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# BEAM DIAGNOSTICS STATUS FOR THE KOREA 4GSR PROJECT

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*Abstract*

The Korean 4GSR project is currently under construction in Ochang, South Korea, with the aim of first beam commissioning in 2027. Designed to achieve an emittance approximately 100 times smaller than that of third-generation synchrotron radiation storage rings, the project requires the development of several high-precision beam diagnostic devices. In particular, the beam position monitor is designed to reduce longitudinal wake impedance, thereby suppressing heating and beam instability. The electronics component has also been developed using RFSOC to enable Turn by Turn data acquisition and Bunch by Bunch beam position monitoring. Additionally, a Beam Loss Monitor utilizing 100 Hz operating-rate scintillating optical fibers has been developed, and an enhanced beam profile monitor has also been created. Furthermore, the development progress of a multi-bunch energy measurement beam position monitor system for linear accelerator energy feedback will be introduced. This presentation aims to provide an overview of the current status of beam diagnostic devices developed for the 4GSR project, including details on the overall system configuration.

## DEVELOPMENT OF 4GSR BPM SYSTEM

The 4th-generation storage ring (4GSR) [1] will have a total of 288 beam position monitors (BPMs) installed. Apart from the high beta straight sections, each of the remaining 28 cells will have 10 BPMs. Figure 1 illustrates the positions of BPMs and correctors in a single cell of the 4GSR storage ring. Both the 4GSR storage ring and the booster ring have completed the design of beam position monitors using button-type pickups. Compared to the 3rd generation, the storage ring has a smaller beam size and vacuum chamber size, necessitating an optimized design to minimize the wake impedance budget, particularly for BPMs. To reduce thermal load on the BPM pickups, two different dielectric materials were used.

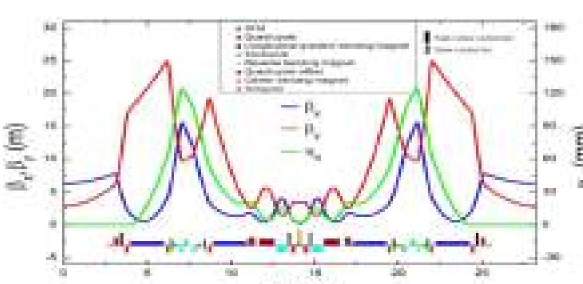


Figure 1: The configuration of BPM for 1cell of 4GSR.

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### *Developments of 4GSR BPM Pick Up Antenna*

The BPM designs utilize two different insulator materials: $SiO_2$ glass and $Al_2O_3$ alumina ceramic.

The first design employs $SiO_2$ glass insulators with a dielectric constant of 4, produced by Kyocera in Japan. This design focuses on minimizing the wake impedance budget by utilizing a low dielectric constant insulator. The high-temperature sealing method of $SiO_2$ glass allows for precise production and uniform manufacturing tolerances. The pickup antenna, made of $SiO_2$ glass with a dielectric constant of 4, is designed using molybdenum with a similar thermal expansion coefficient to the insulator. The antenna housing utilizes KOVAR for its favorable thermal expansion properties. Figure 2 shows a cross-sectional view of the $SiO_2$ & $Al_2O_3$ BPM.

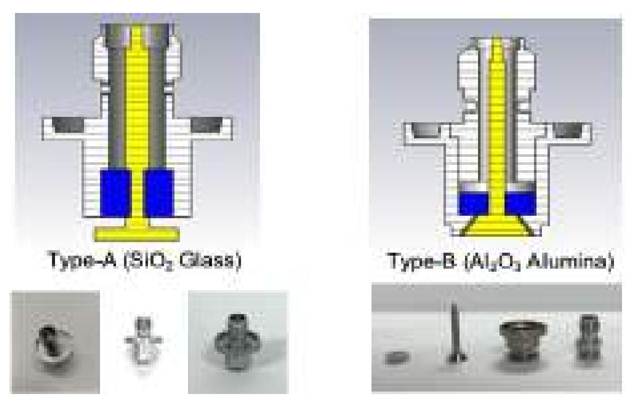


Figure 2: 4GSR BPM pick-up designs. Type-A was used for $SiO_2$ glass insulator (left) and Type-B was used for $Al_2O_3$ alumina ceramic insulator (right).

