

# COMPREHENSIVE INTEGRATION AND INNOVATION ON THE 1.5 GHz SRF HARMONIC CAVITY CONTROL SYSTEM AT NSRRC

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## Abstract

This paper presents a self-developed, comprehensive electronic control system for the Superconducting Radio-Frequency passive Harmonic Cavity (SRF HC) at the Taiwan Photon Source (TPS) in Hsinchu, Taiwan. The system integrates the Break Out Box (BOB) interfaces for the cavity, Valve Box (VB), cooling water signals, and interlock systems. Additionally, it includes an intuitive correction module and updates for the discontinued or unmaintainable dial gauge module, ensuring that the system operates safely and transparently with clear status display.

## INTRODUCTION

The TPS is a third-generation 3 GeV synchrotron light source. To meet the increasing demand for high-brightness, the National Synchrotron Radiation Research Center (NSRRC) has deployed various high-performance insertion devices (IDs) [1] to enhance beam brightness and experimental capability. However, although bunch shortening is beneficial for increasing peak brightness, it is often accompanied by an increase in bunch charge density, which intensifies the Touschek scattering effect and consequently reduces beam lifetime. This not only requires more frequent top-up injections, but also increases the power consumption of Radio-Frequency (RF) systems and the thermal load on the magnet systems.

To effectively address these challenges, NSRRC conducted a preliminary technical evaluation and officially launched the TPS 5-year Upgrade Project in 2020 to build up a 1.5 GHz double-cell SRF HC system [2-7]. Upon completion, this system is expected to significantly extend beam lifetime, reduce thermal loading, and improve overall operational efficiency.

The core design is based on the proven KEKB-type SRF HC technology. The niobium (Nb) cavity and the higher-order-mode (HOM) damping structures were fabricated by

Mitsubishi Heavy Industries (MHI) and RI Research Instruments GmbH (RI), whereas the cryostat was independently designed and assembled by NSRRC. Similar SRF HC technologies have already been implemented and validated at international light source facilities such as the Shanghai Synchrotron Radiation Facility (SSRF) [8], demonstrating excellent operational stability.

## ARCHITECTURE AND DESIGN OF THE SRF HC ELECTRONIC CONTROL SYSTEM

Based on experience gained from the installation of three KEKB-type SRF systems, NSRRC has developed an in-house electronic control architecture (Fig. 1) for TPS. The design addresses critical constraints, including limited installation space, power distribution limits, and component obsolescence. The system consists of four main sections: signal integration, control logic, upgrade modules, and infrastructure optimization. Details of each section are given below.

### Signal Interface and Conditioning

To ensure effective signal isolation and transmission under the susceptible on-site conditions of the TPS, the system integrates four Break Out Boxes (BOBs) and hardware-level buffer modules:

### SRF HC BOB

Two BOBs (Fig. 2) [9] dedicated to the SRF HC are housed beneath the support structure. To enhance environmental resilience in this specific location, a dual-layer physical protection scheme was implemented: externally, a 10 mm acrylic cover safeguards against potential cooling-water leaks, while internally, a 3 mm lead plate mitigates the effects of ionizing radiation.

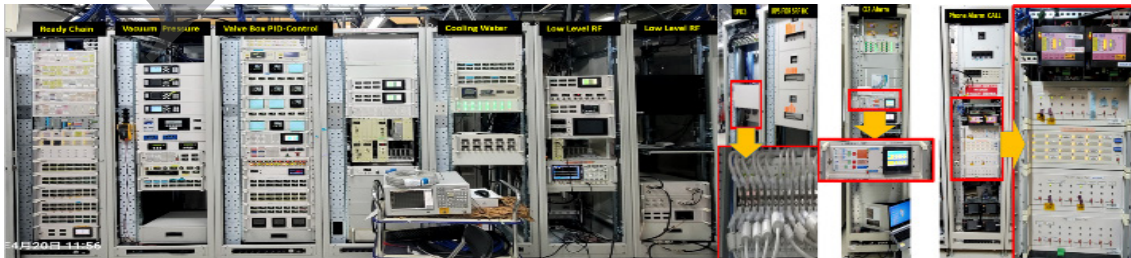


Figure 1: SRF harmonic cavity electronic-control system rack.

