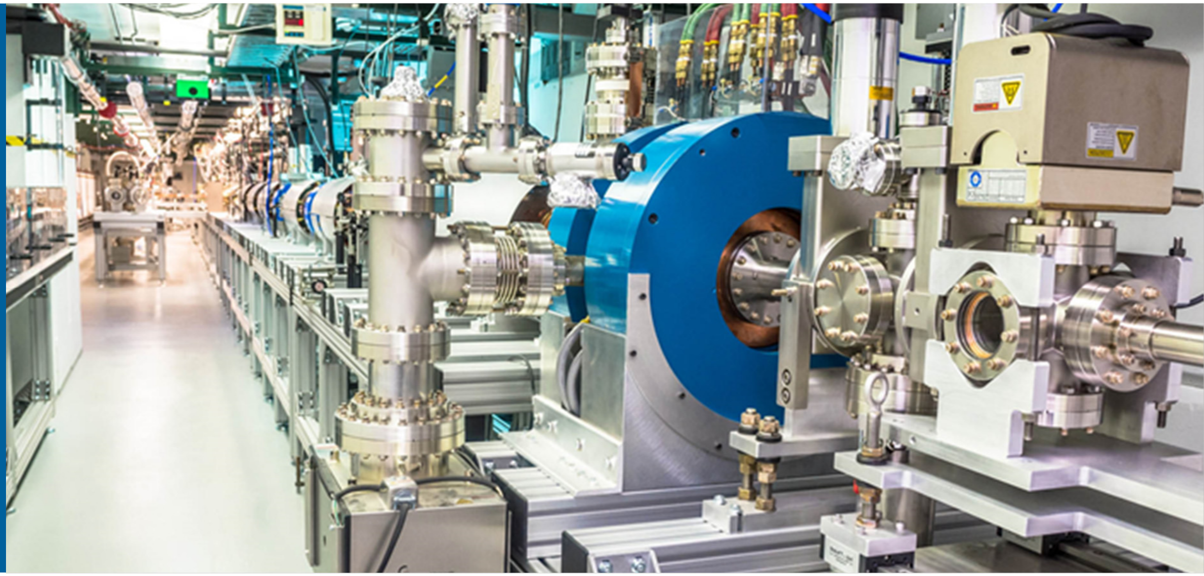
# UPDATE ON BPM SIGNAL PROCESSING CIRCUITRY DEVELOPMENT AT AWA



**WANMING LIU**
On behalves of Argonne Wakefield Accelerator Group & Euclid TechLabs LLC



NAPAC2019

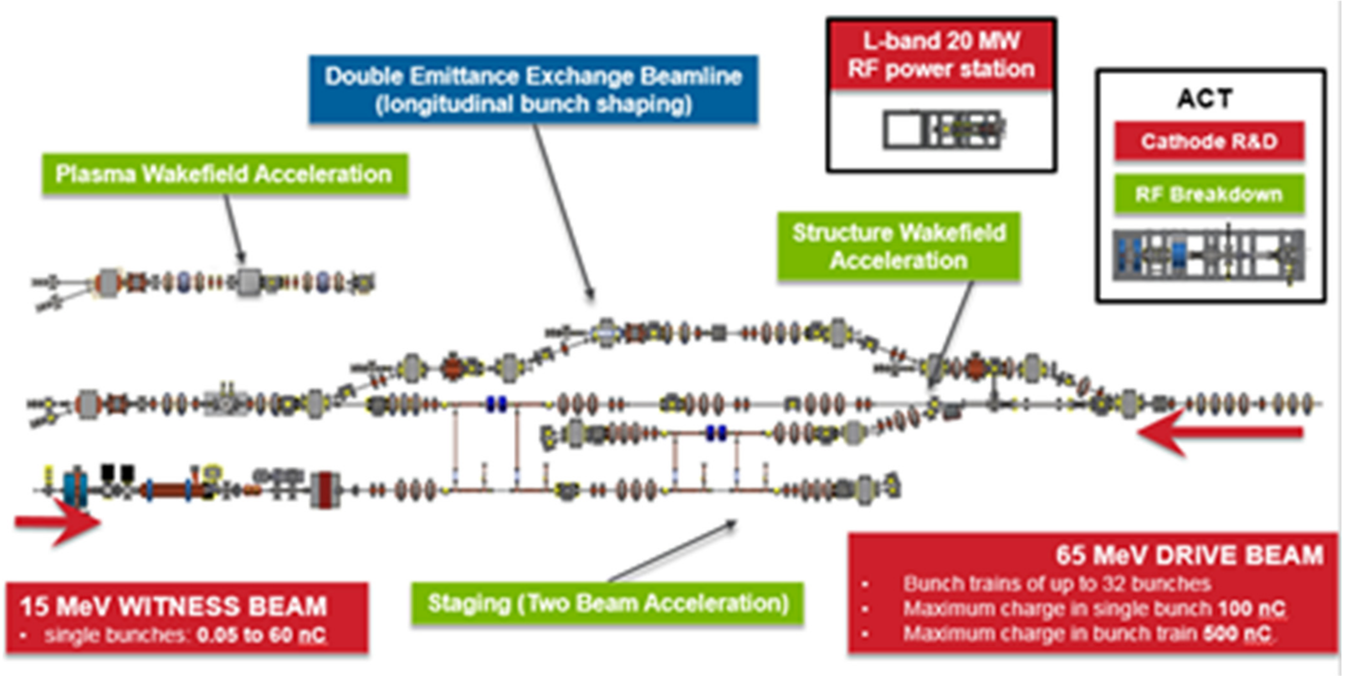
# OUTLINE

- Motivation
- Results from breadboard prototyping
- Result from PCB prototyping
- Solutions for signals from low charge beams
- New front end design with dynamic range covering pC to uC
- Preliminary design for the controller
- Summary

# MOTIVATION

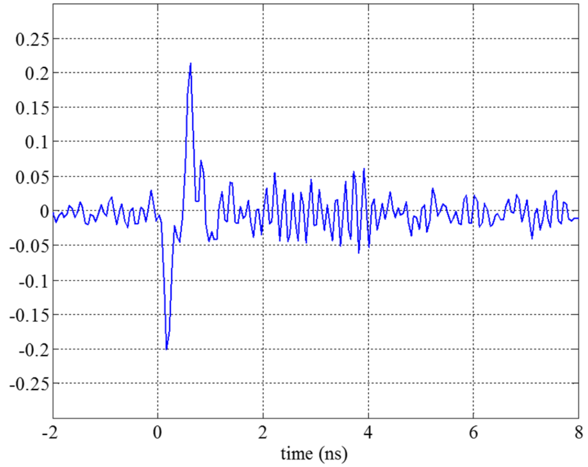
- BPM is a great beam monitoring and diagnose device.
- There are many places on our beamline can use some helps from BPMs.

- The electronics for processing the signals are expensive for a small facility like AWA to own in quantity.
- We decided to develop our own low cost processing circuitry to fit in our budgets.

