Development of single-pulse high dynamic range BPM signal-detector design at AWA

Edward Siebert*, S. Baturin

Northern Illinois University

W. Liu, C. Whiteford, E. E. Wisniewski, G. Ha, J. H. Shao, J. G. Power, P. Piot, S. Doran

High Energy Physics Division, Argonne National Lab

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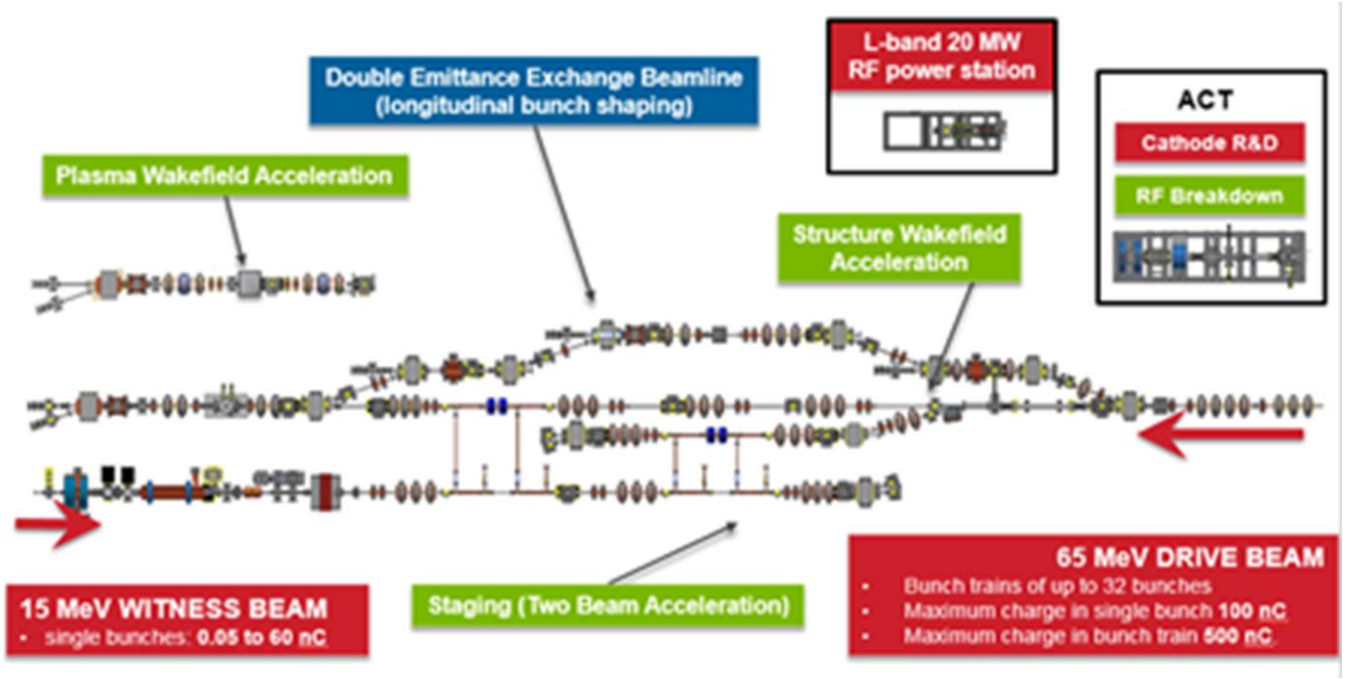
Motivation

- BPM is a great beam-monitoring and diagnostic device.
- There are many places on our beamline that can use some help from BPMs.

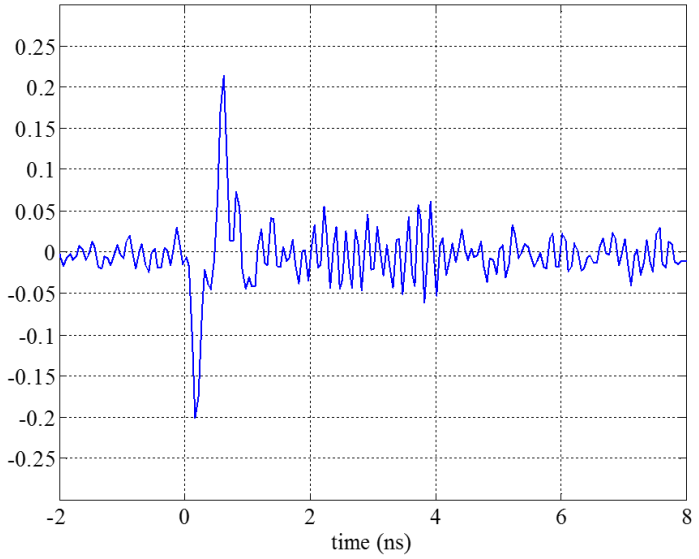
- For a small facility like AWA lab, the electronics for processing the signals are expensive (in quantity) to purchase.
- We decided to develop our own low-cost processing-circuitry that fits within budget at AWA lab.



