RF Reference Phase Control System in the SuperKEKB Injector Linac

TUPB037

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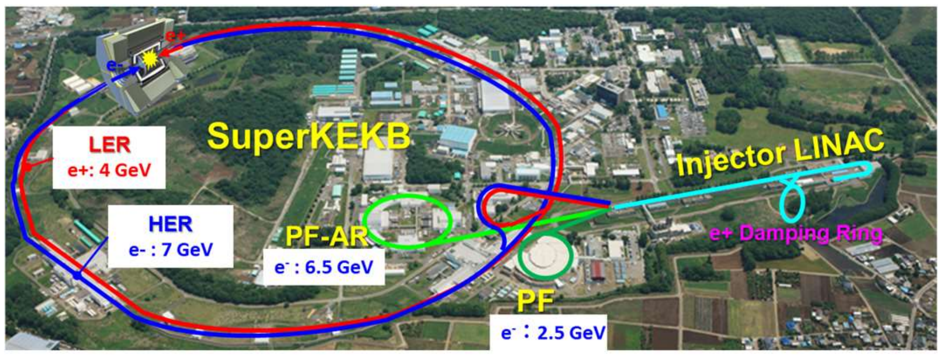
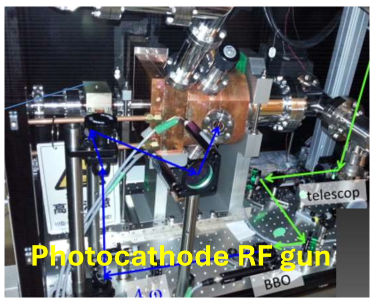
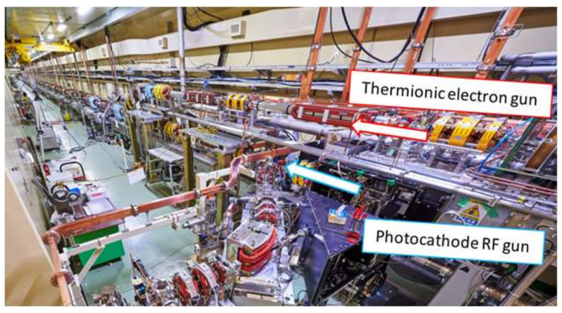
The KEK injector linac delivers **low emittance e-/e+ beams** to the SuperKEKB HER/LER rings.



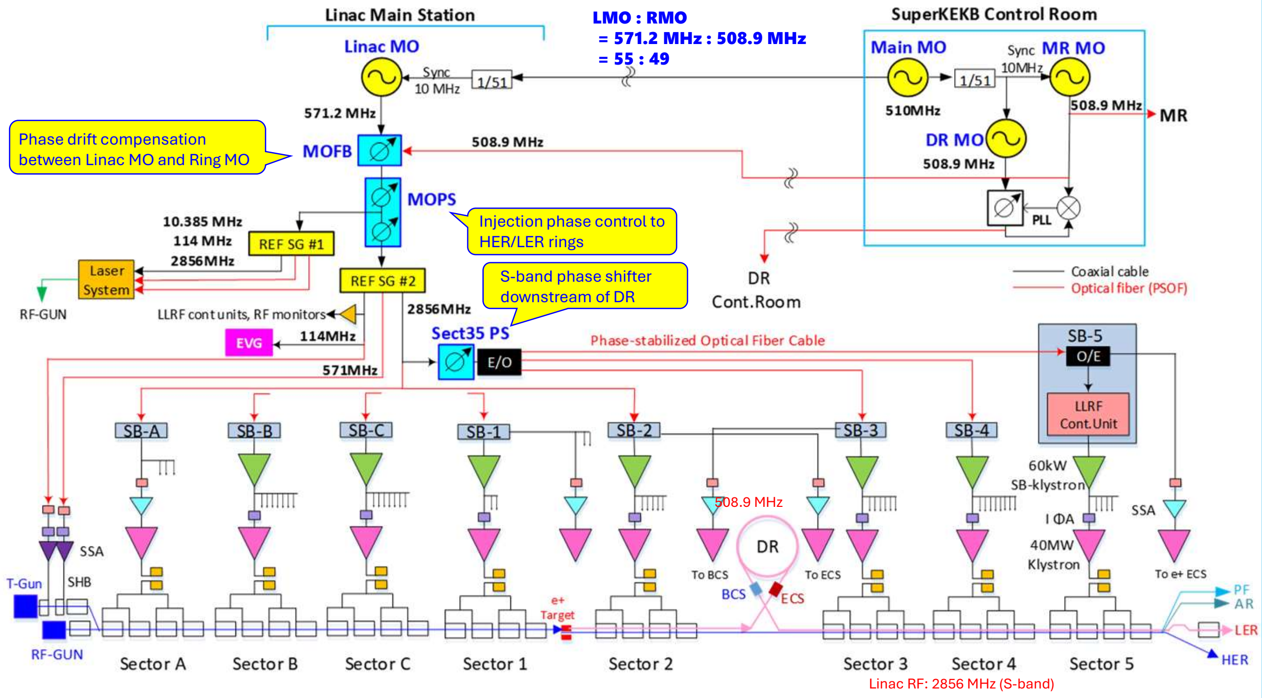




For realizing low emittance beam,
e- beam for HER : Photocathode RF gun with a laser system
e+ beam for LER : Positron damping ring (DR)

RF reference control and distribution system

With the upgrade to SuperKEKB, three new phase controllers, **MOFB**, **MOPS**, and **SECT35PS**, were introduced for the linac RF reference.