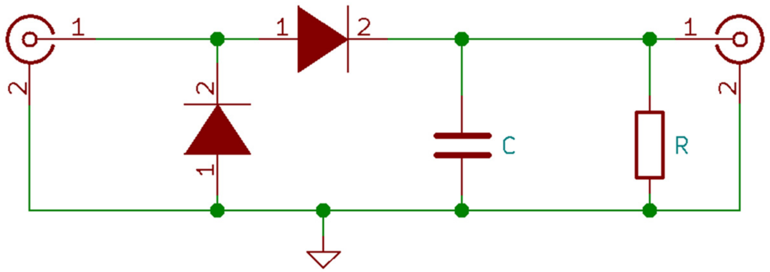


# OUR TYPICAL BEAM PARAMETERS AND BPM PICKUP RESPONSE

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

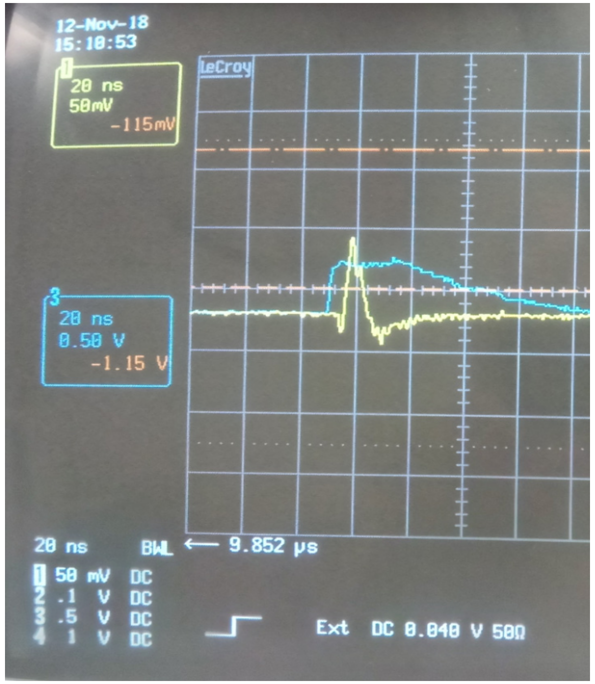


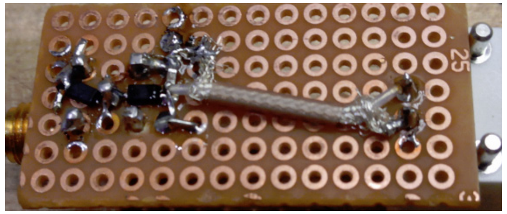

The response from BPM pickup to AWA electron bunch is typically a negative pulse with a pulse length of about 100ps FWHM followed by a positive pulse.



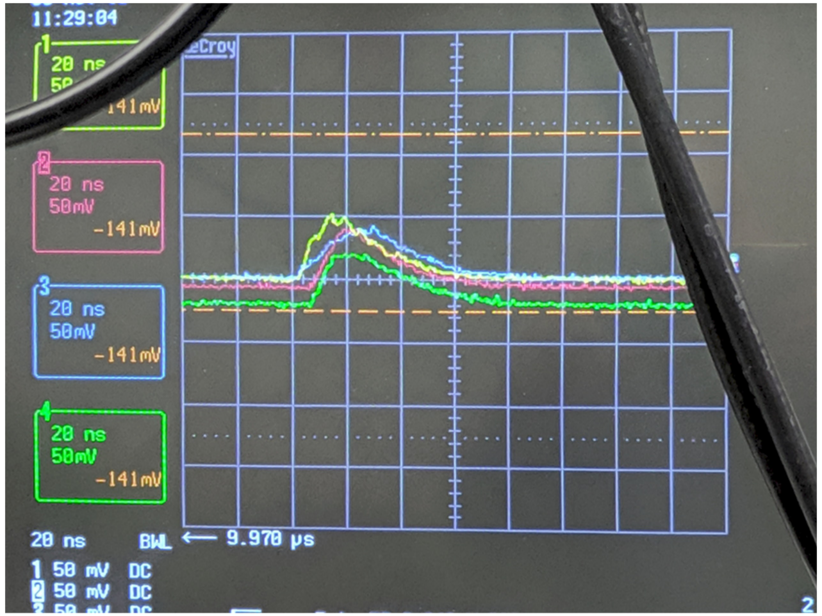

Based on the fundamental physics on how BPM pickup works, the BPM pickup can be treated as a pulsed current source. So it is possible that we can use a fast diode to rectify the signal and store the captured charge on to a capacitor. By selecting the capacitance of the capacitor, we should be able to select between a wide dynamic range of the charge intensities.

# SIGNAL FROM 1ST AND 2ND PROTOTYPE CIRCUIT – SIMPLE HALF WAVE RECTIFIER



2nd version




Comparing 1st and 2nd version

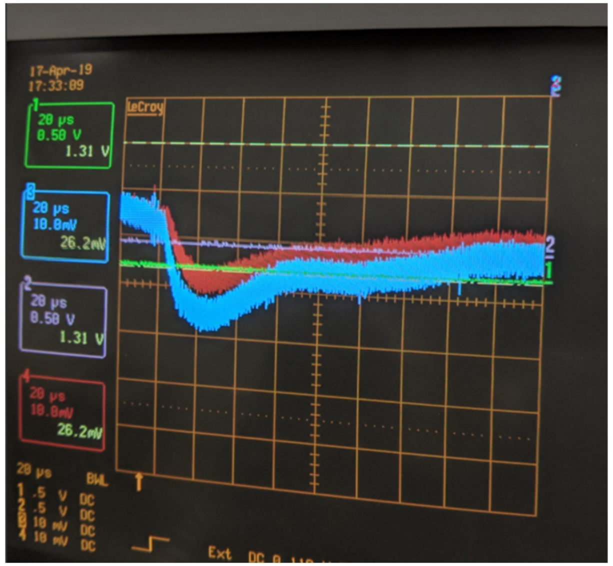
Signals from button BPM after the detector circuit