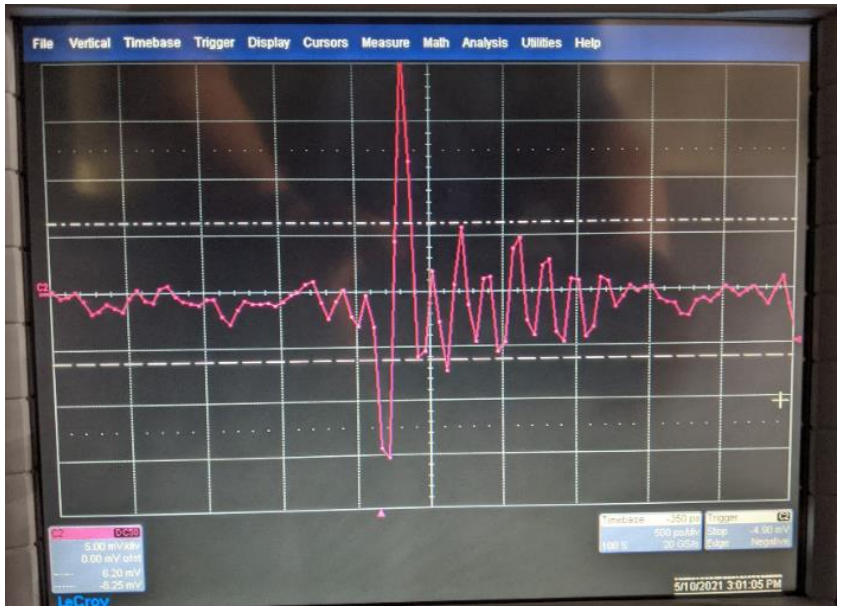
Our Typical Beam Parameters and BPM pickup response

- **AWA beam parameters: Charge: ~1pC to ~μC; Repetition rate: 2Hz; Bunch length: ~8ps**

Strip line BPM



The response from the BPM pick-up to AWA electron-bunch is typically a negative pulse that has a FWHM width of about 100ps and followed by a positive pulse.



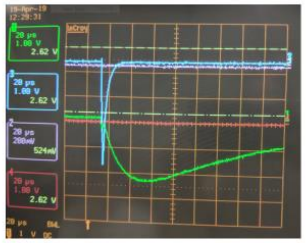
In-flange button BPM output

- The oscilloscope is set at 5mV/div (vertical axis) and 500ps/div (horizontal axis).
- The sampling rate is at 20GS/s
- There are inline attenuators of 40dB to protect the scope. The power loss on the scope cable is estimated to be about 6dB.
- **The actual magnitude of the signal at the BPM output is about 4V for a beam that has about a 900pC charge.**

Previous efforts on BPM signal detector

RLC RESONATOR BASED CIRCUIT

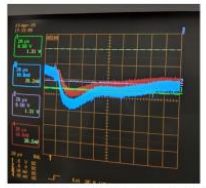
- The BPM pickup response to AWA electron bunch is very short and thus broad band.
- We might be able to use it to excite a low frequency resonator and use resonator output as a measure.
- A RLC resonator based detector was built and tested on bread board. It worked.
- The lowest charge detected by this RLC prototyping circuit is about 2nC with a button BPM.



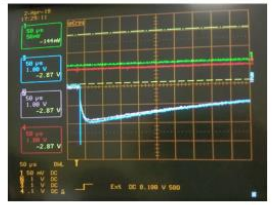
A HALF WAVE RECTIFIER FOLLOWED BY A VOLTAGE FOLLOWER

Advantage: providing isolation between detector and downstream circuit. With the isolation in place, we can now stretch the pulse length and make it easier and cheaper to process.

The prototyping circuit was further revised to use jumper to select different charge level by selecting different capacitors. A circuit with 4 channels was built and tested .



From the test, with the strip line BPM on our drive beam line, the lowest charge it can detect was about 100pC.



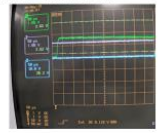
The charge in electron beam is about 10nC

USING A MODIFIED PEAK DETECTOR

One prototyping circuit was modified again into a modified peak detector circuit. The schematic of this circuit is given here.

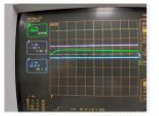
This prototype was then tested with a button BPM

The signal is about 2.7V for 28nC

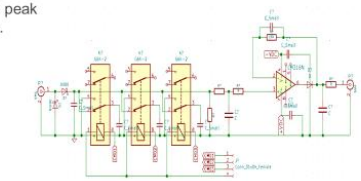


The signal is about 1.7V for 17nC

The signal is about 0.48V for 4.5nC



The signal is about 0.09V for ~1.5nC



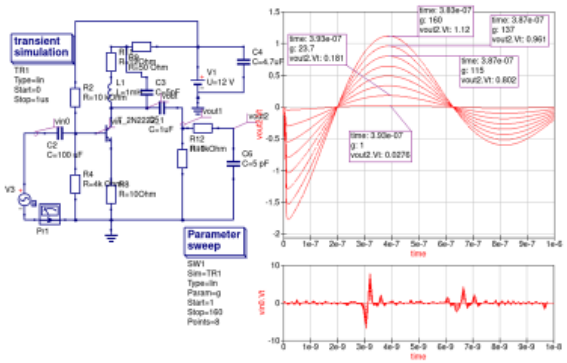
The lowest charge detected by this prototyping circuit was about 1.5nC with the button BPM. The circuit was built this way just to see if the positive going pulse can give us enough signal so that we don't need to invert the signal later.