On the other hand, the second design utilizes traditional $Al_2O_3$ alumina ceramic insulators with a higher dielectric constant of 9-9.9. Prototype production, conducted by the Pohang Accelerator Laboratory, focuses on optimizing the wake impedance budget with a Bell-shape design to compensate for the higher dielectric constant. This design complexity requires precision machining of the ceramic to a thickness of 2 mm and tight manufacturing tolerances. The post-assembly antenna rigidity, crucial for performance, will be validated through various stiffness tests after producing prototypes.

### *Development Status of 4GSR BPM Electronics*

The 4GSR storage ring is equipped with a total of 288 BPMs. Each BPM electronics unit can connect to 4 BPMs, necessitating a total of 72 BPM electronics units for the storage ring. Each cell in the 4GSR storage ring

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contains 10 BPMs. Of these, 8 are used for Fast Orbit Feedback (FOFB) and 2 for Slow Orbit Feedback (SOFB).

The prototype BPM electronics [2] were tested at PLS-II and met the stringent requirements for the 4GSR storage ring. The specifications include turn-by-turn beam position monitoring at 375 kHz with a resolution of 1 µm, fast beam position monitoring at 10 kHz with a resolution of 200 nm, and slow beam position monitoring at 10 Hz with a resolution of 10 nm. Additionally, the system is capable of bunch-by-bunch monitoring, ensuring comprehensive and precise beam position data collection for optimal performance.

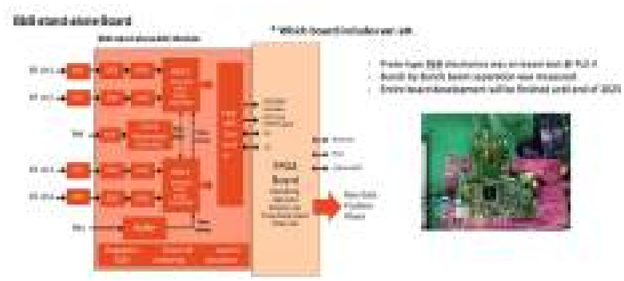

Figure 3: The configuration of 4GSR BPM electronics.

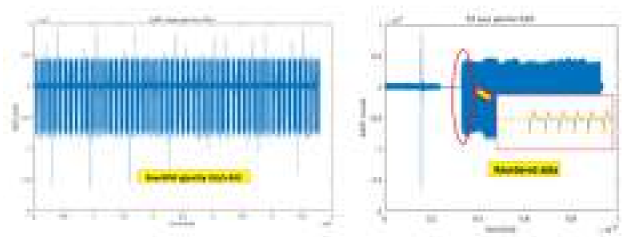

Figure 4: The beam test results of proto-type 4GSR BPM electronics.

Figures 3 and 4 show the circuit configuration of the 4GSR prototype BPM electronics and the results of the bunch-by-bunch (BbB) beam position monitoring tests conducted at the PLS-II storage ring.

## VISIBLE LIGHT SOURCES BEAM DIAGNOSTIC HUTCH

The beam size, emittance, and mechanical vibration measurements are conducted using a visible light interferometer at two locations: VDH-S15, a bending magnet (LGB, 0.7 T) which is almost dispersion-free and located right after the long straight section, and VDH-B16, a bending magnet in the booster synchrotron. Additionally, online bunch length and fill-pattern, as well as longitudinal beam instability, are monitored using a fast photodiode at VDH-S15B, a center bend in the main synchrotron, and VDH-B16, if needed. Beam instability is also analyzed using a streak camera.

Transverse size measurements involve cross measurements of the same physical quantities where the beta function and dispersion function of the electron beam are equal. Additionally, they are utilized to measure vertical and horizontal emittance by separating chromaticity when measuring transverse beam sizes at different locations. The measurement technique involves using a visible light interferometer with a monochromatic light source near 450 nm wavelength. Figure 5 shows the location of visible light beam diagnostics hutch for 4GSR storage ring and booster ring.

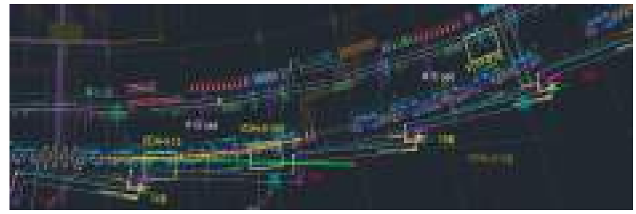

Figure 5: A visible light diagnostics hutch for 4GSR.