MO Phase Feedback (MOFB)

Phase drift compensation between LMO and RMO

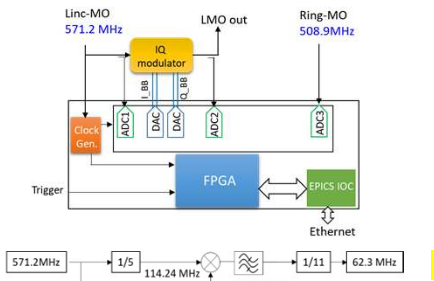
Common Frequency

Linac MO(**LMO**) 571.2 MHz = **55** * 10.3855 MHz
Ring MO (**RMO**) 508.9 MHz = **49** * 10.3855 MHz

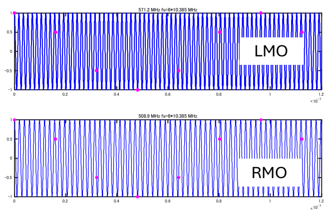
The LMO and RMO are under-sampled by ADCs with 700 MHz band-width and 16-bit.

Sampling Clock: f_s = 10.3855 MHz *6 = 62.3 MHz

$f_{LMO}(571.2\text{ MHz}) = (9 + 1/6)f_s$,
$f_{RMO}(508.9\text{ MHz}) = (8 + 1/6)f_s$.



Both LMO and RMO have one cycle per 6 data samples.



I/Q components are obtained by digital down-conversion (DDC) in FPGA.

$$I = \frac{2}{6}\sum_{i=0}^{5}\cos\left(2\pi\frac{i}{6}\right)\cdot D(i) = \sum_{i=0}^{5} C(i)\cdot D(i)$$
$$Q = -\frac{2}{6}\sum_{i=0}^{5}\sin\left(2\pi\frac{i}{6}\right)\cdot D(i) = \sum_{i=0}^{5} S(i)\cdot D(i)$$
$$\theta = \tan^{-1}\frac{Q}{I}$$

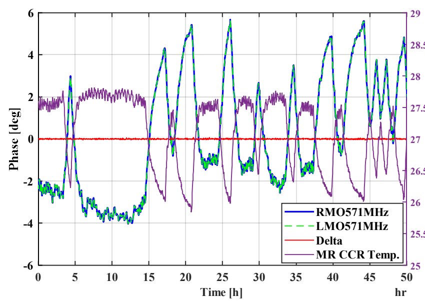
RMO Phase is normalized to LMO frequency.

$$\theta_{RMO571MHz} = \theta_{RMO} * \frac{55}{49}$$

The LMO phase is changed to make $\Delta\theta$ constant by FB control.

$$\Delta\theta = \theta_{RMO571MHz} - \theta_{LMO\_OUT}$$

Result of MOFB

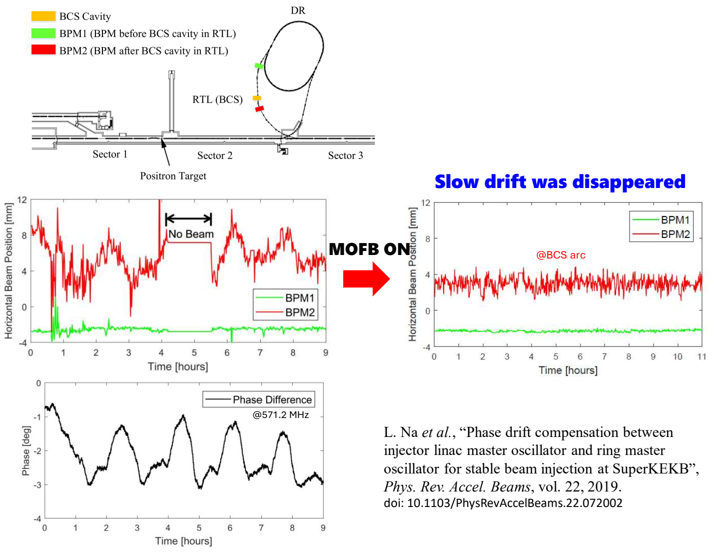


The phase drift of several degrees was observed.

Phase drift of RMO is correlated with room temperature in the MR central control room (CCR)

- **The LMO phase is well controlled to follow to the RMO.**
- **The MOFB continues to work to keep the injection phase stable into the MRs.**

Orbit Drift due to Phase Drift between LMO & RMO



L. Na *et al.*, “Phase drift compensation between injector linac master oscillator and ring master oscillator for stable beam injection at SuperKEKB”, *Phys. Rev. Accel. Beams*, vol. 22, 2019. doi: 10.1103/PhysRevAccelBeams.22.072002

MO Phase Shifter (MOPS)

LMO phase must shift smoothly to the injection phase for the HER or LER rings every 20 ms.
However, laser system does not accept such rapid phase changes.
MOPS has been developed to satisfy the requirements of the laser system and injection phase switching.

