DEVELOPMENT OF MULTI-CHANNEL TIME-DIVISION MULTIPLEXING RF SIGNAL CONDITIONING FRONT-END FOR CAFE2 BPM SYSTEM

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Abstract

The construction of the China Accelerator Facility for Superheavy Elements (CAFe2) is advancing, building upon the foundation of the Chinese ADS Front-end Demo Linac (CAFe). However, the existing BPM read-out elec-tronics from CAFe are insufficient to accommodate the increased number of BPM probes required for CAFe2 and cannot meet the measurement demands for low-intensity heavy ion beams. To address these issues, a high-speed RF switch array was developed, featuring multi-channel multiplexing, tunable gain and filtering, and web-based parameter configuration. This device functions as a front-end for RF signal conditioning, offering microsecond-level channel switching capabilities, and is capable of receiving, filtering, and amplifying multiple beam signals. When integrated with the existing RF front-end and digi-tal signal processing platform, the new BPM read-out electronics system can support simultaneous measurement of 32 signals from 8 BPM probes. Test results indicate that the high-speed RF switch array achieves channel isolation exceeding 60 dB, with phase differences between channels less than 6 ° and amplitude discrepancies under 4%. These results demonstrate excellent amplitude-phase consistency and channel isolation performance, fully meeting the BPM measurement requirements of CAFe2.

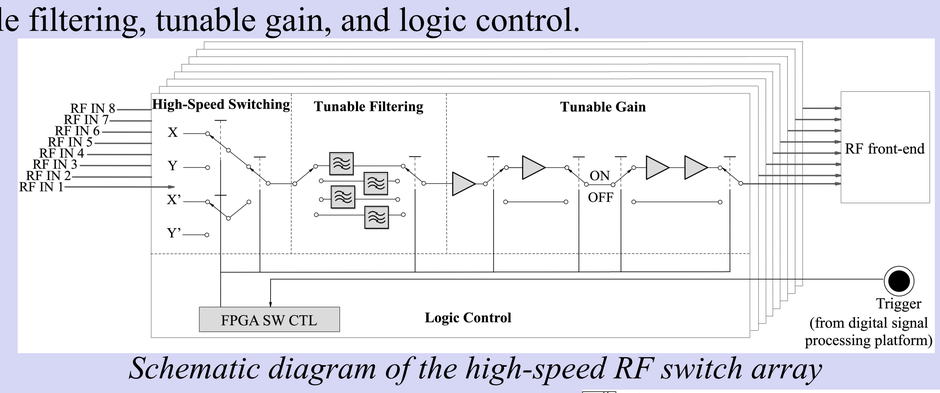
INTRODUCTION

- Since 2021, the CAFe had been upgraded to CAFe2, which is designed to provide an advanced experimental platform for the synthesis of new isotopes.
- According to design specifications, CAFe2 are equipped with 24 BPM probes along the beamline, operating with a beam intensity of less than 0.1 mA.
- This paper proposes a high-speed RF switch array as the RF signal conditioning front-end., enabling the CAFe2 BPM system to achieve multi-channel time-division multiplexing measurements of low intensity ion beams across varying beam currents.
  - In CAFe, each set of read-out electronics can only measure signals from a single BPM probe, with a minimum detection limit of 10 mA for beam currents.
  - Expanding the system with the existing method would result in high costs and complex structures, and cumulative device errors could degradie the overall performance.

Schematic diagram of the CAFe2

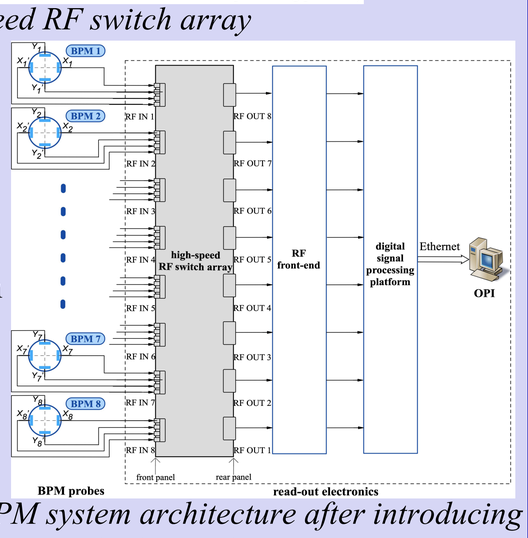
DESIGN SCHEME FOR HIGH-SPEED RF SWITCH ARRAY

- The high-speed RF switch array consists of four modules: high-speed switching, tunable filtering, tunable gain, and logic control.