## PHOTON BEAM POSITION MONITOR

The development of Diamond Blades for Hard X-ray has been completed and installed in PLS-II since 2020. These blades are capable of scanning the full range of photon beams with low heat deposition. The Read-Out (R/O) module utilized is the Libera-photon current integrator. However, it remains impossible to remove contamination photons generated by the up/down-stream bending magnet, which are in motion due to the SOFB system.

The Gas chamber for Soft X-ray is currently undergoing development, including build-up simulation processes and design optimization. This chamber is designed to have no contamination effect. Additionally, it allows for the measurement of both the center of charge and the profile of the X-ray beam. Figure 6 shows the two types of 4GSR PBPM.

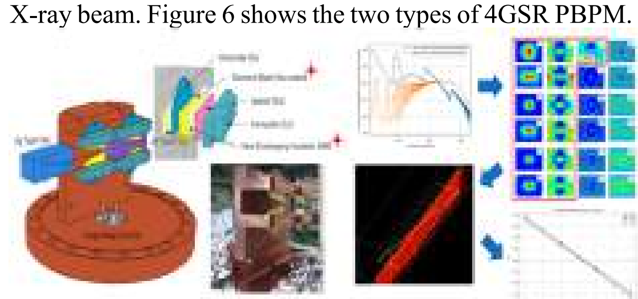

Figure 6: Two different types of 4GSR photon beam position monitor.

## MULTI-BUNCH FEEDBACK SYSTEM

To achieve highly intense photon beams in 4th generation synchrotron radiation facilities, maximizing beam current in the storage ring is crucial. Increasing the bunch charge or stabilizing numerous electron bunches within the storage ring is key to boosting beam current. However, interactions with RF cavities, vacuum chambers, BPMs, etc., can induce wakefields, leading to coupled bunch mode instability (CBMI). CBMI amplifies beam oscillations, limiting maximum beam current. Suppressing CBMI through multi-bunch feedback systems is essential for maximizing storage ring beam current.

For multi-bunch feedback, 4GSR storage ring is considering both in-house development and commercial products for the transverse and longitudinal feedback system (TFS/LFS) digital processor. Beam tests for commercial products for TFS are scheduled to be conducted at PLS-II in 2024. Additionally, the kicker design for TFS and LFS

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has completed its design phase, and preparations are underway for prototype production (see Fig. 7).

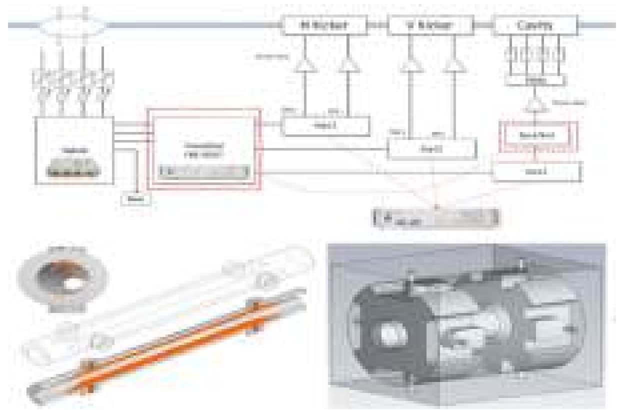


Figure 7: The configuration of TFS/LFS for 4GSR (top). The kicker designs for TFS/LFS (bottom).

## ONLINE BUNCH LENGTH MONITOR

The development of the online bunch length monitor has been completed and it is currently operational in PLS-II [3]. The first upgrade, performed at 2023, was focused on fast processing. This monitor will be used for Korea 4GSR to perform online monitoring of bunch length (BbB), longitudinal instability (in phase), and filling pattern. Figure 8 shows the beam test results of online bunch length monitor.

