system is illustrated in **Fig. 4**. The electromagnetic valves are controlled through the digital output of the Galil controller, establishing EPICS server PV control switches. The pressure gauge uses the Modbus/RS485 interface to read the chamber pressure, which is then transmitted to the Galil controller, establishing the EPICS server PV. There is no readily available flow meter for use. Therefore, EPICS support software components for flow meters have been developed to ensure that all devices in the automation system support the EPICS architecture. Users and beamline managers can directly design experimental processes for different operational features without considering new hardware control issues through PVs. This component enables the rapid development of the **TLS 07A1** automation system, achieving the expected results of automated experiments in a short period. (Reported by Chin-Kang Yang)

**Reference**

1. H. S. Wang, W.-Y. Lai, K.-H. Hsu, C.-K. Kuan, C.-W. Hu, S.-A. Chen, B.-Y. Shew, "Design and Implementation of the Automic Control System at TLS 07A1 Endstation," NSRRC Internal Report (2022).

# Operation of a 300-kW TPS Solid-State Power Amplifier

Solid-state radio frequency (RF) technology applied in high-power RF sources is a trending topic in the field of accelerators. This technology involves low-power solid-state power amplifier (SSPA) modules to output a maximum RF power of approximately 1 kW. These modules are then combined to output high RF power, potentially replacing conventional vacuum tube equipment. Solid-state RF technology does not require high-voltage devices; instead, it operates with tens of volts of DC voltage to drive the transistors. Additionally, due to the total power output being composed of multiple stacked modules, such systems have substantial redundancy, enabling them to maintain stable output even in the case of a failure in a few modules, preventing system trips.

Since 2011, the NSRRC has developed solid-state technology in house, progressing from circuit boards of solid-state modules[1] and power combiners to combinations of high-power units[2] and prototype testing in the RF laboratory.[3] Finally, in 2021, a 500-MHz and 300-kW SSPA RF transmitter was successfully constructed at the Taiwan Photon Source (TPS), and long-term operation commenced in August 2023. The development timeline of solid-state technology in the NSRRC is illustrated in **Fig. 1**. This 300-kW solid-state RF transmitter can reliably deliver approximately 250 kW of output power during user operation at the TPS with a beam current of 500 mA. Furthermore, this device produces significantly reduced

