

# THE DEVELOPMENT OF BUTTON TYPE BPM ELECTRONICS FOR RAON

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## Abstract

RAON is a heavy ion accelerator for the Rare Isotope Science Project in Korea. The main goal of RAON is to accelerate various stable ions from ECR ion source and rare isotopes ions from ISOL beam line. For the stable beam operation, the beam diagnostics equipment is very important. Recently, we developed digital board electronics for the button type beam position monitor (BPM) to measure the position of ion beams. In this presentation, design of electronics, beam signal simulation results, and RF measurement test results with a developed button BPM will be described.

## INTRODUCTION

RAON (Rare isotope Accelerator complex for ON-line experiments) [1] is a key research facility of RISP. The goal of RAON is the achievement of heavy ion beam acceleration up to 200MeV/u by using superconducting linear accelerator. Figure 1 shows the schematic of RAON setup.

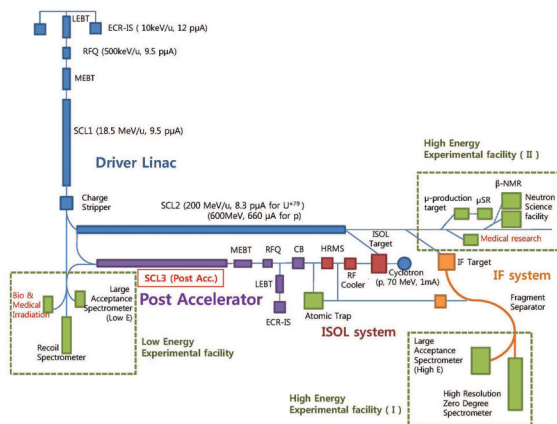


Figure 1: Schematic drawing of RAON setup.

The main purpose of beam position monitor system of RAON is the measurements of stable ion beam position and beam phase for the stable beam operation. A prototype two BPMs are fabricated and successfully tested by using the wire test bench at RISP in 2016. In total, 213 button type BPM pick-ups will be installed at RAON, from which 151 BPMs are distributed along three sections of superconducting linear accelerator.

Currently, two more BPMs are fabricated. These devices will be installed for the SCL(superconducting linear accelerator) Demo run to measure beam positions and RF phases of

accelerated ion beams. The prototype of BPM electronics system was developed in 2016 and the integration test is currently being carried out.

## SYSTEM REQUIREMENTS

The requirement of button BPM electronics system are summarized in Table 1. The requirements of beam position resolution and accuracy for button BPM system are decided by the investigation of beam dynamics error simulation. The investigated requirements of position information are 0.1mm of position resolution and  $\pm 0.4$ mm of position accuracy, which requirement will help to check an irregularities of machine operation. The phase measurement also required to identify optimum accelerating cavity phase by measuring TOF(time of flight), which phase measurement is required  $\pm 2$  degrees and 0.5 degree of phase resolution at 81.25MHz(1st harmonics). Additionally, the button BPM system will be used for the measurement of relative beam intensity.

Table 1: A Requirements of BPM Electronics

Parameters	Value
Position resolution with 100 $\mu$ A	100 $\mu$ m
Position accuracy	$\pm 0.4$ mm
Dynamic range	more than 40dB
Operation mode	1st & 3rd harmonics
Phase resolution	0.5 degrees
Phase accuracy	$\pm 2$ degrees

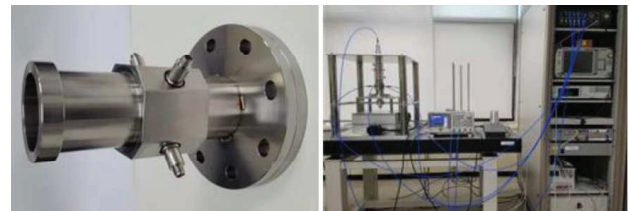


Figure 2: A developed button BPM of RAON and a configuration of test bench.