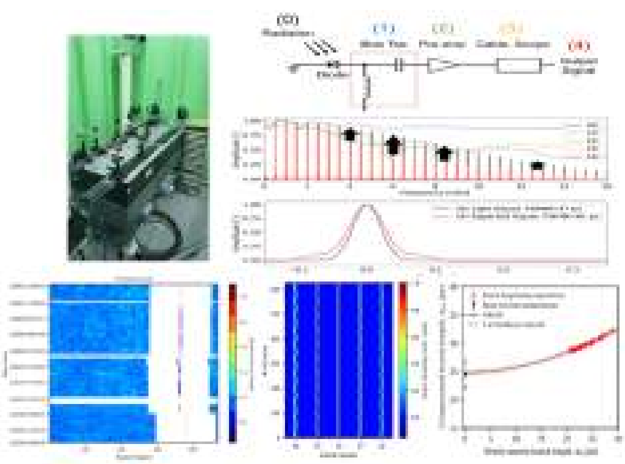

Figure 8: Online bunch length monitor system for 4GSR.

## LINAC BEAM DIAGNOSTICS

The configuration and arrangement of diagnostic devices in the linear accelerator are shown in Figure 9, along with a summary of the required diagnostic beam parameters and measurement methods. In the linear accelerator, seven measurement variables are assessed using five diagnostic devices.

Beam position is measured using 10 BPMs, and beam position and shape are measured using 7 BPRMs. Emittance and Twiss parameters are measured via Q-Scan using BPRM 4/5 and QM3/QM9. The first section uses QM3 and BPRM4 to measure emittance and Twiss parameters immediately after acceleration. Twiss parameter matching for LTB transfer is performed using seven QMs, and the matched Twiss parameters are verified with QM9 and BPRM5.

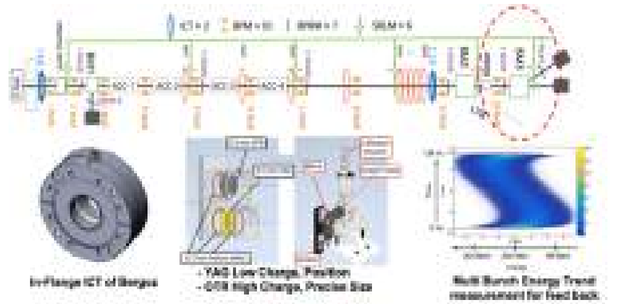


Figure 9: The beam diagnostics for 4GSR LINAC.

## BEAM LOSS MONITOR

In the 4GSR ring, beam loss will primarily be monitored using high-speed beam loss monitors for turn-by-turn beam loss monitoring, with low-speed beam loss monitors used as a supplementary measure [4]. For linear accelerators and beam transport lines with lower beam repetition rates, low-speed loss monitors will be used to measure beam loss. In the 4GSR ring, both high-speed and low-speed beam loss monitors will be employed. Figure 10 shows the development of slow beam loss monitor system for 4GSR.

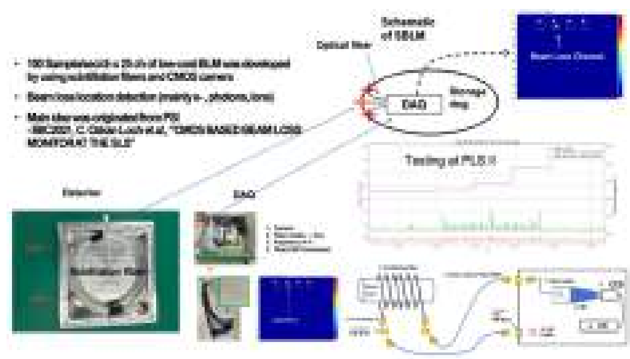


Figure 10: The development of slow beam loss monitor for 4SGR.

## CONCLUSION

The Korea 4GSR project in Ochang is currently under construction, aiming for completion by 2027. The BPM system for 4GSR is in development, and initial beam tests have been conducted using the 1st stage BPM electronics prototype. A beam diagnostics hutch will be installed at the top of the tunnel, utilizing visible light. This hutch will house a streak camera, interferometer, and photo diode. To suppress the BbB beam Instability in the SR, TFS/LFS will be employed. The Linac diagnostic system is also well-prepared. An improved BPRM for multi-bunch energy feedback will be installed at the end of the linac. Additionally, a slow beam loss monitor system has been developed using scintillating fiber with a CMOS camera. It has been successfully tested and operated at a repetition rate of 100 Hz to measure beam loss in the storage ring. Various other beam diagnostics equipment is also well-developed and prepared for the 4GSR beam operation.

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