The 1st and 2nd version are essentially the same except the 1st version used regular rectifier diode while the 2nd version used surface mount Schottky diode. The 2nd version yields a much stronger signal.
4 "identical" circuits were made and tested with a button BPM on our witness beamline. The charge was about 1.5nC

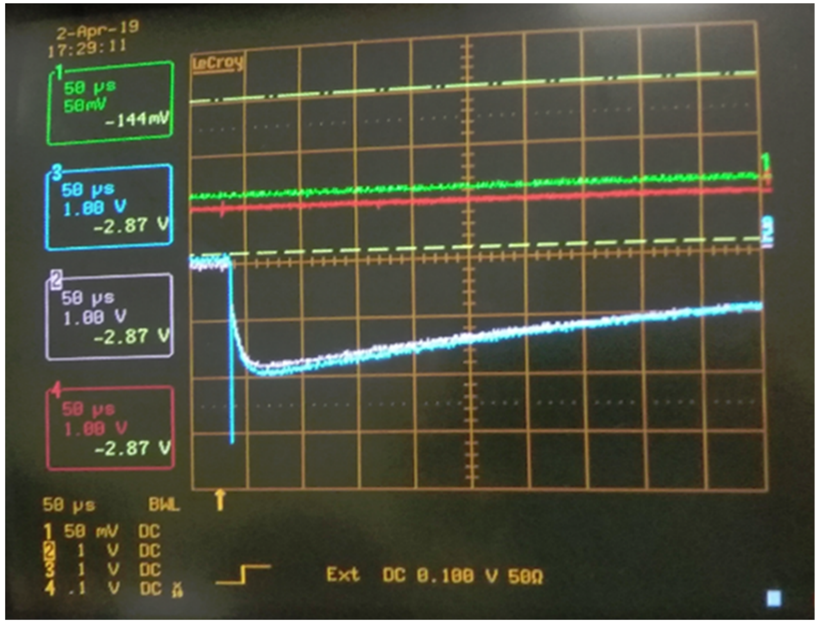
# A HALF WAVE RECTIFIER FOLLOWED BY A VOLTAGE FOLLOWER

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 .