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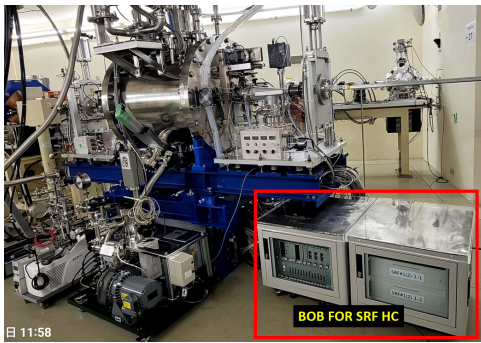


Figure 2: BOB for SRF harmonic cavity.

### VB BOB

This unit integrates signals from the Cryogenic Linear Temperature Sensor (CLTS) and the Pressure Transducer (PT) as shown in Fig. 3. The use of a dedicated BOB simplifies the interface architecture by eliminating redundant HEX-line circuits and consolidating the cabling.

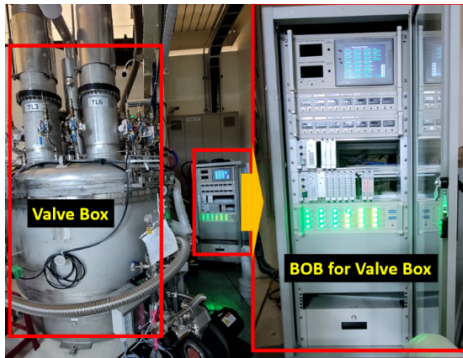


Figure 3: BOB for the Valve Box.

### HOM Cooling BOB

A dedicated interface was established to monitor critical parameters of the HOM cooling water system as shown in Fig. 4, including the chiller module status, flow rate, inlet/outlet water temperatures, and water resistance. This ensures continuous supervision of the cooling process required for the HOM dampers to dissipate the induced heat load at a nominal operating temperature of 25°C.

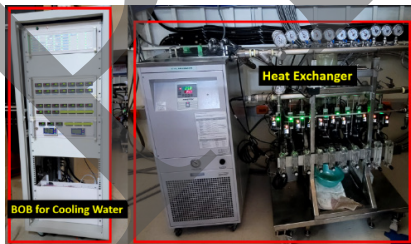


Figure 4: BOB for cooling-water and heat-exchanger.

### Signal Conditioning

Before data processing via the EPICS architecture, buffer modules are introduced to isolate signal sources from the data acquisition system. This hardware-level conditioning improves noise immunity and ensures signal integrity across the extended transmission distances of the site.

### Control Logic and Hierarchical Protection

The system employs a hierarchical control strategy to manage both steady-state regulation and rapid transient protection:

#### Software-Based Regulation

For cryogenic fluid and temperature regulation, the system utilizes Proportional-Integral-Derivative (PID) control to adjust flow rates of liquid helium and nitrogen. In the present system, conventional physical relays were replaced with software logic implemented in a Programmable Logic Controller (PLC). This approach enables real-time linkage between I/O signals and the Human-Machine Interface (HMI), reducing wiring complexity and improving debugging efficiency (Fig. 5).

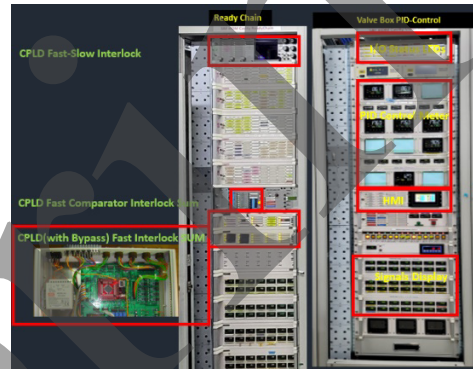


Figure 5: Update for VB Control Rack.

#### Fast and Slow Interlocks

To address events requiring extremely rapid response, such as RF system failures, a hardware protection module based on a Complex Programmable Logic Device (CPLD) was installed in the Ready Chain rack. This allows for microsecond-level fast interlock cut-off, overcoming the scan-cycle limitations of the PLC. Slow interlocks manage vacuum pressure monitoring, telephone alarm calls, and oxygen detection to ensure equipment and personnel safety.

