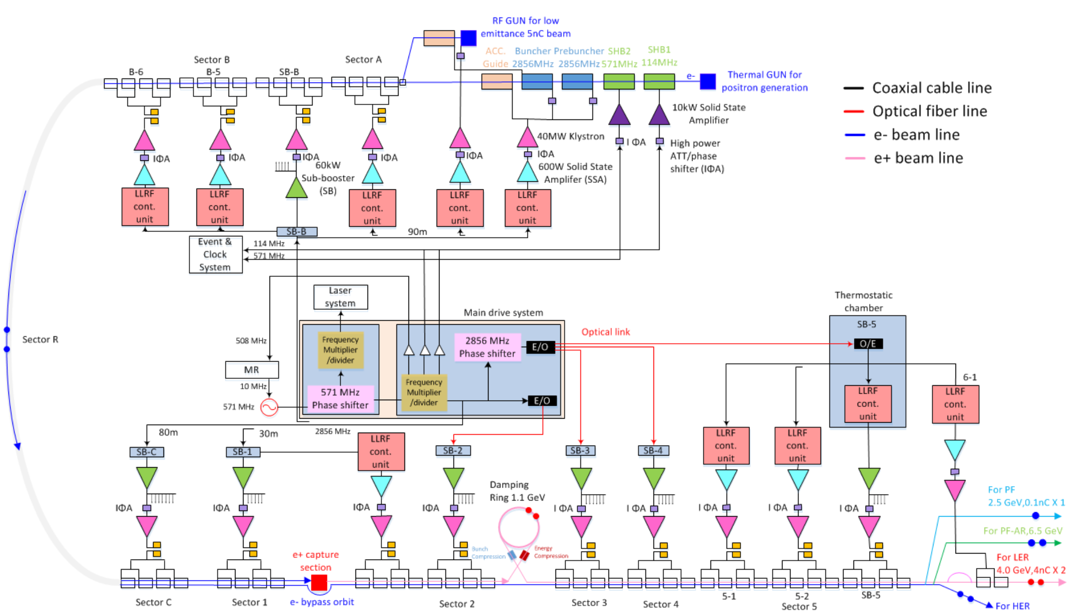

Figure 1: Diagram of the upgraded RF system for the SuperKEKB

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signals of 10.38 MHz, 114 MHz, and 2856 MHz are required from the main drive system. In the KEKB injector linac, the switching of the HER/LER beam mode and the injection phase adjusting was controlled with the phase shifter located in the KEKB ring, as shown in Figure 2(a). However, we found that the laser oscillation could not be maintained by the signal phase modulation caused by the fast (~50 Hz) beam mode switching.

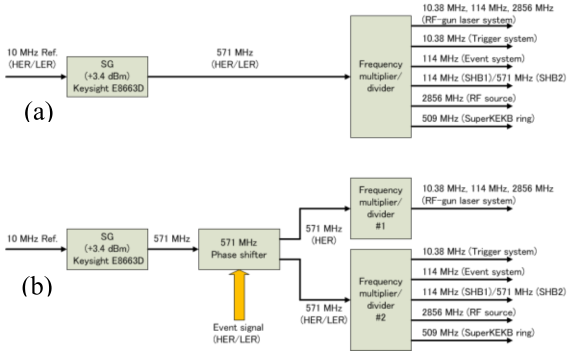

Figure 2: Configuration of the main drive system for the (a) KEKB injector linac, (b) SuperKEKB injector linac

To establish the compatibility between the laser oscillation and the fast beam mode switching, the 571-MHz phase shifter was developed and the main drive system was reconfigured, as shown in Figure 2(b). The 571-MHz phase shifter consists of two I/Q modulators located in series and an event-receiver (EVR), and its phase modulation is controlled with the event-based system. The first I/Q modulator adjusts the HER injection phase with the phase modulation speed (~1 degree/ms) that the laser oscillation is maintained. The second I/Q modulator is used for the injection phase switching between the HER and LER and for adjusting the LER injection phase.

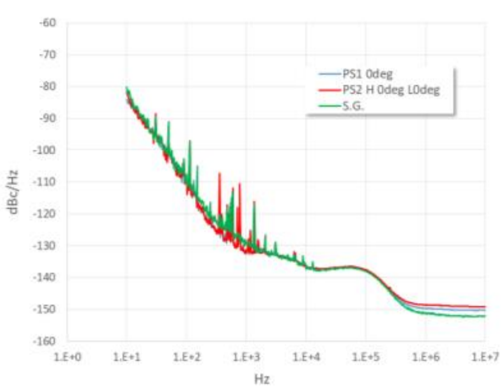

Figure 3: Phase noise distribution of the signal from the first I/Q modulator (blue), the second I/Q modulator (red), and signal generator (green)

The phase noise of output signals from the first and second I/Q modulators are measured. The result show no additive phase noise compared with the phase noise of the signal generator.

2856-MHz Phase Shifter

The positron beam emitted from the DR is accelerated with RF sources located from sector 3 to sector 5, as shown in Fig.1. However, the operating frequency of the DR and the HER/LER (508.9 MHz) is not an integer relation with the operating frequency of the linac (571.2 MHz). Owing to this relation, the positron injection to the LER is limited by a certain condition. To perform the positron injection to the LER effectively, the 2856-MHz phase shifter was installed. This phase shifter was developed based on the LLRF control unit [4] and changes the phase during the positron injection mode. The output signal is converted into an optical signal with an E/O convertor and transmitted to sectors 3, 4, and 5. The demonstration will be performed in the near future.