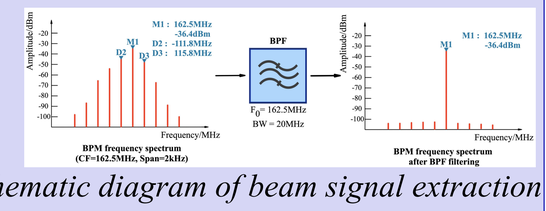
Schematic diagram of the high-speed RF switch array

- High-speed switching module features three dual-channel SPDT switches, enabling eight independently controllable four-channel paths. Leveraging this module, the read-out electronics system equipped with the RF switch array expands to 32 channels, allowing simultaneous measurement from up to eight BPM probes.



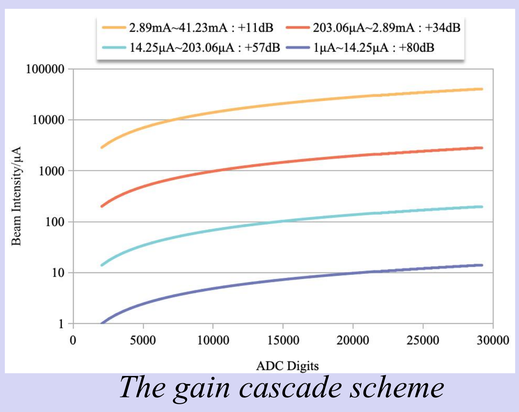
BPM system architecture after introducing the high-speed RF switch array

- Tunable filtering module utilizes a SAW filter to extract beam signals and suppress harmonics. It supports frequency ranges from 81.25 MHz to 650 MHz, allowing the system to adapt to both CAFe2 and CiADS.



Schematic diagram of beam signal extraction

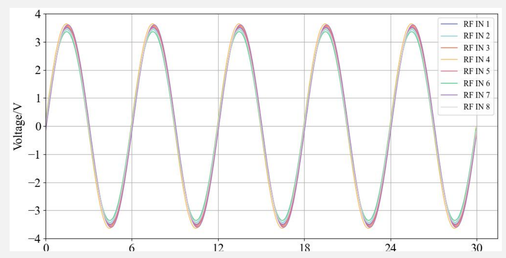
- Tunable gain module, based on cascaded LNAs and SPDT switches. It provides four selectable gain settings—11 dB, 34 dB, 57 dB, and 80 dB. This design accommodates a wide signal input range from 1 μA to 41 mA.