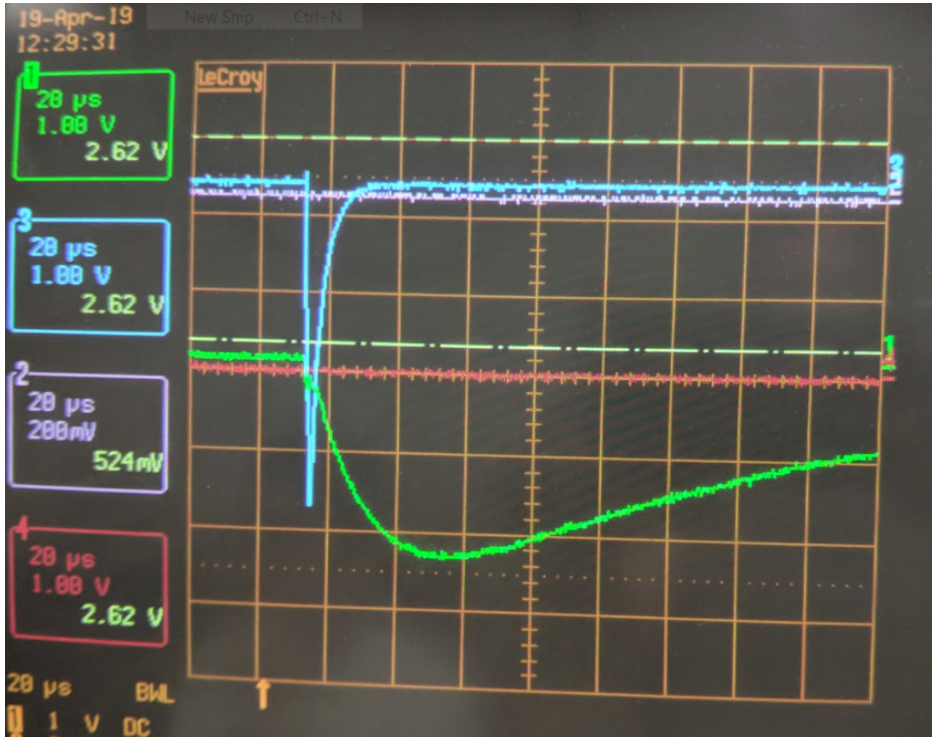

From the test, with the strip line BPM on our drive beam line, the lowest charge it can detect was about 100pC.




The charge in electron beam is about 10nC

# 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.

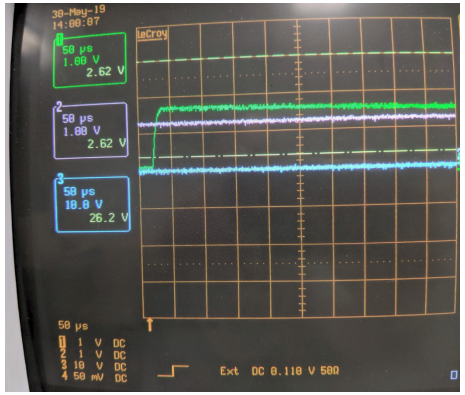


# USING A MODIFIED PEAK DETECTOR

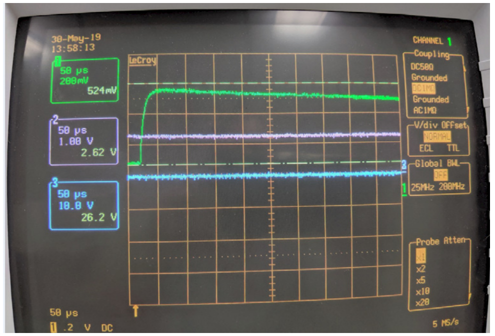
One prototyping circuit was modified again into a modified peak detector circuit. The schematic of this circuit is given here.

