SACLA Beam Performance

Introducing 476 MHz solid-state amplifiers

Beam injection from the SACLA linear accelerator into the SPring-8 storage ring was implemented in 2020. In response to increasing demands for higher availability and greater reliability of the SACLA accelerator, new 476 MHz solid-state pulse amplifiers have been introduced.

The 476 MHz booster cavity, located at the most upstream section of SACLA, is highly sensitive to beam performance, as shown in Fig. 1. The radio frequency (RF) source for this cavity must deliver 100 kW of power with 50 μs pulse width, maintaining high pulse-to-pulse stability of $\delta_A/A < 0.05\%$ for amplitude and $\delta_\phi < 0.025$ degrees for phase. Previously, this requirement was fulfilled by an inductive output tube (IOT). However, the operational range of the IOT had diminished due to aging-related degradation, and procurement of replacement parts has become increasingly difficult. Consequently, a transition to solid-state amplifiers has been undertaken. The modular configuration of solid-state amplifiers, utilizing a combiner, enables continuous operation in the event of individual module failure and simplifies repairs. Furthermore, unlike IOTs, their design eliminates the necessity for high voltage, which is expected to improve fault tolerance.

A new solid-state amplifier (SSA) was initially introduced to the SACLA main linac, which provides both hard X-ray free electron laser (XFEL) and beam injection into the SPring-8 storage ring. The standalone performance of this SSA was independently evaluated in 2020. Following this assessment, it was installed at SACLA (Fig. 2(a)) as an addition to the existing IOT, facilitating a smooth transition of SSA into actual beam operation and improving availability by maintaining the other RF source as an active spare. XFEL lasing and its performance were successfully verified using the SSA outputs at the end of 2021. After undergoing minor modifications in 2022 to enhance operational efficiency, the SSA began continuous operation as the main RF source at the beginning of 2023, and has maintained stable operation to date.

Following the successful introduction of the SSA to the SACLA main linac, an additional SSA was introduced to SCSS+ (BL1 linear accelerator), which provides soft-XFEL. This SSA was manufactured in 2023, tested and evaluated in the first half of 2024,

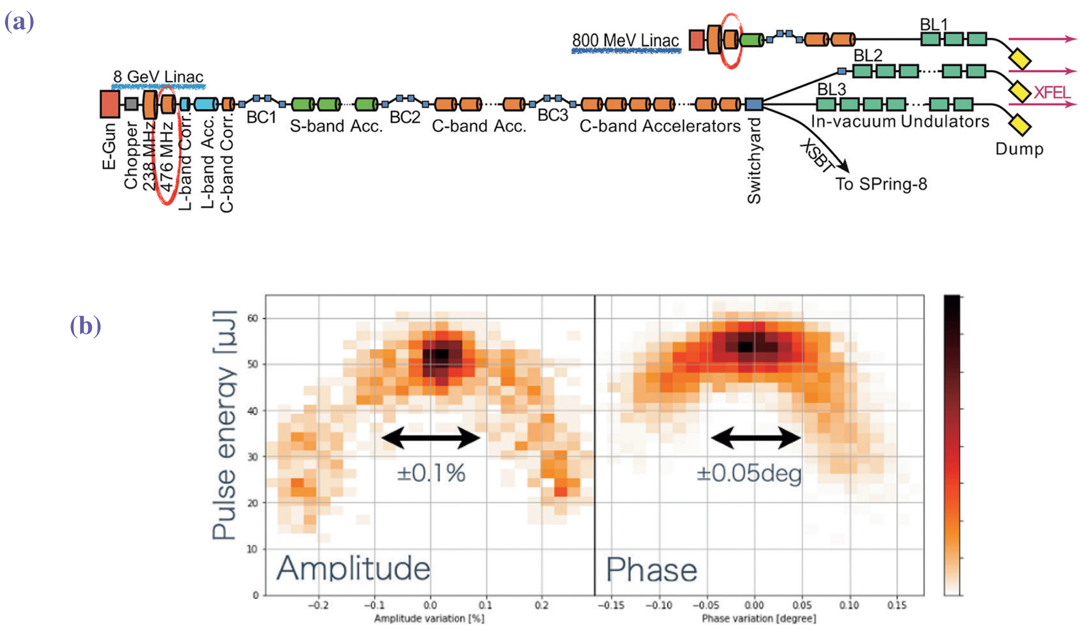

Fig. 1. **(a)** Locations of the 476 MHz booster cavities. **(b)** Dependences of XFEL pulse energy on the 476 MHz amplitude and phase (SCSS+ case as an example).

(a)

(b)


Fig. 2. **(a)** The 476 MHz solid-state amplifiers installed in the SACLA and **(b)** SCSS+.

and then installed in the summer of 2024 to 'replace' the existing IOT (Fig. 2(b)). Continuous operation commenced after the summer shutdown period in 2024, and this SSA has likewise maintained stable operation to date.

As noted, both SSAs have maintained stable operation without any failures since their continuous operation began. The observed pulse-to-pulse stability for the SACLA SSA is $\delta_A/A = 0.007\%$ for amplitude and $\delta_\phi = 0.022$ degrees for phase. For the SCSS+ SSA, the corresponding values are $\delta_A/A = 0.028\%$ for amplitude and $\delta_\phi = 0.022$ degrees for phase as shown in Fig. 3 (these values include intrinsic fluctuations of the RF inputs and the resolution of measuring instruments). The observed stabilities satisfy the requirements of the RF sources used in the 476 MHz booster cavities.

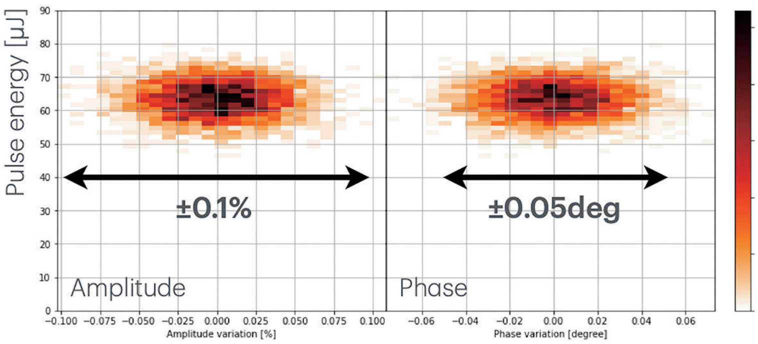

Fig. 3. Measured amplitude and phase stability of the SSA with respect to XFEL pulse energy (SCSS+).

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