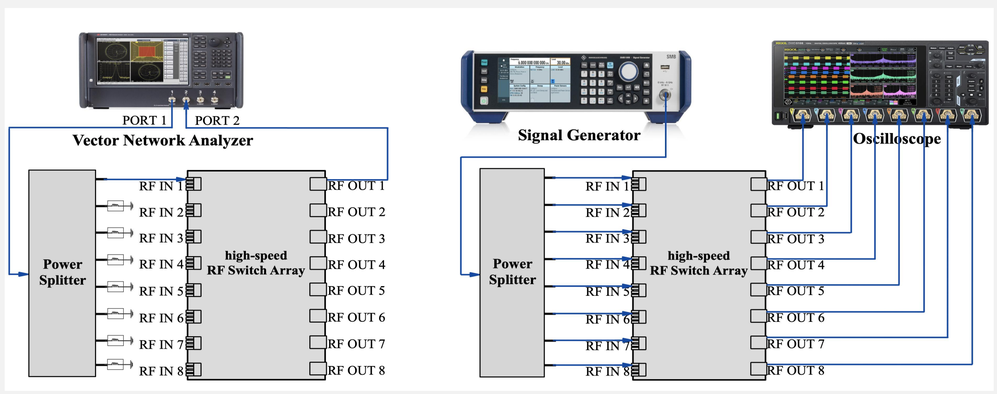
The gain cascade scheme

PERFORMANCE TEST

- Channel isolation test *(LEFT)*
  - The isolation test evaluates signal shielding between channels.
  - The isolation exceeds 60 dB, with greater isolation observed between channels spaced further apart.
- Channel consistency test *(RIGHT)*
  - The consistency test assesses the amplitude and phase alignment across all channels.
  - The phase difference between channels is less than 6 ° , and the amplitude difference is under 4%.



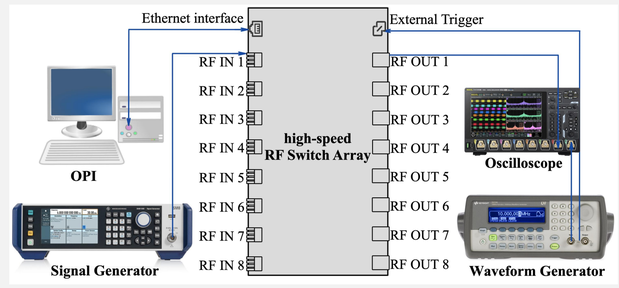
Result of channel consistency test



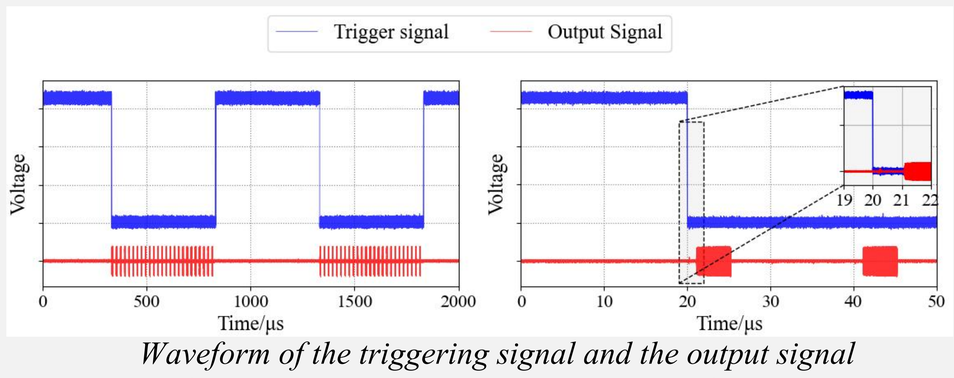
LEFT: Channel isolation test platform *RIGHT: hannel consistency test platform*

FUNCTIONAL VERIFICATION

- An experimental platform was constructed to verify the feasibility of controlling the high-speed RF switch array for high-speed switching using an external trigger signal.
  - The high-speed RF switch array initiating at the trigger's falling edge and cycling during low level *(LEFT)*. The 20 μs switching cycle matches the 5 μs interval , demonstrating the array's microsecond-level switching capability *(RIGHT)*.
  - Internal trigger circuitry introduces a delay after detecting the falling edge, preventing interference from initial signal noise *(enlarged view in RIGHT)*.



Experiment platform for high-speed RF switch array switching function



Waveform of the triggering signal and the output signal
LEFT: Sam-pling Time Span:2000 μs RIGHT: Sampling Time Span:50 μs

CONCLUSION

This study presents the development of a high-speed RF switch array tailored to meet the demands of the CAFe2 BPM system. Compared to traditional read-out systems, the integration of this array significantly improves system integration and multiplexing capabilities. It enables accurate measurement of low-intensity beams across varying beam currents and frequencies. Additionally, the array allows simultaneous input from multiple BPM probe signals, enhancing support for differential BPM measurement schemes and improving the precision of beam position measurements. Overall, the high-speed RF switch array offers an efficient and reliable solution for multi-channel time-division multiplexed BPM measurements.