Frequency Multiplier/Divider

The frequency multiplier/divider generates a 2856-MHz signal for the linac fundamental frequency, 571.2 MHz for SHB2, 114.24 MHz for SHB1, and clock signal for the event-based control system, 10.385 MHz for the beam trigger signal, and 508.8 MHz for the monitor signal to the SuperKEKB ring.

The frequency multiplier/divider was manufactured to have a low noise performance to minimize any RF phase jitter. The block diagram of the frequency multiplier/divider is shown in Figure 4 and the measured phase noise of each frequency is listed in Table 1.

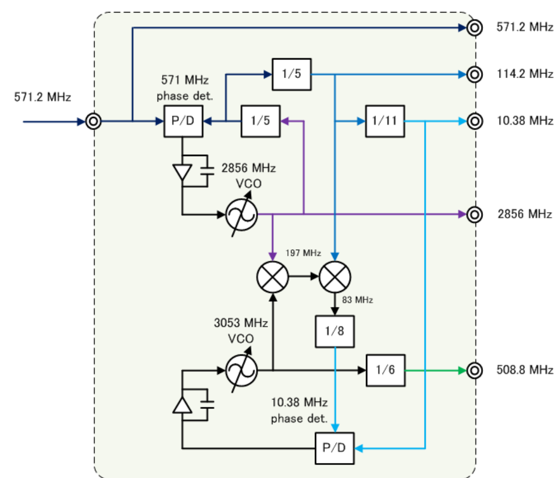

Figure 4: Block diagram of the frequency multiplier/divider

Table 1: Phase noise and jitter integrated from 10 Hz to 1 MHz of the outputs of the frequency multiplier/divider

Signal	Phase noise (jitter)
114.24 MHz	3.2 mdeg. (78 fs)
571.2 MHz	10.4 mdeg. (51 fs)
2856 MHz	54.7 mdeg. (53 fs)
508.8 MHz	10.4 mdeg. (57 fs)

The components of the main drive system are installed into a thermostatic chamber and placed under a temperature control of 28 ± 0.03 °C. The thermostatic chamber is composed of two Peltier devices with an endothermic quantity of 250 W and a heater for precise temperature control [6]. By adopting a Peltier component instead of a compressor, the RF components located inside the thermostatic chamber are not affected by mechanical vibrations and a long operational life can be expected.

The phase drift of the signals (114.24 MHz/571.2 MHz/2856 MHz/508.9 MHz) output from the main drive system is measured with a sampling oscilloscope (Tektronix; TDS8000) and the measured data is recorded to the EPICS archiver. A one-day drift tendency of zero-cross position at each frequency triggered with 10.38 MHz is shown in Figure 5. The jitter, the fluctuation of the zero-cross position, of each frequency is estimated with the data shown in Fig. 5 and is listed in Table 2.

Figure 5: One-day's drift tendency of zero-cross position at each frequencies: 114 MHz (red), 571 MHz (light green), 2856 MHz (blue), and 508 MHz (orange)

Table 2: Jitter estimated one-day's drift tendency of each signals triggered with 10.38 MHz

Signal	**Jitter (estimated)**
114.24 MHz	1.71 ps
571.2 MHz	1.10 ps
2856 MHz	1.75 ps
508.8 MHz	1.15 ps

SUB-BOOSTER SYSTEM

In the KEKB injector linac, eight sub-boosters are available and each sub-booster supplies power to four or eight high-power klystrons, as shown in Figure 5(a). However, for special purposes such as ones in the electron bunching section, positron target and focusing section, and energy spread adjustment, one high-power klystron is directly driven with one 600-W solid-state amplifier. The specification of the 600-W solid-state amplifier is shown in Table 3.

Table 3: Specification of the 600-W solid-state amplifier

Type	Solid-state, AB class
Frequency	2856± 10 MHz
Output power	600 W
Gain	57.8 dB
Pulse width	200 ns – 5 μs
Gain	57.8 dB
Cooling	Water cooling
Power supply	AC 100 V(1 ϕ 50/60Hz), 8.0 A

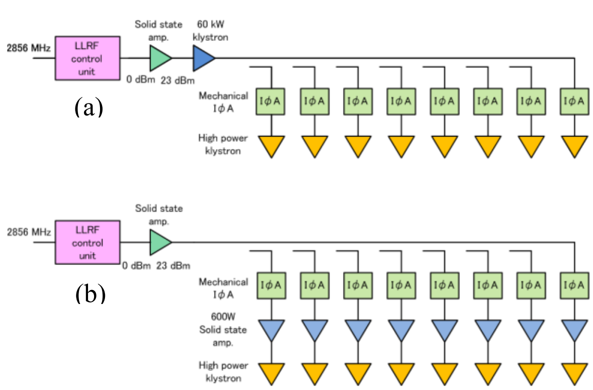

Figure 6: Diagram of the sub-booster system (a) in the KEKB injector linac, (b) planned for the SuperKEKB injector linac

Owing to the recent technological advances and cost reduction in solid-state amplifiers, the cost of one 60-kW klystron and that of eight 600-W solid-state amplifiers necessary for constructing one sub-booster system is balanced. Therefore, 60-kW klystrons are expected to be obsoleted in the future and replaced with new sub-booster systems of 600-W solid-state amplifiers, as shown in Figure 6(b).

SUMMARY

To satisfy the operational requirements for the SuperKEKB and synchronize with the event-based system for top-up injection, the LLRF system of the KEKB injector linac has been upgraded.

Various developments and changes have been planned and implemented for the LLRF system of the linac. The main drive system was reconstructed to operate the RF-gun and the DR. We intend to construct new sub-booster system constructed using only 600-W solid-state amplifiers.

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