- Each signal-detector works for input-signals that have a charge-level higher than about 1 or 2 nC on the button BPM.
- But they are not good enough to cover the whole dynamic-range of AWA beam parameters.

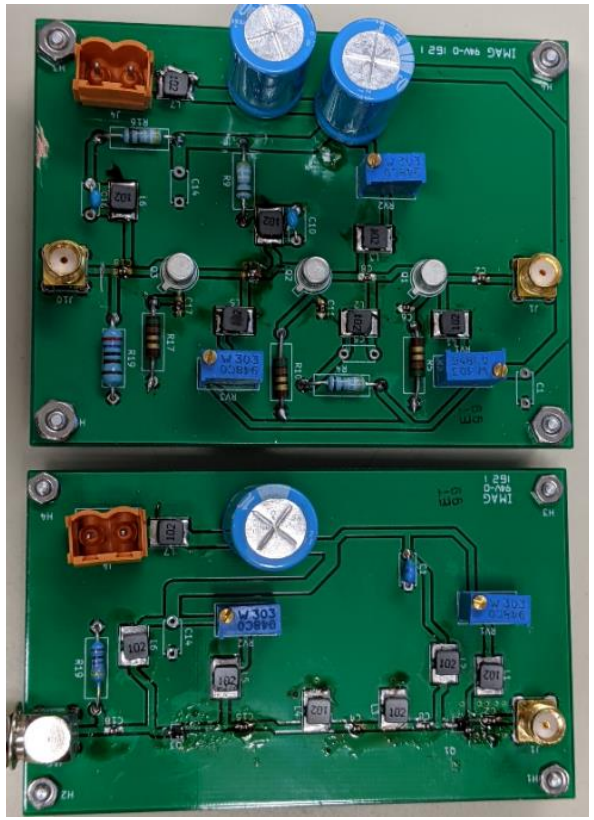
Active-filter for BPM signal detector prototyping

SOLUTION FOR LOW CHARGE BEAM

- When charge intensity is low, the BPM signal will be too weak to be detected by our prototyping detector circuit.
- A straight forward solution would be amplify the signal before send it to the detector circuit.
- But due to the limited detector circuit sensitivity, amplified signal smaller than about 380mV will still not be seen by the circuit.
- Instead of amplify the signal and send it down to the prototyped diode based or resonator based circuit, we will just use an active filter circuit, shown in the figure in this slide, to generate amplified signals at a frequency low enough for the modified peak detector in the prototyped circuit to work on.



As showing in the simulation results using 2N2222, the circuit is good for BPM signals from 50mV up to about 8 volts.



- **The idea of an active-filter for the BPM was conceived based on circuit simulations.**
- **The latest prototype results are presented in this poster**

- Shown on the top is the prototype using 2n2222. It has 3 amplifying stages.
- Shown on the bottom is the prototype using 2SC4083 which has two amplifying stages.

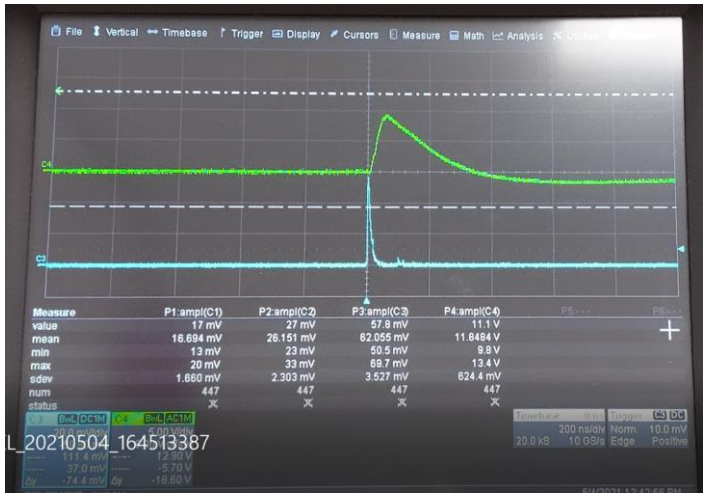
- **Both circuit designs are still under development**.

Latest Bench-Test Results

Channel 4 is showing the attenuated input-signal used as input to the active-filter prototypes. Channel 3 is a teed off from the input-signal before attenuation and is used as a trigger to the oscilloscope.