This prototype was then tested with a button BPM

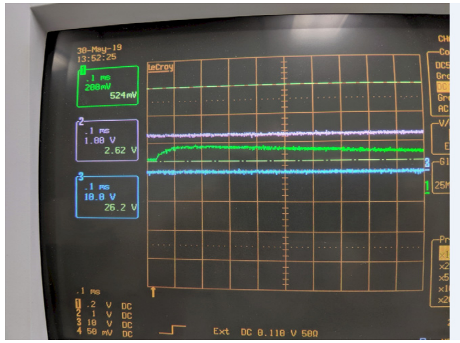
The signal is about 2.7V for 28nC



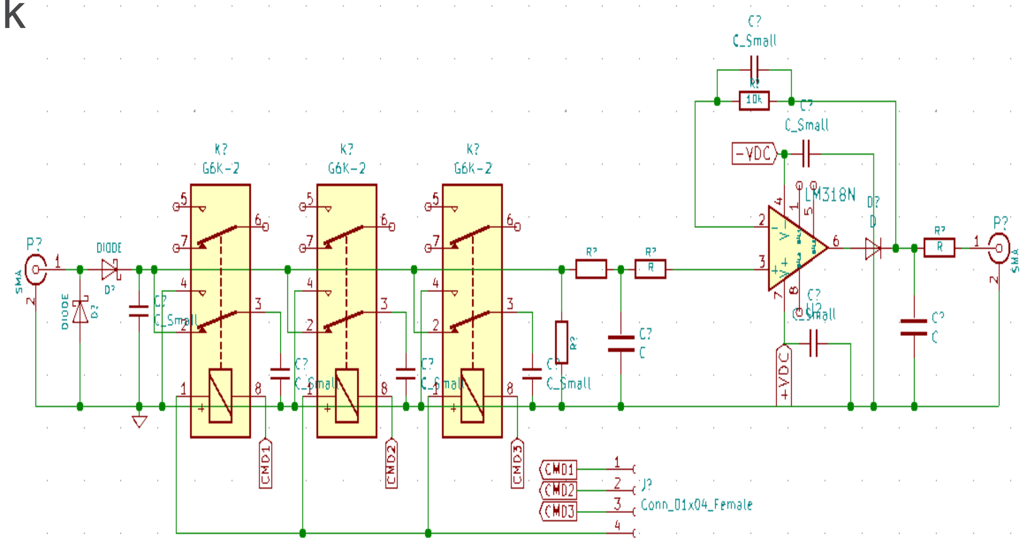
The signal is about 1.7V for 17nC



The signal is about 0.48V for 4.5nC



The signal is about 0.09V for ~1.5nC

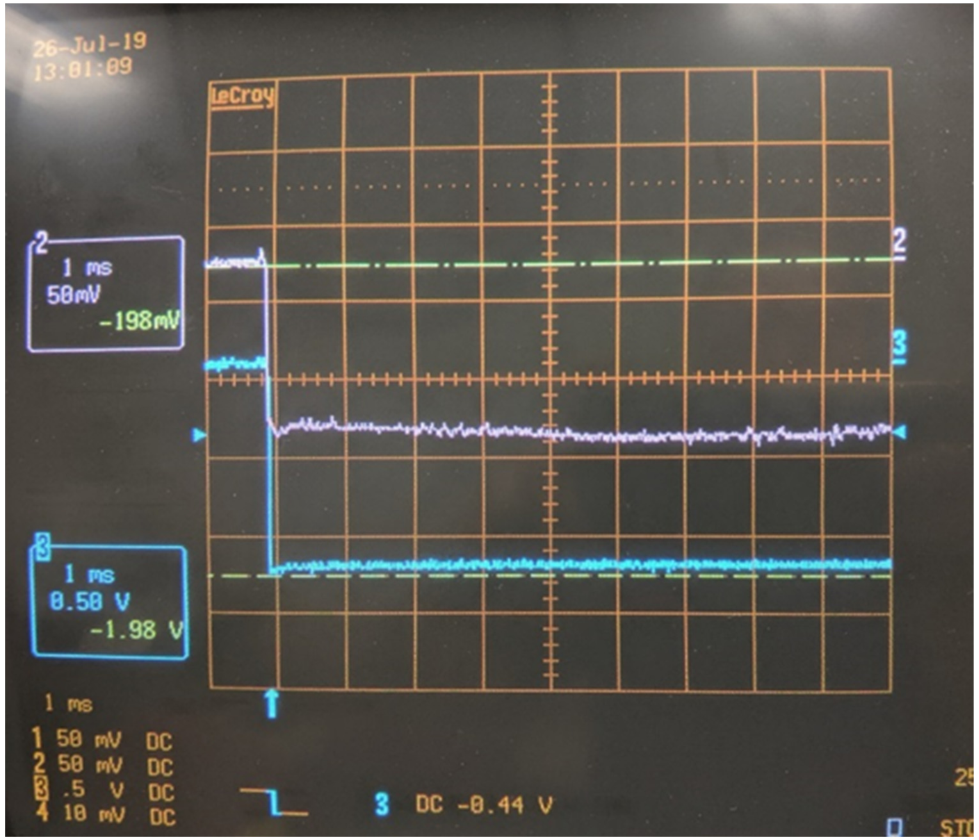



The lowest charge detected by this prototyping circuit was about 1.5nC with the button BPM. The circuit was built this way just to see if the positive going pulse can give us enough signal so that we don't need to invert the signal later.

