ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB287

THE DEVELOPMENT OF SINGLE PULSE HIGH DYNAMIC RANGE BPM SIGNAL DETECTOR DESIGN AT AWA*

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Abstract

Single-pulse high dynamic range BPM signal detector has been on the most wanted list of Argonne Wakefield Accelerator (AWA) Test Facility for many years. Unique capabilities of the AWA beamline require BPM instrumentation with an unprecedented dynamic range, thus cost-effective solution could be challenging to design and prototype. Our most recent design, and the results of our quest for a solution, are shared in this paper.

INTRODUCTION

Beam position monitor is a device widely used on accelerator beamlines worldwide. It can provide information on beam centroid nondestructively. One can also obtain charge information from the signals with careful calibrations. For some applications, BPM might even provide the temporal distribution information of charged bunch. Researchers around the world have studied the properties of many different BPM configuration in detail and published many review papers. For detail and quantitative expression on the BPM properties, one can find them in those review papers [1-6]. As presented in references, a typical BPM system consists of a customized signal pick-up device and specialized processing electronics. The processing electrons are usually specialized to the BPM signals of the specific pickups chosen based on the specific beam parameters of the specific facilities and are usually expensive.

AWA is a small accelerator research facility which has limited budget and resources. But since BPM is such a wonderful device, we would like to install as much as possible on our beamlines. In order to fulfill our need with our limited budget and resources, we decided to design our own BPM signal processing electronics.

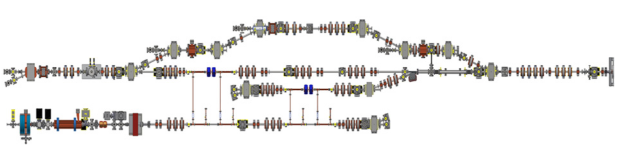

Figure 1: AWA beamline layout.

As shown in Fig 1, there are many places on our beamline that can use the help of BPMs. With the help from BPMs, we will be able to monitor the beam positions on the beamline without using YAG screens, which gives us the opportunity to use feedback-control to stabilize and automatically tune the beam.

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Currently at AWA, we have one stripline BPM pickup installed on our drive beam line right after the last linac. This stripline BPM pickup was specially designed to maximize the signal response at 1.3 GHz, the L-band RF frequency of our RF system. The objective of this stripline BPM pickup is to enable us to not only obtain beam-position information but to also obtain beam-phase information from the same pickup. We previously worked with Euclid TechLabs to develop such signal processing electronics, called Euclid BPPM funded by DoE 2009 SBIR Phase1 project under Contract # DE-SC0002513. The results were very promising, but the project was cut off due to lack of funding.

We also have two commercial in-flange button-type BPM pickups purchased from MDC Vacuum Products®. One is installed on our ACT (Argonne Cathode Test Stand) beamline and one on our witness beamline. Some efforts were put into studying and characterizing the response of these button-type BPMs to our beam structure. Some preliminary efforts were also put into designing the signal processing circuitry [7].

Previous BPM signal-detector design efforts at AWA facility have been discussed in the paper that we provided for the NAPAC-19 conference proceedings [8]. In that paper, three separate signal-detector design proposals were examined (RLC resonator-based circuit, half-wave rectifier with voltage-follower based circuit and modified peak-detector circuit). The final bench and target testing-results on those designs indicated that they were able to produce promising output results for beam charge-levels at or above 1 or 2 nC, but were unsatisfactory in producing any meaningful results below those levels of charge.

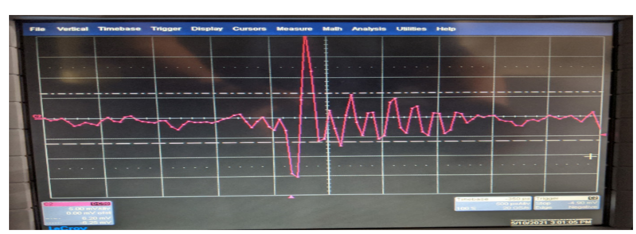

Figure 2: Typical button BPM output.

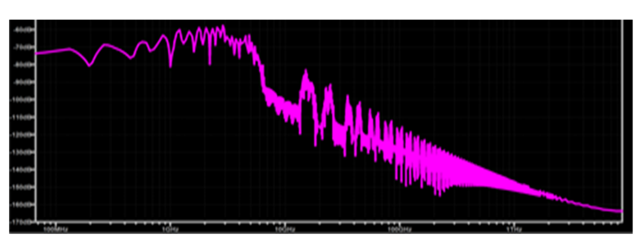

Figure 3: FFT results of the button BPM output.