## BPM Pick-up

The fabricated button BPM has 40mm diameter and four button pick-ups with in horizontal and vertical axes, in which button pick-ups are used to curved type. The RF test of fabricated button BPM was performed at the BPM test bench. Figure 2 shows the developed button type BPM of RAON and the configuration of test bench.

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### SYSTEM ARCHITECTURE

The main purpose of button BPM electronics is the signal processing to calculate the precise beam position and phase information by using 1st and 3rd harmonics RF signals. For this signal processing, the button BPM electronics of RAON consists of analog front-end and digital FPGA parts. The front-end analog part mainly consists of LNA(Low Noise Amplifier), LPF(Low Pass Filter) and RF switcher.

The digital board consists of ADC and FPGA board. The specification of ADC electronics is a 5-channel, 16-bit 2.5Vp-p and providing sampling rates of 105MS/s, which sampling rate was optimized by the analytical calculation. The digital signal processing electronics are used to Virtex 6 FPGA boards. Figure 3 shows the schematic diagram of the developed button BPM electronics.

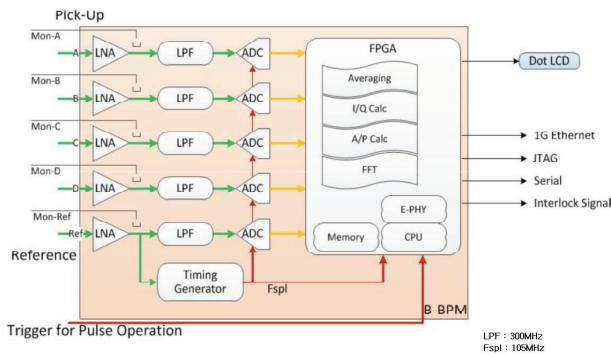


Figure 3: A schematic diagram of button BPM electronics.

### A DIGITAL SIGNAL PROCESSING

The digital signal processing of button BPM electronics is performed a 105MHz signal sampling by ADC, digital filtering, digital signal mixing, DC signal mixing, IQ calculation, beam position and beam phase calculation [2]. Figure 4 shows the digital signal processing flowchart.

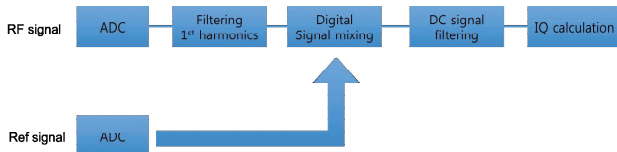


Figure 4: The digital signal processing flowchart for the 1st harmonics signal case.

After the signal sampling, a time step between each sample is 9.52ns and the number of sampled data during 1μs is 105 samples. By using this 105 sample data, we can reconstruct original button BPM pick-up signal. Figure 5 shows the sampled ADC data and a reconstructed pick-up signal by using 105 sample data.

A sampled signal by using ADC still have a several harmonic frequencies as shown in Fig. 6. For the digital signal mixing, we should filtered a specific harmonic frequency. The frequency of 1st harmonics signal after ADC

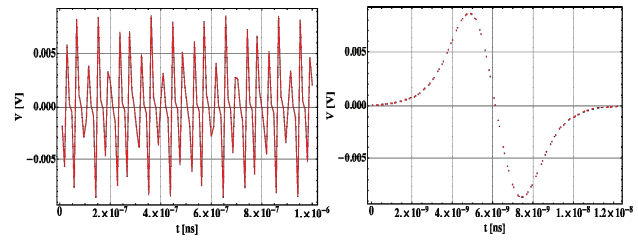


Figure 5: The sampled ADC data(left) and a reconstructed pick-up signal by using 105 sample data(right).

is 23.75MHz and the frequency of 3rd harmonics signal is 33.75MHz. After the digital filtering, the RF signal was mixed with two reference signal with 90 degree phase difference. A mixed two signals are performed digital filtering to get the DC signal. Two DC signals with 90 degree phase difference are called I and Q signal.