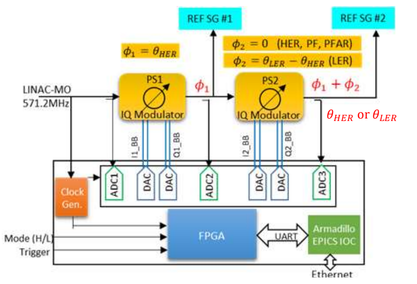
MOPS has two phase shifters, PS1 and PS2, connected in series.

PS1: ϕ_1 is fixed θ_{HER}.
PS2: ϕ_2 is changed pulse to pulse based on the beam injection mode at 50 Hz.

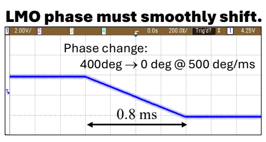
HER: $\phi_1 = \theta_{HER}$, $\phi_2 = 0$,
LER: $\phi_1 = \theta_{HER}$, $\phi_2 = \theta_{LER} - \theta_{HER}$.

Table 1: Specification of Phase Shifter

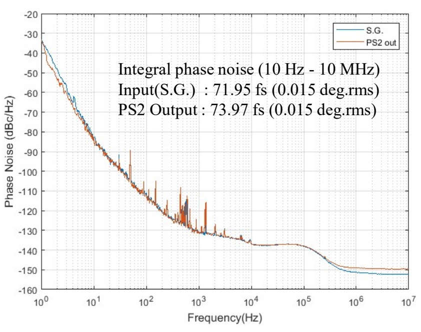
Phase Range	-450.00 deg ~ + 450.00 deg
Resolution	0.01 deg
Speed	1 deg/ms ~ 1000 deg/ms
Linearity	< 0.1 deg
Mode	High: LER / Low: HER



LMO phase must smoothly shift.

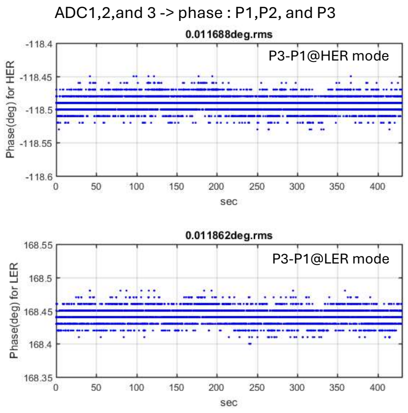


Current settings of phase change speed:
PS1 = 1 deg/ms
PS2 = 100 deg/ms



Single sideband (SSB) phase noise of MO phase shifter input/output signals.

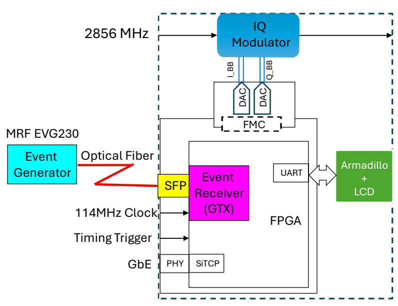
ADC1,2,and 3 -> phase : P1,P2, and P3

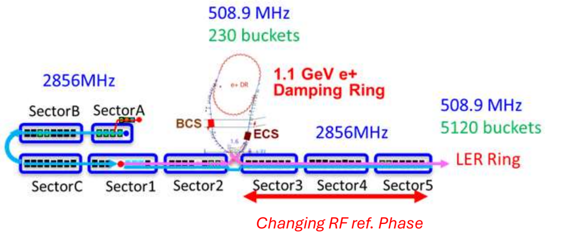


S-band SECT35 Phase Shifter

To increase the synchronization probability among DR, Linac, and LER buckets,
the Linac RF reference phase at the downstream of the DR is changed from pulse to pulse by the bucket selection system.

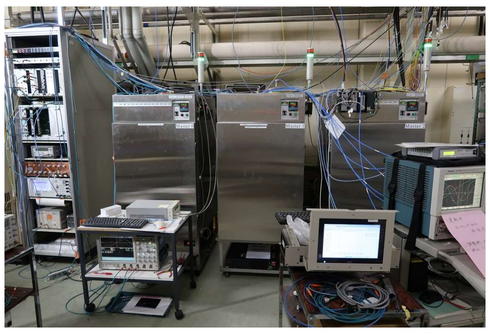
S-band PS for SECT35





Event receiver (EVR) was built into the FPGA in this module to directly receive the set phase sent via optical fiber cable from EVG.

Summary



With the upgrade to SuperKEKB, three new phase controllers, MOFB, MOPS, and SECT35PS, were introduced for the linac RF reference.

They were installed in a thermostatic chamber to prevent the temperature drift.

These phase control systems are working well and realizing stable injection into the main rings.