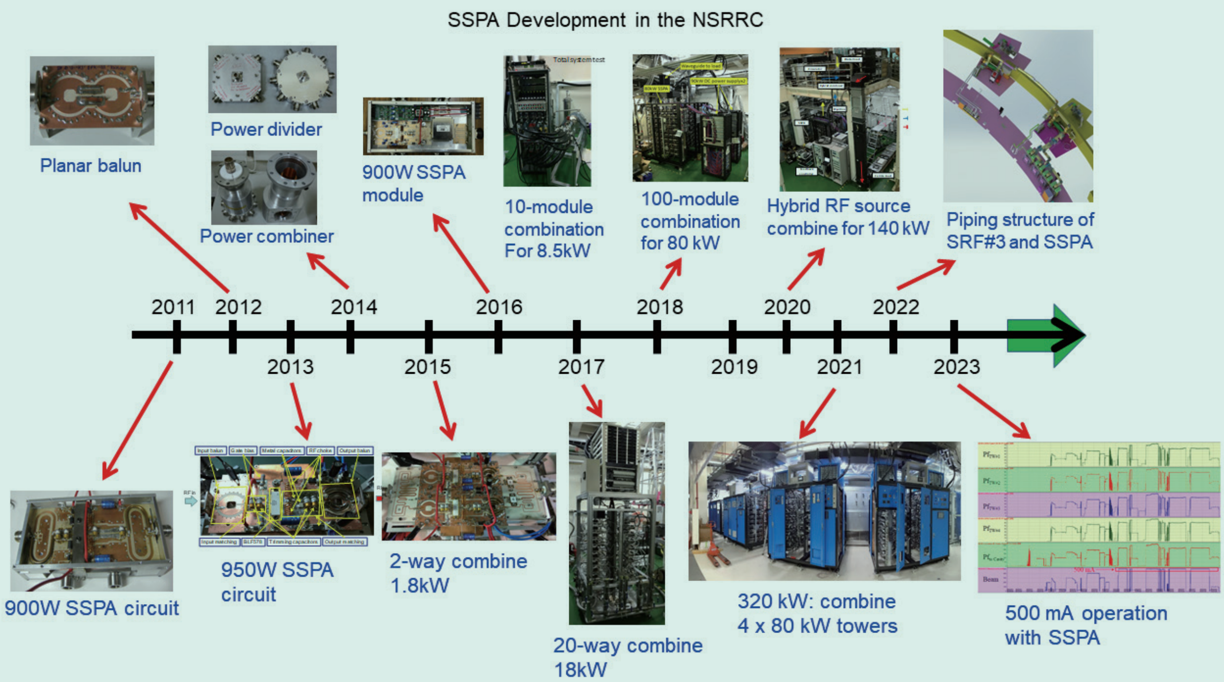


**Fig. 1**: Development timeline of solid-state technology in the NSRRC.

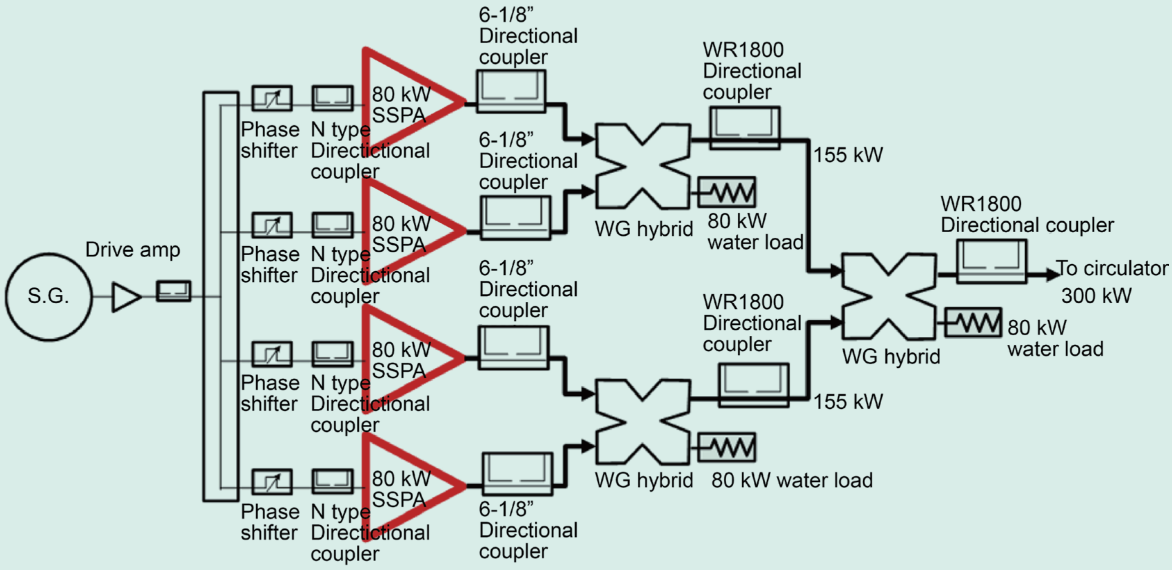


Fig. 2: Architecture of the 300-kW SSPA RF transmitter.

noise levels from high-voltage switching in traditional klystron-type RF transmitters, further minimizing disturbances to the electron beam.

