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UPDATE ON BPM SIGNAL PROCESSING CIRCUITRY DEVELOPMENT AT AWA*

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Abstract

Beam position monitor (BPM) is widely used in accelerator facilities worldwide. It is a device which is capable of providing, non-destructively, accurate beam centroid and charge information of a passing charged beam. A typical BPM system contains customized hardware and specialized processing electronics. The cost is often too high for small facilities to afford them. As a small facility, Argonne Wakefield Accelerator (AWA) decided to develop a solution with high cost-efficiency to fit in its budget. Some details about the development are presented in this paper.

INTRODUCTION

Beam position monitor is a device wide 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 details 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 is consisted of customized signal pick up device and a 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 they are usually expensive.

AWA is a small accelerator research facility which has limited budget and resource. 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 the limited budget and resource, we decided to design our own BPM signal processing electronics.

As showing 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 will give us the opportunities to use feedback control to stabilize the beam and also provide us an objective for automatic beam tuning in the future.

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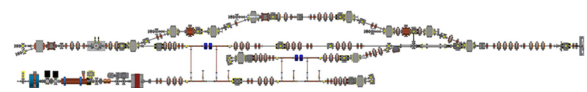

Figure 1: AWA major beamline layouts.

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 1.3GHz, the L-band RF frequency of our RF system. The objective of this stripline BPM pickup is to enable us to be able to not only obtain the beam position information but also obtain the beam phase information from the same pickup. We have been working 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 are very impressive but the project was cut off due to lack of funding.

We also have two commercial inlange button-type BPM pickup 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 putted in to study and characterize the response of these button-type BPM to our beam structure. Some preliminary efforts were also putted in to design the signal processing circuitry [7].

Recently, some breakthroughs have been made on BPM signal processing circuitry design and prototype. We are now very close to complete and realize our low cost BPM signal processing electronics.

LOW COST BPM SIGNAL DETECTOR PROTOTYPING

AWA Beam Parameters and Typical Inflange Button BPM Response to AWA Electron Beam

At AWA, we typically operate our beamline at 2Hz repetition rate. The nominal bunch length of AWA beam is about 8ps. 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 showing 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 positions. 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

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and slow signal so that it can be processed with cheaper electronics.

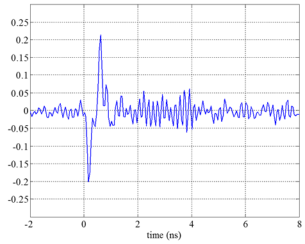

Figure 2: Typical response from BPM.

Prototyping of Detector Circuit

Based on the fundamental of how BPM pickup works, the signal from the pickup is actually a current pulse. So it is possible that we can use a fast diode to rectify the signal and store the captured charge on to a capacitor as showing in Fig. 3. By selecting the capacitance of the capacitor, we should be able to select between a wide dynamic ranges of the charge intensities.

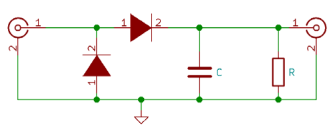

Figure 3: The conceptual basic detector.

Based on the above concept, we made two versions of prototyping test circuits. One with regular diode and the other with surface mount Schottky diode. As expected, the 2nd version yields a much stronger signal. 4 "identical" circuits were then made and tested with a button BPM on our witness beamline. The charge was about 1.5nC. The results is showing Fig. 4.

As shown in Fig. 4, the BPM signals got stretched out from100ps to more than 30ns long. After the successful prototyping of the detector circuit, we advanced the circuit design to include a voltage follower. The purpose of using a voltage follower is to isolate the front end with downstream circuits. By isolating front end with the downstream circuits, we could then further stretch out the signal with higher discharging resistor. We also added jumpers to select capacitors so that we can work with different charge intensities. Several prototyping circuit were built and tested based on the new design. As showing in Fig. 5, the BPM signals can be stretched out to >300 µs for signals from bunches of about 10nC with the new prototyping circuit.

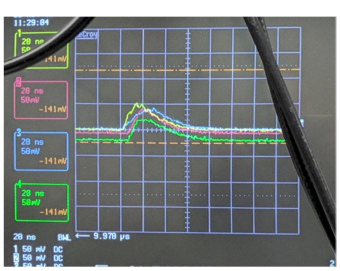

Figure 4: Signals from prototyping detectors.

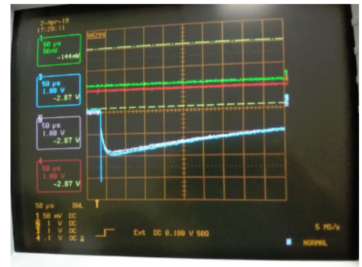

Figure 5: BPM signal stretched out to >300µs for a 10nC bunch.

We used jumpers to select different capacitors to change the dynamic range on these new prototyping circuits. The lowest charge it can detect was about 100pC with the stripline BPM when the smallest capacitor, 5pF, on the circuit was chosen. The results is showing in Fig. 6.

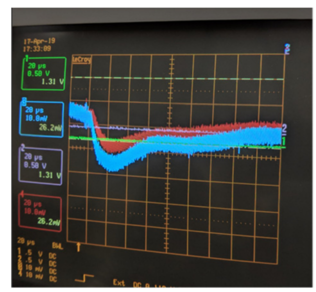

Figure 6: The signal from lowest charge the prototyping circuit can detect from stripline BPM.