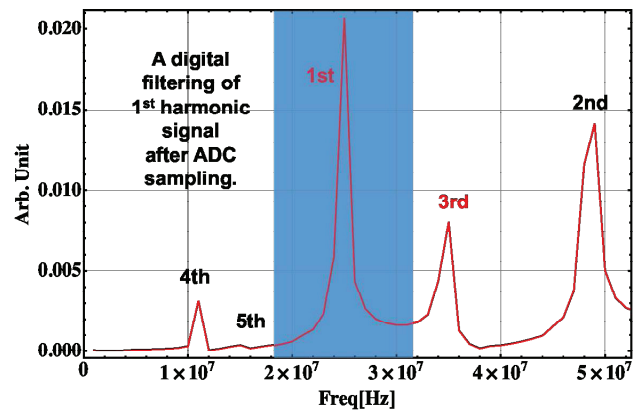


Figure 6: FFT results of sampled ADC data.

By using I and Q signals, we can calculate the beam position and beam phase information. The beam phase was calculated by the average of 4 pick-up phase information and the beam position can be calculated as follows equation:

$$X = K_X * \frac{A_L - A_R}{A_L + A_R} + X_{OFFSET} \tag{1}$$

$$Y = K_Y * \frac{A_U - A_D}{A_U + A_D} + Y_{OFFSET} \tag{2}$$

### A PERFORMANCE OF BPM ELECTRONICS

The preliminary electronics test was performed by using wire test bench [3]. The test signal was generated a short width square sine pulse from a pulse generator. The beam position resolution study was performed. The button BPM pick-up current was assumed to 100uA condition and 1st harmonic signal was used for the beam position resolution test. Figure 7 shows the X port calibration run results with Sum, Delta and Sum over Delta values.

The measured beam position resolution limit of X and Y ports are 7.4um. The measured beam position accuracy of X and Y ports with narrow range (±5mm) are 35.6μm and 51.4μm, respectively. The measured beam accuracy

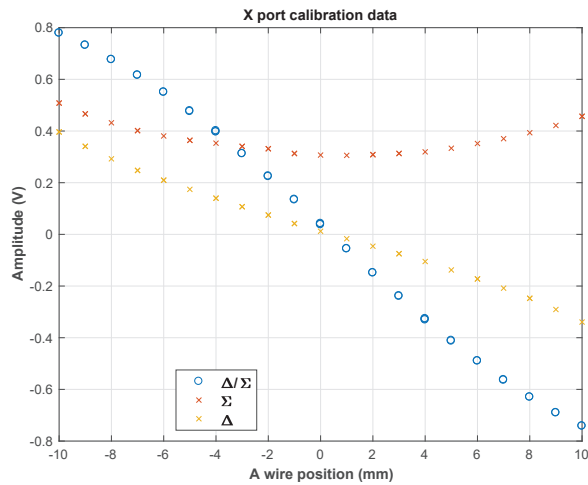


Figure 7: The calibration results of button BPM electronics. The measured calibration slope of X-port is  $-90.5\text{mV/mm}$  and offset is  $36.7\mu\text{m}$ .

of X and Y ports with wide range ( $\pm 10\text{mm}$ ) are  $539.5\mu\text{m}$  and  $569.2\mu\text{m}$ , respectively. Figure 8 shows the beam position resolution test results of X-port.

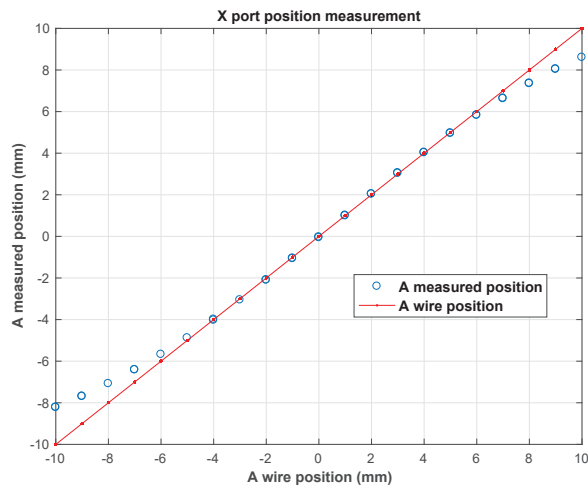


Figure 8: The beam position resolution measurement of button BPM electronics.