#### SRF HC and Frequency Control

To compensate for beam-loading effects, including Lorentz force detuning and thermal drifts, and to preserve resonant frequency stability, the Low-Level RF (LLRF) system of the SRF HC adopts a dual-mode tuner control scheme. Under transient accelerator operating conditions, such as low-current injection or beam decay below 200 mA, the beam-induced voltage is insufficient for accurate phase measurement. Therefore, the tuner is held in fixed-position control mode to prevent the loop from tracking noise. Closed-loop tuner phase feedback control is enabled only after the beam current exceeds 200 mA and ramps toward the nominal operating current of 500 mA, ensuring a sufficient signal-to-noise ratio (SNR). By preventing erratic tuner movements during low-current transients, this strategy effectively mitigates beam instabilities and reduces system trips caused by artificial cavity frequency drift.

## Instrumentation Upgrades and Component Replacement

To improve maintainability and compatibility with the existing TPS system, several in-house testing kits (Fig. 6) were developed alongside a modernized displacement measurement system.

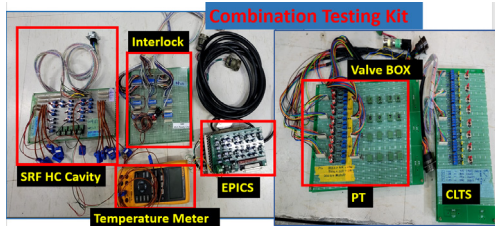


Figure 6: In-house testing kit for machine-status.

The original dial gauge structure, which relied on an obsolete C8051F120 microcontroller and Raspberry Pi 2, faced significant operational risks due to the discontinuation of key components. To ensure system stability under a tight implementation schedule, a commercially available integrated module was adopted as a replacement. In this configuration, displacement data are first read locally via an RS-232 interface and subsequently converted to the RS-485 protocol to ensure stable long-distance transmission to the HMI located 35m away in the control area (Fig. 7). Although this solution remains subject to certain vendor specifications, such as the lack of a remote reset function, it represents a practical and effective strategy for maintaining stable operation.

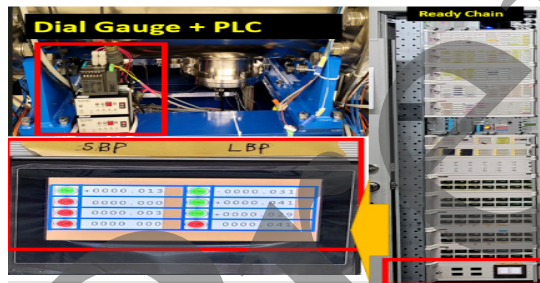


Figure 7: Dial-gauge module.

## Infrastructure Optimization

The system was engineered to adapt to the specific power and spatial constraints of the TPS site. Electrical stability is maintained through a branch connection from the existing 40 kVA uninterruptible power supply (UPS), supported by a dedicated power-distribution cabinet to mitigate the impact of transient mains voltage sag on sensitive electronic modules. To enhance on-site operational safety and maintenance efficiency, cable trays were reconfigured and local lighting was improved. Furthermore, the infrastructure incorporates multiple pressure-relief protection devices and manual valve-switching modules to accommodate abnormal operating scenarios, such as cryogenic system failure or recovery.

## CONCLUSION

The development and integration of the in-house electronic control system for the TPS SRF HC system successfully addressed critical engineering challenges, primarily driven by the need to resolve component obsolescence through system wide upgrades while adhering to site-environment constraints. By implementing a hierarchical control architecture and optimized signal interfacing, the system has significantly improved operational reliability and maintenance efficiency. This work validates NSRRC's capability to execute complex equipment upgrades and iterations, ensuring the long-term sustainability of accelerator operations.

With the completion of hardware installation, the electronic system provided the essential infrastructure and safety interlock required for the SRF HC to transition into the beam-commissioning phase in March 2026. The system was validated through preliminary beam test in hybrid mode with a storage ring current of 500 mA, during which it ensured robust equipment protection and precise environmental monitoring, allowing the cavity to effectively extend the bunch length from 16.6 ps to 30 ps. These results demonstrate that by consolidating signal interfaces and implementing multi-layer protection logic, the custom electronic system establishes a secure and stable operational platform for the SRF HC. Through continued refinement of monitoring parameters and interlock thresholds, the system will continue to play a vital role in sustaining high-performance operations.

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