The disadvantage of these diode based circuit is that there will be a voltage threshold (about 340mV or 700mV depending on what diode is used) that the signal must meet before it can be detected by the circuit. This threshold will impose a limit on the sensitivity of the circuit. In order to improve the sensitivity of the detector circuit, we also prototyped a resonator based circuit. With the RLC resonator based prototype circuit, the lowest charge it could see was about 2nC with the button BPM.

One channel of the prototyping circuit was further modified into rectifier followed by a modified peak detector. With this modified prototype detector, the pulse length was further stretched out as showing in Fig. 7.

Figure7: Scope trace showing detector prototype with modified peak detector.

PCB prototype circuits were also made to test for diode biasing to see if sensitivity can be improved or not. It turns out that biasing the diode is not going to help at all.

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Solution for Beam with Low Charge

It was confirmed with PCB prototyping that biasing the diode is not going to increase the sensitivity of detector. We have to find other ways to cover the low charge beams, 1pC up to 2nC. Encouraged by RLC resonator based detector prototype, we come up an idea of active filtering solution. As showing in Fig. 8, by passing the BPM pickup signal directly through the active filter circuit, the fast BPM signal can be turned into a slow signal good for the peak detector to handle. As showing in the simulation results using 2N2222, the circuit is good for BPM signals from 50mV up to about 8 volts.

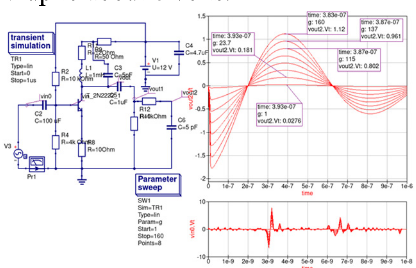

Figure 8: Simulation results of active filtering.

When charge intensity is less than 10pC, with the button BPMs, the signal will be mini volts to sub mini volts level based on our measurements. In such cases, a high speed small signal voltage amplifier should be used. As showing in Fig. 9, a simulation using BFP640, a NPN RF transistor, has shown that a voltage gain of about 100 can be achieved with a load about 500Ohms. As long as we can get the input impedance of active filter to about 500 Ohms, the circuit in the simulation should be able to properly amplify sub mini volts signals to a level good for active filter circuit to work on.

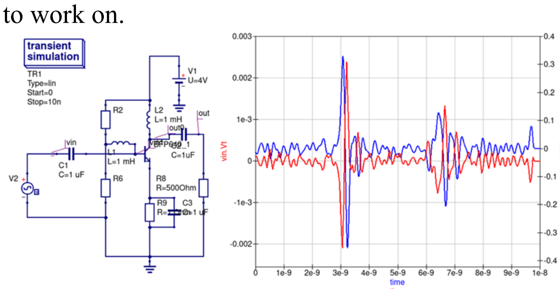

Figure 9: Simulation of small signal voltage amplifier using BFP640

PLAN FOR NEXT PCB PROTOTYPE AND FRONT END BOX

An updated schematic for our next PCB prototype is given in Fig. 10. This version will have 5 selectable charge levels. For the lowest charge level, all 4 relays will need to be energized. Signal will first be amplified and then active filtering will be used before the modified peak detector. For the 2nd lowest charge level, the last relay will not be energized while all other 3 will be on. Unalike the lowest charge level, the signal will be routed directly into active filter. With this new version, we can also test changing gains of the modified peak detector. 2n2222 will be used in the active filtering circuit while we will evaluate and test BFP640 or other RF transistors for the amplifier stage.

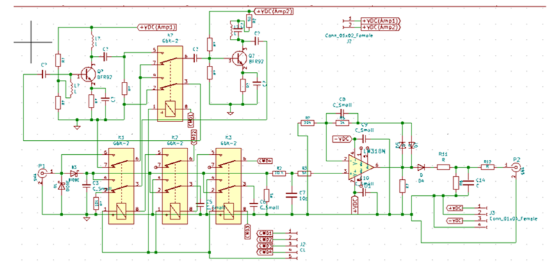

Figure 10: Schematic of next detector PCB prototype.

Each BPM will be connected to one front end box with 4 detector head circuit. There will be one power and signal hub circuit inside each front end box. BPM signals from detector head will be gathered and send to controller box over 4 twisted pairs in a 15 conductors cable. Control signal and power will be received from controller using all other conductors in the same 15 conductor cable and distributed to detector head using two 4 conductor cables (one for power and one for charge level selection). DC Power can also be locally supplied.

PLAN FOR CONTROLLER BOX

As showing in Fig. 11, each control box will serve two BPMs through two DB15 connectors. BPM signals from front end box are each connected with a voltage follower. The output from voltage followers will be routed to an 8 channels 18 bit simultaneous sampling ADC, LTC2358-18, for digital readout. We have two trigger options. The first one is called self-triggering where all 8 channels BPM signal will be summed and pass to a differential circuit followed by a voltage comparator to generate the trigger. The 2nd is external trigger which will use our machine trigger. An 8 channels DAC is also going to be included to enable future automatic beam control. Currently, we are planning on using Raspberry Pi for data processing and controlling.

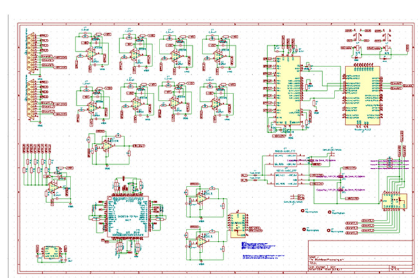

Figure 11: Schematic of controller.

SUMMARY

The low cost BPM signal processing circuitry development for AWA successfully prototyped the BPM signal detector head for AWA nominal beam intensity and above. Preliminary design of controller circuit is done and prototyping controller circuit will be made and test when resources are made available.

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