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12th Int. Particle Acc. Conf. IPAC2021, Campinas, SP, Brazil JACoW Publishing
ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB287

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AWA BEAM PARAMETERS AND TYPICAL IN-FLANGE BUTTON BPM RESPONSE TO AWA ELECTRON BEAM

At AWA, we typically operate our beamline at 2 Hz repetition rate. The nominal bunch length of AWA beam is about 8 ps. The charge of our electron bunches can be set from about 1 pC up to near µC. So the detector circuit need to be able to handle the input from mV up to kV.

As shown in Fig. 2, the typical response of the button BPM to AWA electron bunch is a short negative pulse followed by a positive pulse. The FWHM of the pulses is about 100ps. The magnitude varies with charge intensity and beam position. The frequency response of BPM button output-voltage is displayed in Fig. 3. As seen in the figure, the frequency spectrum of an incoming BPM signal, as measured from the button pick-up, has a 3-dB bandwidth of roughly 1.7 GHz with center-frequency of roughly 1.9 GHz. The processing electronics for this kind of fast signal is going to be expensive. Our goal is to find a way to transform the short BPM response into a long and slow signal so that it can be processed with cheaper electronics.

PROTOTYPING OF NEW SIGNAL-DETECTOR BOARD

Simulation results on an active-filter as proposed in [8] were promising at the time, so it was decided to prototype the circuit using a 2N2222-based transistor for the active-filter and then cascade it into three separate stages. A second active-filter cascaded into two stages was also designed that utilized a 2SC4083 RF-transistor to amplify the incoming BPM signal. The prototype boards for both active-filter designs are displayed in Fig. 4.

The idea for utilizing an active-filter design for the BPM signal-detector board (using the 2N2222 transistor model) was conceived and referenced in [8], but only simulation-studies were done during that time. As indicated in [8], the simulation results at the time for the 2N22222 active-filter were promising and revealed that a good output-response was produced for input-signals falling within the range of 50 mV to 8 V.

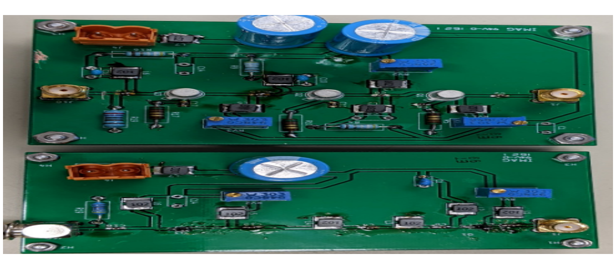

Figure 4: BPM active filter prototype boards.

Bench Test Results

Bench-tests were recently performed on the newly designed 2N2222 and 2SC4083 active-filter boards and revealed promising results. Limited by availability of equipment, an external waveform-generator was used to generate a unipolar pulse having a peak amplitude of approximately 15 mV and a FWHM pulse-width of approximately 20 ns. The signal was fed into the signal-detector board from the waveform-generator using a standard 50 Ω BNC cable.

As seen in Fig. 5, the output of the three-stage active-filter using the 2N2222 transistor was significantly stretched out, having a FWHM pulse-width of approximately 2 µs and is a promising width for down-stream peak-detector or sample-and-hold circuit to track and/or hold. As seen in the same figure, the output peak-amplitude of the 2N2222 based active-filter was modestly amplified as well to approximately 380 mV. As seen in Fig. 6, the output of the 2SC4083 two-stage active-filter board has been modestly stretched to a FWHM pulse-width of approximately 300 ns. Moreover, the peak-amplitude of the 2SC4083 active-filter output signal was significantly amplified to approximately 13.4 V.

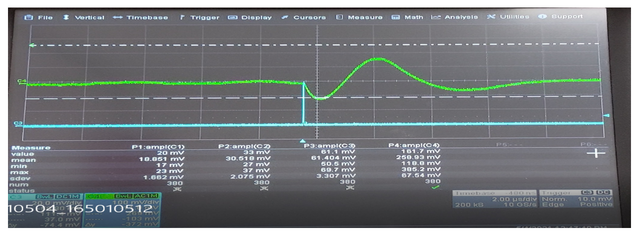

Figure 5: Bench test results of BPM active filter using 2n2222.

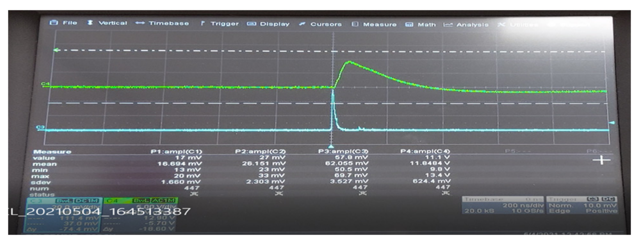

Figure 6: Bench test result of BPM active filter using 2SC4083.