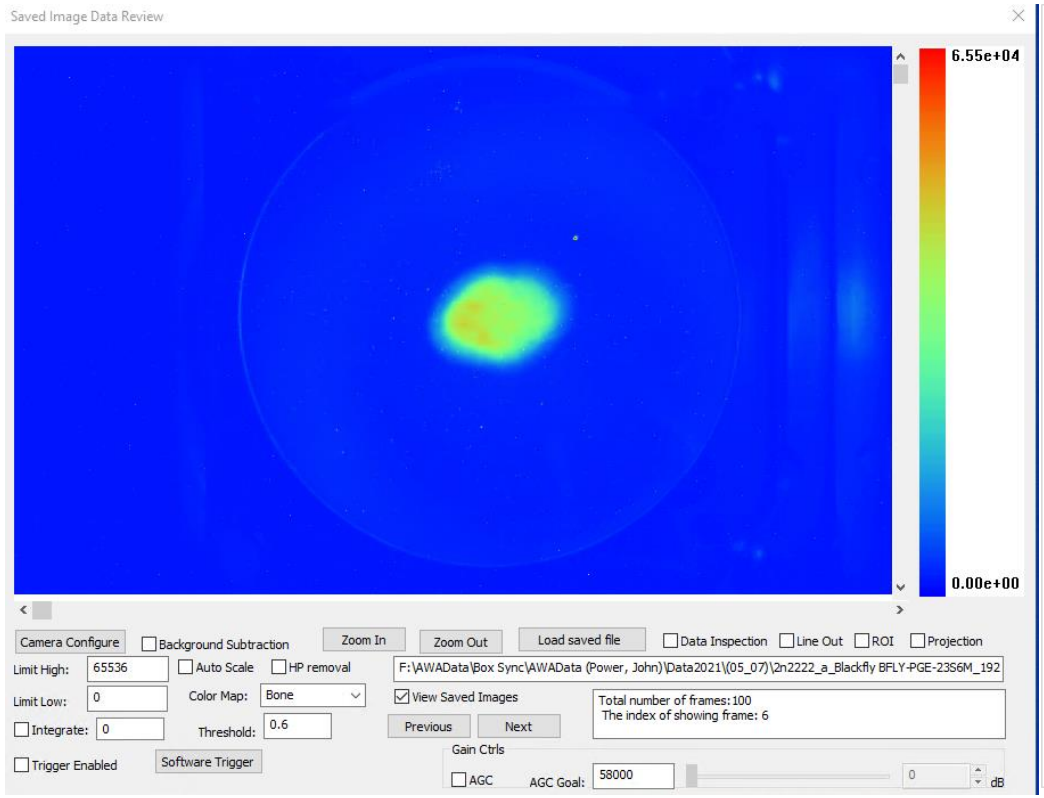
The input level to the active-filter is about 15mV based on the scope trace.

Channel 4 is showing the output of the active-filter prototype using 2n2222. Compared with the input signal on the previous slide, **the output has been significantly stretched out and modestly amplified.**