# PCB PROTOTYPING --- RESULTS WITH BUTTON BPM PICKUP SIGNAL

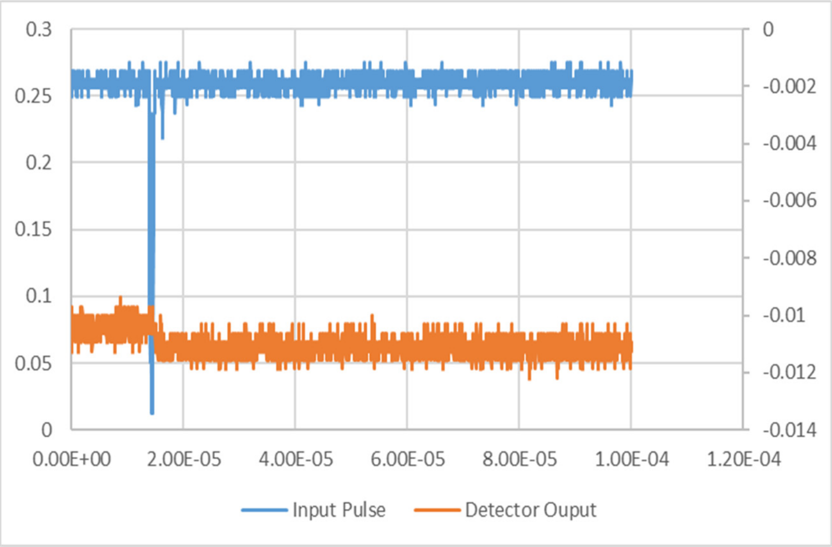
- Objective:
  – Testing diode biasing option to see if it can increase the sensitivity
  – Prepare for down stream circuit development.

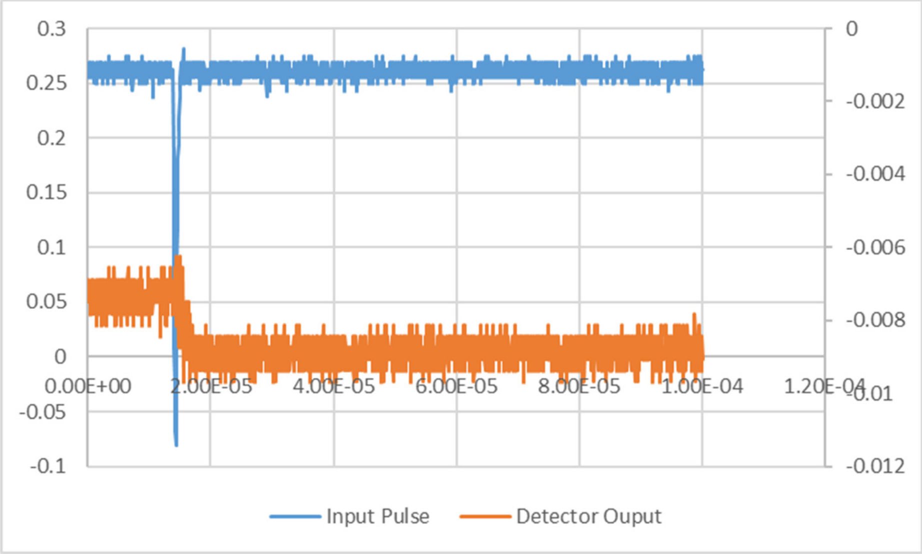
- Channel 2 is a circuit with biased diode while channel 3 is connected to a circuit without bias.
- Biased circuit also has a smaller RC constant on purpose and thus should give stronger signal when other factors are the same.
- Scope traces are taken with MOhms termination.
- The signal from circuit with bias is about 10 times smaller than the one without bias.
- The signal from biased circuit did appear with smaller charge when the other signal has completely gone.



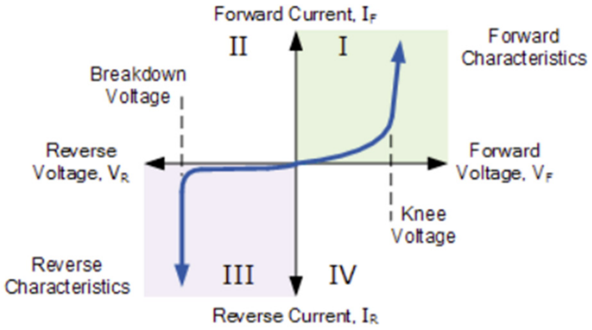
# PCB PROTOTYPE ---BENCH TEST

The effect of diode biasing, bench tested with a pulse generator




- With the biased circuit, the circuit can response to input pulse as low as about 250mV. But comparing the response to 350mV(right figure) and 250mV (left figure), the excitation changed by about 100mV while the response changed only about 2mV at most.
- Thinking about the problem a bit more deeper and we found out why biasing is not going to help.