**Figure 2** illustrates the architecture of the 300-kW SSPA. This RF transmitter comprises a total of four 80-kW SSPA towers, achieving the required output of 300 kW through a two-stage power combination. Each 80-kW tower consists of 100 SSPA modules, each capable of delivering a maximum output power of 1 kW. These modules, designed by the NSRRC, include planar balun push-pull power amplification circuits, the RF power chip BLF578XR, a circulator, a strip-line load, and analog circuits for monitoring purposes. In addition to the SSPA modules, each tower includes two 2-way isolated power dividers/combiners, ten 10-way 300-W nonisolated power dividers, ten 10-way 10-kW nonisolated power combiners, one 10-way 80-kW nonisolated final-stage coaxial power combiner, two 96-kW DC power supply racks, and a programmable logic controller with a man machine interface.

This 300-kW SSPA RF transmitter has been in continuous operation at the TPS since August 2023, where it is undergoing regular module checks during shutdown maintenance periods. After approximately five months of operation with an RF power output of approximately 250 kW, a total of nine SSPA modules were damaged. However, there were no RF trip events caused by the SSPA during the user beam time, indicating that the occurrence of a few module failures would not impact the system operation. This finding highlights an enhancement in the reliability of the RF system, as the transmitter operation remains unaffected despite a few module failures.

Each of the four 80-kW SSPA towers undergoes a two-stage power combination at a 1:1 ratio. After ensuring identical phase and power amplitudes between the towers, the overall combining efficiency exceeds 93%. With this 300-kW SSPA RF transmitter, the DC drain voltage of the chips can be adjusted between 42 and 56 V based on the operational conditions, impacting both the maximum output power and efficiency. If the DC voltage is adjusted to 48 V, the 300-kW SSPA RF transmitter can output a maximum of 300 kW to the load. At this output level, the overall AC-to-RF efficiency, including the power combination, is approximately 50%. However, as the output power decreases, the efficiency decreases accordingly. Considering the current operation at an RF output of approximately 250 kW, selecting a drain voltage of 45 V for operation in a single 80-kW SSPA tower yields a DC-to-RF efficiency of approximately 58%. Considering the power combination, the overall AC-to-RF efficiency of the entire 300-kW SSPA RF transmitter reaches 50%, which is slightly better than the power efficiency of the original Klystron-based system at the same output power (approximately 50% for DC to RF). Further enhancements in efficiency can be pursued in the future to achieve energy-saving benefits.

In terms of system stability, the original klystron-based RF transmitter generates high voltage by sequentially switching 86 sets of 800 V DC voltage modules, introducing approximately 7 kHz of high-frequency noise into the RF output power. This noise can affect the stability of the orbit of the electron beam. However, the SSPA RF transmitter, which does not rely on high voltage, avoids this high-frequency noise and thus prevents any impact on the stability of the orbit of the electron beam. **Figure 3** shows the spectra of the electron beam orbit when using the klystron-based RF transmitter and the SSPA RF transmitter. It is evident that when operating with the SSPA RF transmitter, the orbit of the electron beam in the horizontal direction shows no disturbance at a high frequency of