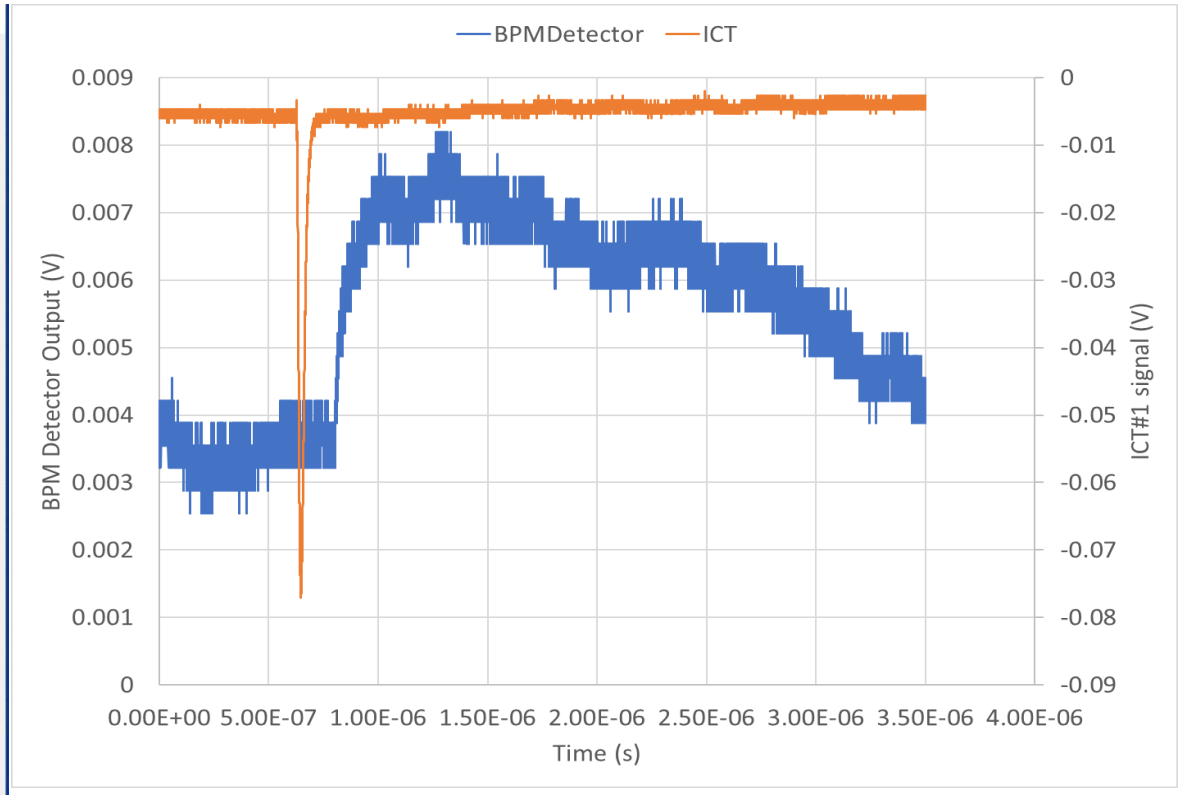


Channel 4 is showing the output of the active -filter prototype using 2SC4083. Compared with the input signal, **the output has been modestly stretched out and significantly amplified.**