Testing of the two prototype boards was then carried out on the linac-beamline at AWA facility using various beam-charge levels to measure the output-response of the active-filter for both 2N2222 and 2SC4083 transistor-based prototype boards. For the beamline test-experiments, a high-speed oscilloscope was used to measure the voltage as seen at the input of the active-filter for both 2N2222 and 2SC4083 prototype boards. Integrated current transformers (ICTs) are used at AWA facility to monitor the charge of electron beam. The ICT signal from ICT#1 was captured on the same oscilloscope as the BPM active-filter circuit output signal.

As seen in Fig. 7, the 2N2222-based active-filter stretched out the BPM input-signal significantly to a FWHM width of approximately 3.5 µs. The peak-amplitude of the output-signal, as measured on the oscilloscope, was approximately 3 mV and a less-than-desired value for the incoming charge-beam of the experiment that had a charge-level of approximately 2 nC.

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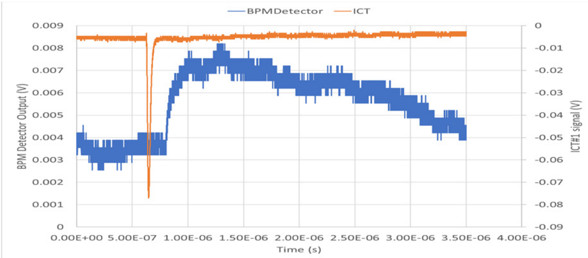

Figure 7: 2N2222 active-filter output response to button BPM with 2 nC charge beam.

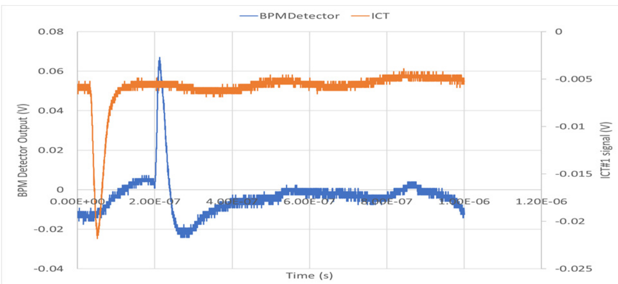

Figure 8: 2SC4083 active-filter output response to button BPM with 500 pC charge.

The 2SC4083-based prototype board was then tested on the AWA linac beamline first for a beam-charge level of approximately 500 pC. As seen in Fig. 8, the results of the experiment, as seen on the oscilloscope, indicate that with less than one-third the charge, 2SC4083-based active filter generated an output that at 60 mV, was approximately 20 times as strong as that of the 2N2222-based prototype board. As seen in Fig. 7, the accompanying noise superimposed on the output-signal of the 2SC4083 active-filter is more pronounced than for the corresponding beamline experiments on the 2N2222-based active-filter.

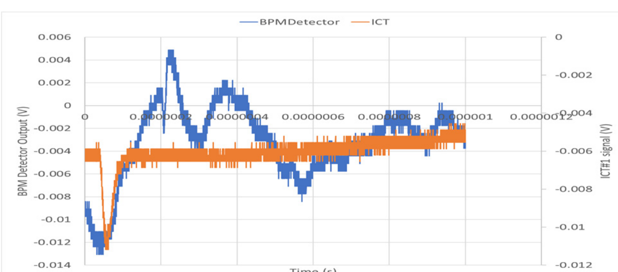

Figure 9: 2SC4083 active-filter output response to button BPM with 150 pC charge beam.

An additional AWA beamline measurement was performed on the 2SC4083-based active-filter using a beam-bunch charge-level of approximately 150 pC. As seen in Fig. 9, the peak-amplitude at the output of the active-filter was approximately 5 mV and again had a visible and prominent amount of noise superimposed onto it.

CONCLUSION

The AWA beamline experiments performed on the three-stage 2N2222-based active-filter reveal that its output response to nominal levels of beam-bunch levels charge is not great enough in magnitude for downstream circuit elements to track and process. As a result of this quantitative shortcoming, the 2N2222-based active-filter design will no longer be pursued as a viable prototype option for use at AWA facility. The AWA beamline experiments on the two-stage 2SC4083 based active-filter yielded more promising results with respect to the peak-amplitude of the output-signal in response to smaller input-signals that corresponded to beam-bunch charge levels of 500 and 150 pC. As such, continued efforts will be made to improve the signal-to-noise ratio of the 2SC4083 prototype design by reconfiguring PCB layout such that unwanted coupling between adjacent circuit elements is further minimized. Another design strategy that will be pursued is to implement a voltage-follower that will isolate the active-filter output and prevent the BNC output-cable from adversely affecting its signal integrity. By adjusting the LC parameters of the tank-circuit (i.e. resonant filter) on the active-filter prototype board, an additional increase in gain can also be prospectively achieved.

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