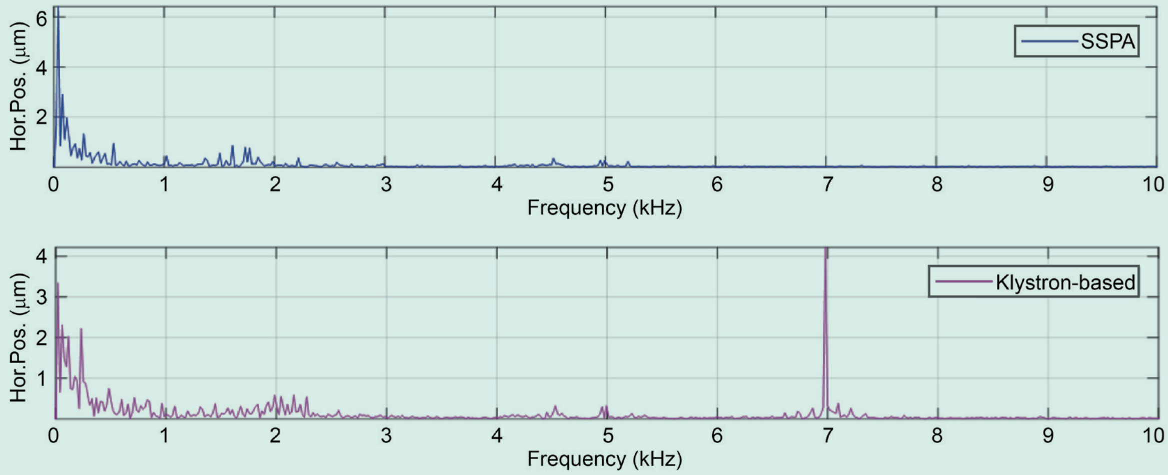


**Fig. 3**: Spectra of the electron beam orbit in the horizontal direction when using the SSPA RF transmitter and the klystron-based RF transmitter. [Figure courtesy of Chih-Hsien Huang]

approximately 7 kHz.

The trend in the accelerator field is the application of SSPAs as high-power RF sources. We have dedicated efforts to solid-state technology development and constructed a 500-MHz and 300-kW SSPA RF transmitter system at the TPS. This SSPA RF transmitter has been employed during routine operations at the TPS, enhancing the RF system power efficiency and stability. This approach effectively reduces disturbances to the electron beam and minimizes trip events. (Reported by Fu-Tsai Chung, Fu-Yu Chang, Shian-Wen Chang and Zong-Kai Liu)

**References**

1. T.-C. Yu, L.-H. Chang, M.-H. Chang, L.-J. Chen, F.-T. Chung, M.-C. Lin, Y.-H. Lin, C.-H. Lo, M.-H. Tsai, C. Wang, T.-T. Yang, M.-S. Yeh, Proc. IPAC'**12**, WEPPD075 (2012).
2. T. C. Yu, Ch. Wang, L. H. Chang, M. S. Yeh, M. C. Lin, C. H. Lo, M. H. Tsai, F. T. Chung, M. H. Chang, L. J. Chen, Z. K. Liu, C. L. Tsai, F.-Y. Chang, Proc. IPAC'**16**, MOP-MY031 (2016).
3. T. C. Yu, Ch. Wang, L. H. Chang, M. S. Yeh, M. C. Lin, C. H. Lo, F. T. Chung, M. H. Chang, L. J. Chen, Z. K. Liu, F.-Y. Chang, S.-W. Chang, Y.-D. Li, Proc. IPAC'**19**, THPTS074 (2019).

# Micro-Focused Single Crystal X-ray Diffraction Beamline at Taiwan Photon Source

**TPS 15A** is a new Taiwan Photon Source synchrotron beamline designed for the analysis of challenging materials and phenomenon thanks to single-crystal X-ray diffraction techniques.[1]

The X-ray source of this beamline comes from a CUT18 cryo-undulator allowing an X-ray energy range of 9 to 35 KeV. A double crystal monochromator allows for the selection of an appropriate wavelength for monochromatic measurements. The undulator can also be used in tapered mode which, combined with a double multilayer monochromator, will allow the generation of an X-ray "pink beam" (poly-chromatic, with bandwidth 3% or 5%). This setting allows for a higher flux, which is particularly useful for ultrafast measurements despite the fact that this requires more complex data analysis.

**TPS 15A** X-ray optics allow investigations of samples structural properties down to just a few microns in size, owing to its X-ray micro-focussing capability, as well as up to very high resolution, due to its high brightness. This allows for fine and detailed analysis of materials atomic scale structures.

**TPS 15A** has two endstations (**15A1** and **15A2**, **Fig. 1**). The first endstation has a beam size at sample position of 150 microns (adjustable by slits) and is equipped with a vertical Eulerian cradle goniometer (four circles goniometer) with a photon