2n2222 BPM signal-detector button BPM beam test result



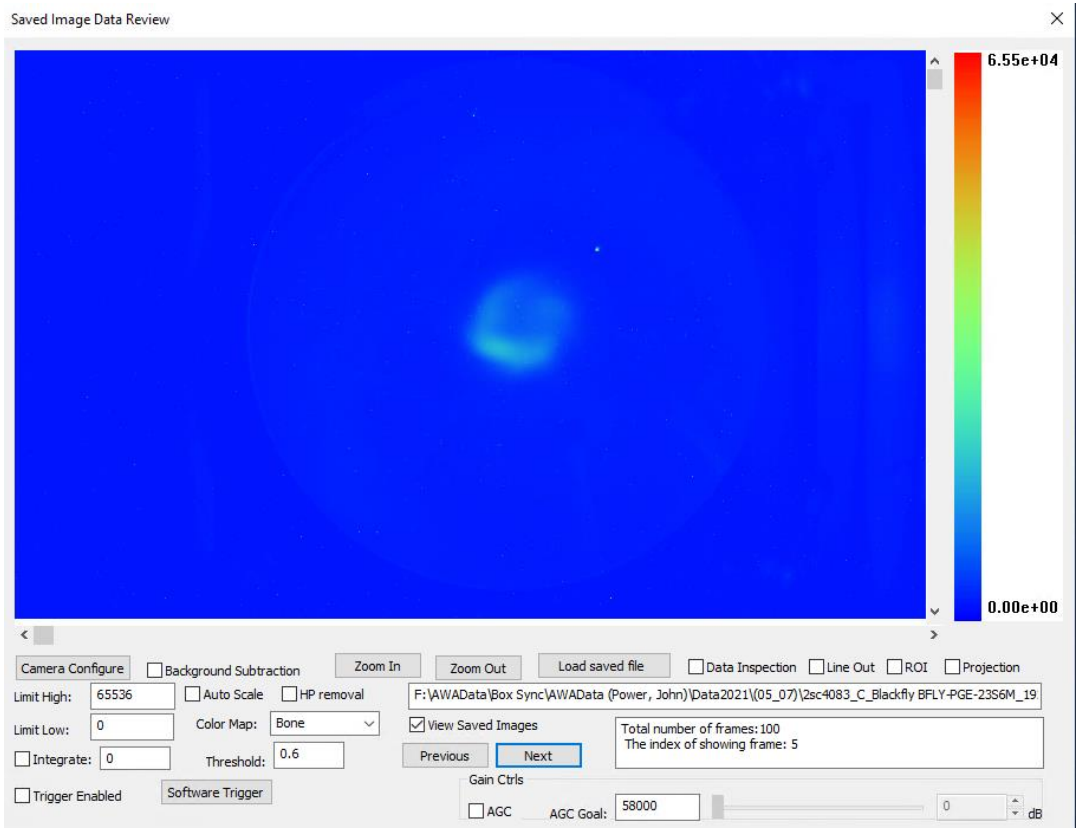
Beam position on YAG after BPM

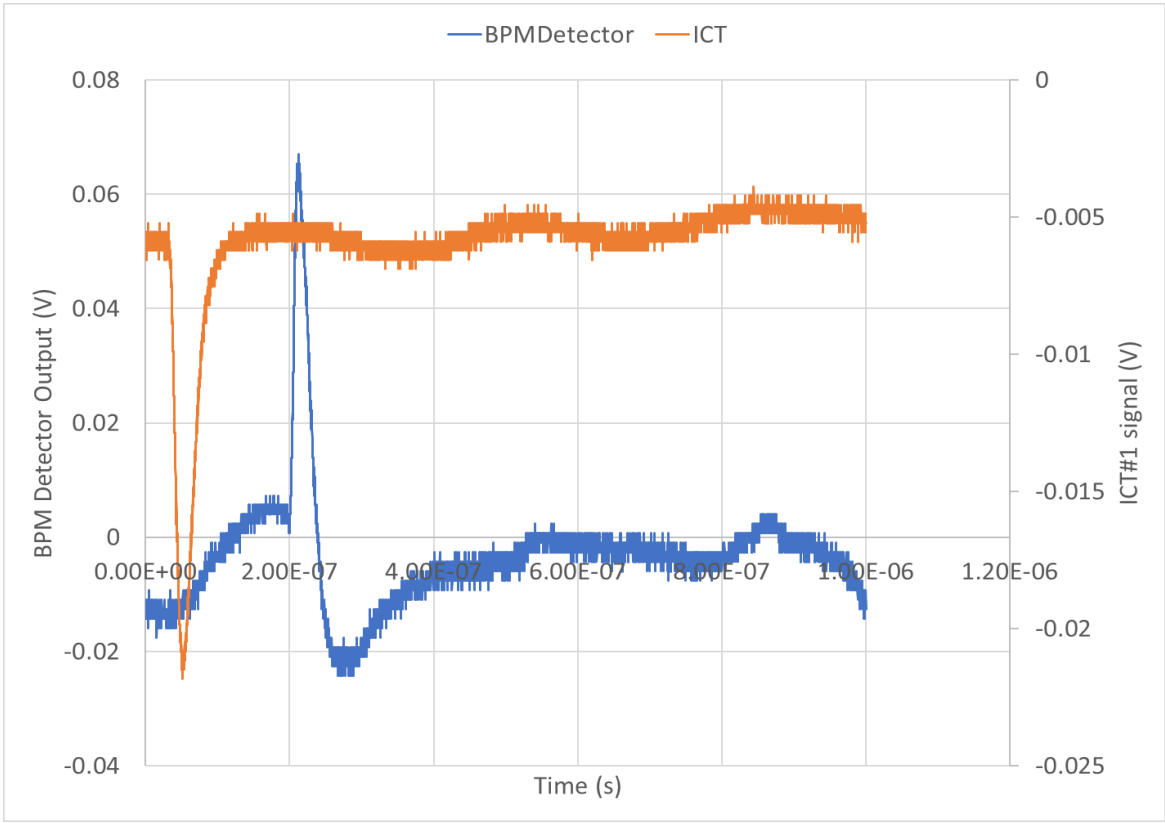


Active filter output and ICT signal

The active-filter stretched out the BPM signal significantly, but the magnitude is too small and **only about 3mV for a beam of about 2nC**. **This circuit is not going to be useful and will not be used further as a prototype design for the signal-detector board.**

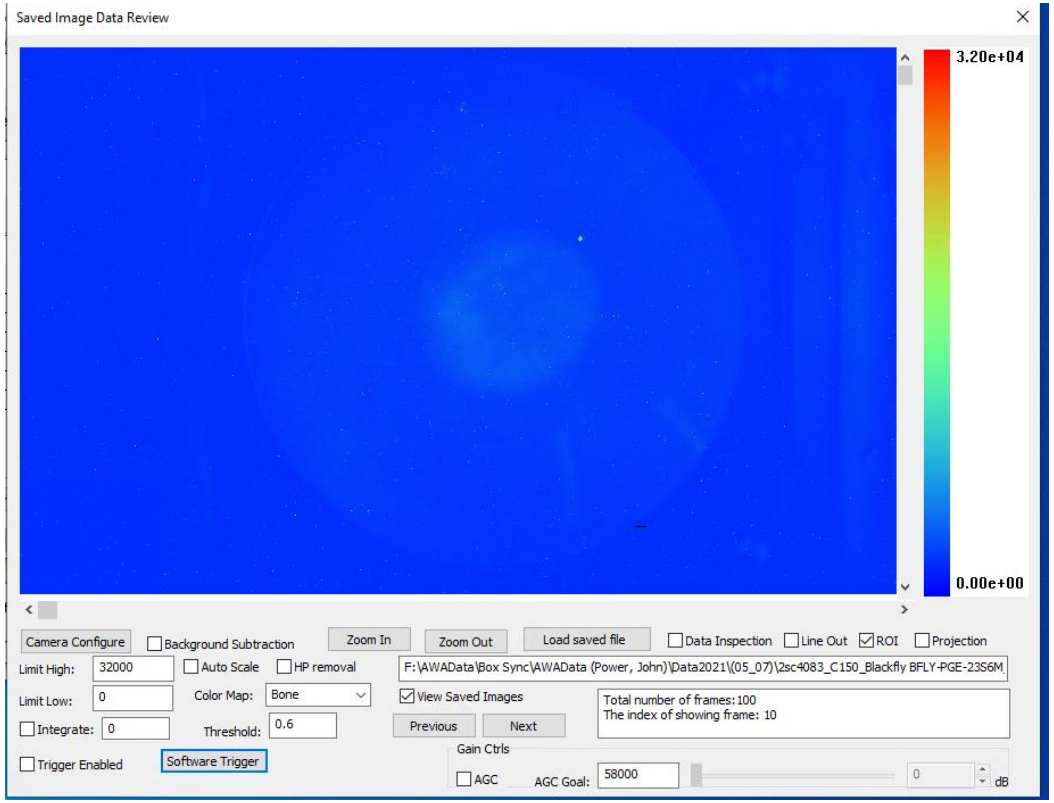
2SC4083 Active filter Button BPM beam test results when charge is about 500pC