Figure 9 shows the beam position 2D mapping data. For the 2D mapping test, we used linear fitting calibration factor. However, if we use the calibration factor of polynomial fitting then we can get more clear 2D mapping data.

The button BPM electronics also can be measure the beam phase information. Figure 10 shows the beam phase measurements results. The measured beam phase resolution is  $0.0278$  degree with 1000 pulses.

## CONCLUSION

In this proceeding, we described the development and test of button BPM electronics. The button BPM electronics was developed to provide the beam position and beam phase

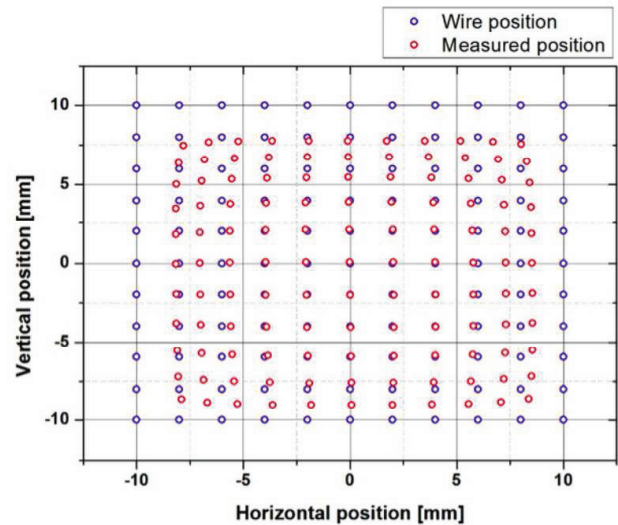


Figure 9: The beam position 2D mapping test results.

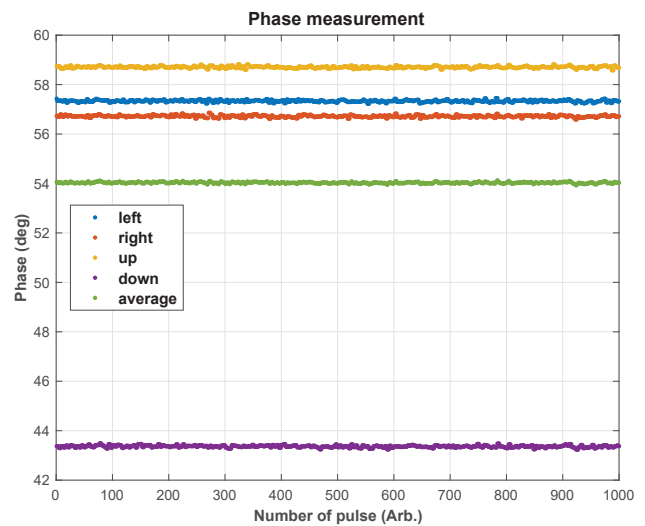


Figure 10: The beam phase measurement with 1000 pulses.

information to helps beam operation. The measured beam position resolution was  $7.4\mu\text{m}$  and the measured beam phase resolution was  $0.0278$  degree. However, the electronics still use only linear fitting calibration factor. To get more good quality of beam position accuracy, we will upgrade the beam position calculation processing with polynomial calibration factor.

## REFERENCES

- [1] RISP web site (<http://risp.ibs.re.kr>)
- [2] H. Hassanzadegan *et al.*, "Beam Position Monitor System of the ESS Linac", in *Proc. HB2012*, Beijing, China, Sept 2012, paper MOP238.
- [3] M. Cargnelli *et al.*, "Evaluation of Libera SinglePass H for ESS Linac", in *Proc. IBIC2014*, Monterey, CA, USA, Sept 2014, paper WEPD07.