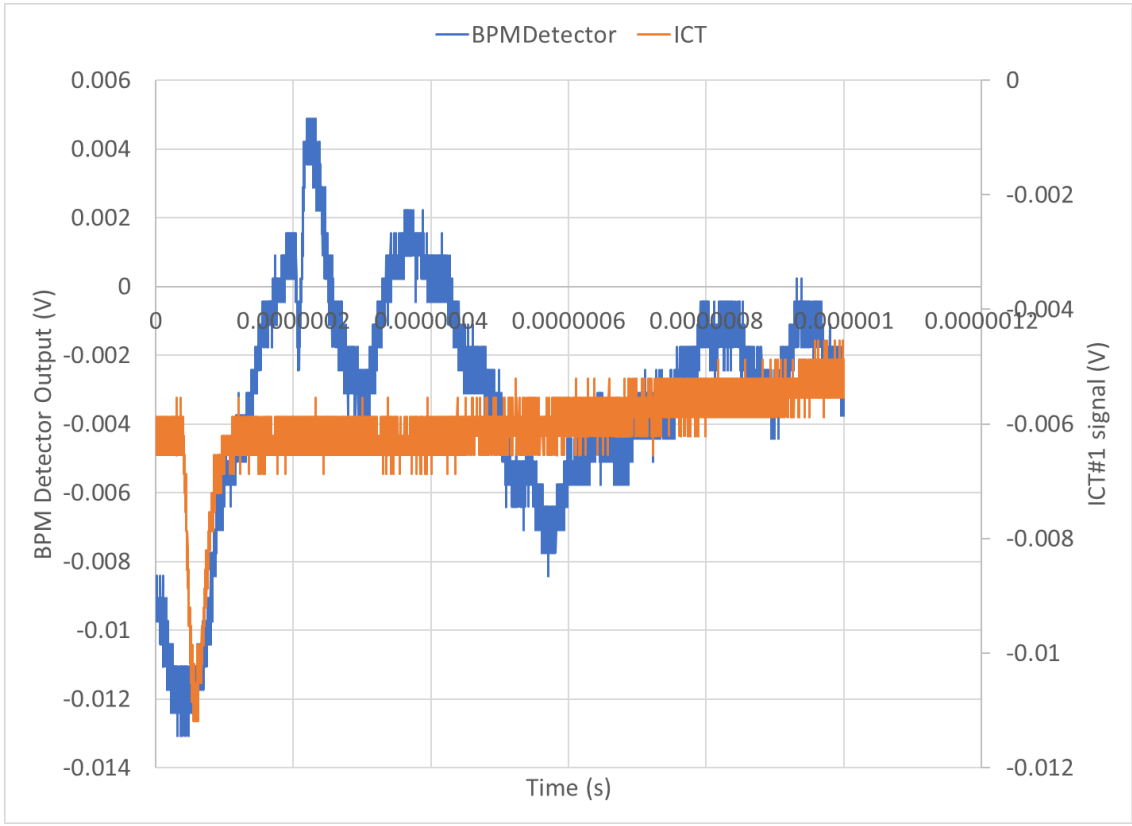




- The signal from the active-filter made with 2SC4083 is much stronger than the signal output from the one made with 2n2222.
- **With less than 1/3 of the charge, this active-filter can generate an output that is about 20 times stronger than the one made with 2n2222.**
- But the noise of this circuit is also higher, so the next prototype will have one more goal, to improve the signal-to-noise ratio.

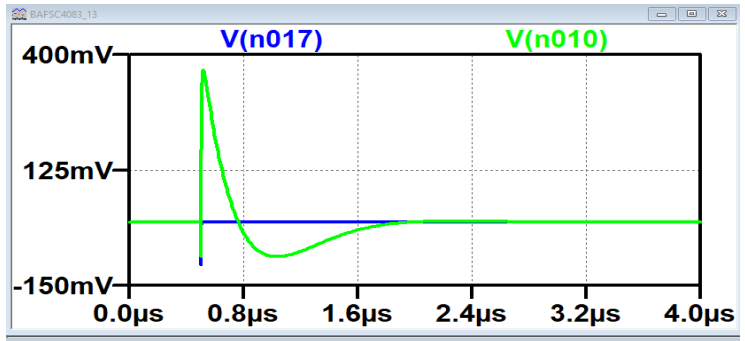
2SC4083 Active-filter Button BPM beam test results when charge is about 150pC

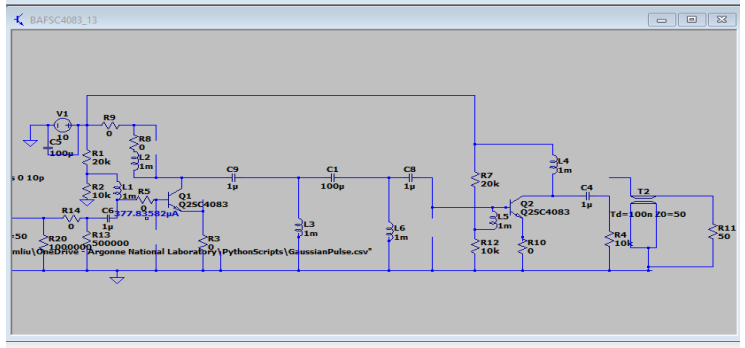


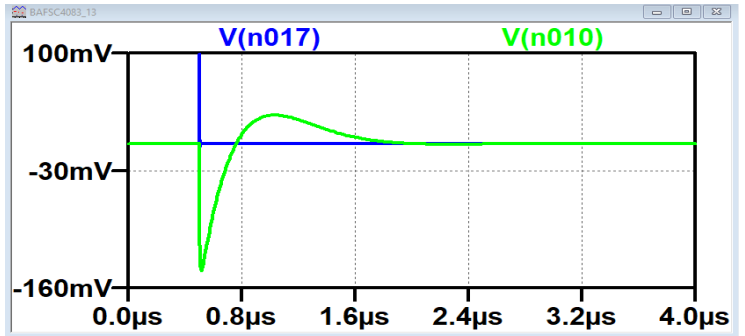


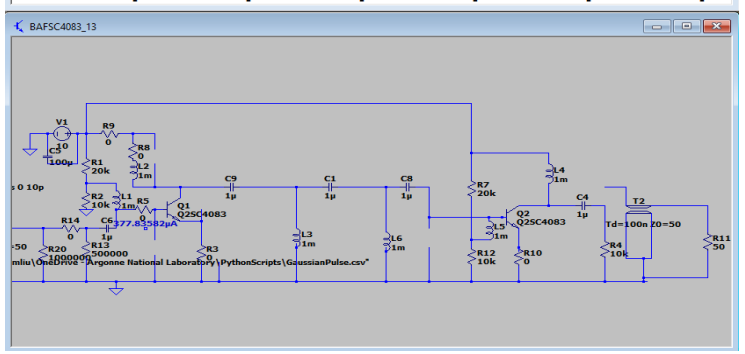
When the charge-level is down to about 150pC, the signal is still visible but is comparable in magnitude with the noise. Improving the signal-to-noise ratio will be an additional goal for the next prototype.

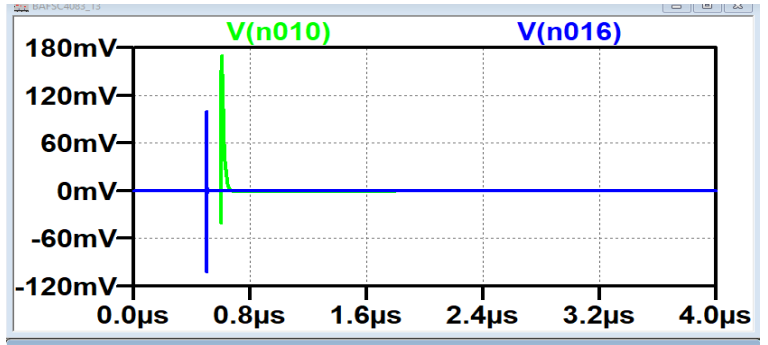
Potential approaches to improve the performance of next prototype

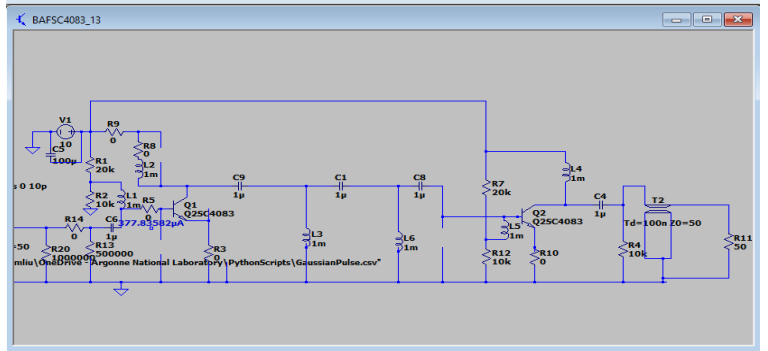












- **Use a voltage-follower that will isolate the output and prevent the BNC output–cable from adversely influencing it.**
- **Use different parameters for the tank-resonator to increase the gain.**
- **implement a careful PCB layout that improves signal-to-noise ratio by avoiding any unwanted coupling between components.**

Thank You