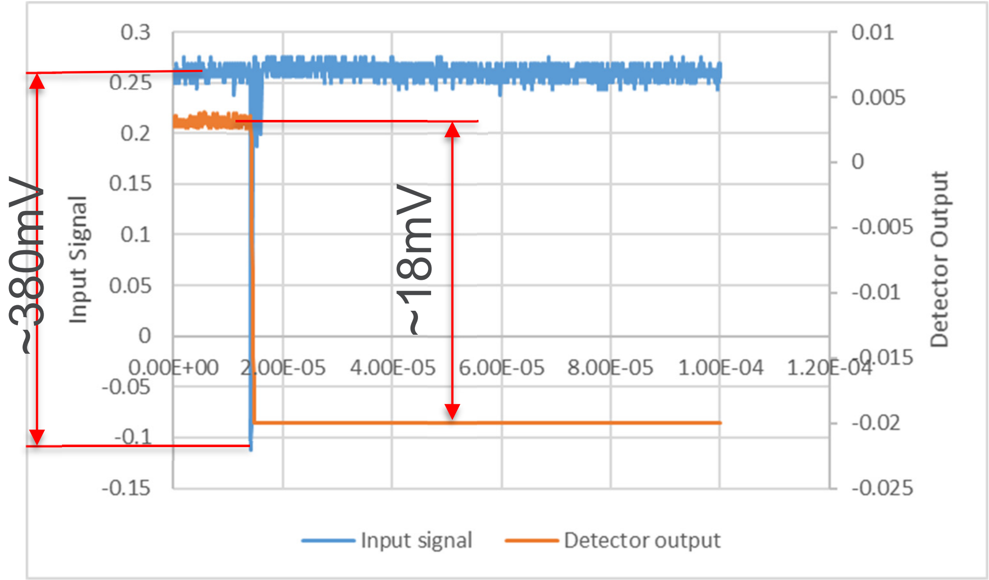


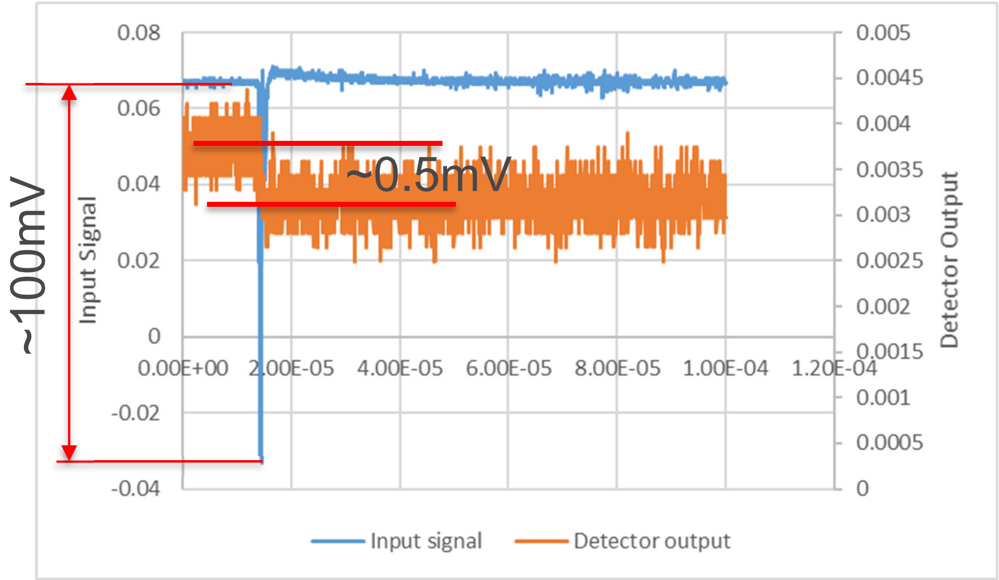

A typical diode I/V curve explains why biasing is not going to help with sensitivity

https://www.electronics-tutorials.ws/blog/i-v-characteristic-curves.html

# PCB PROTOTYPE ---BENCH TEST,

## Resonator based circuit



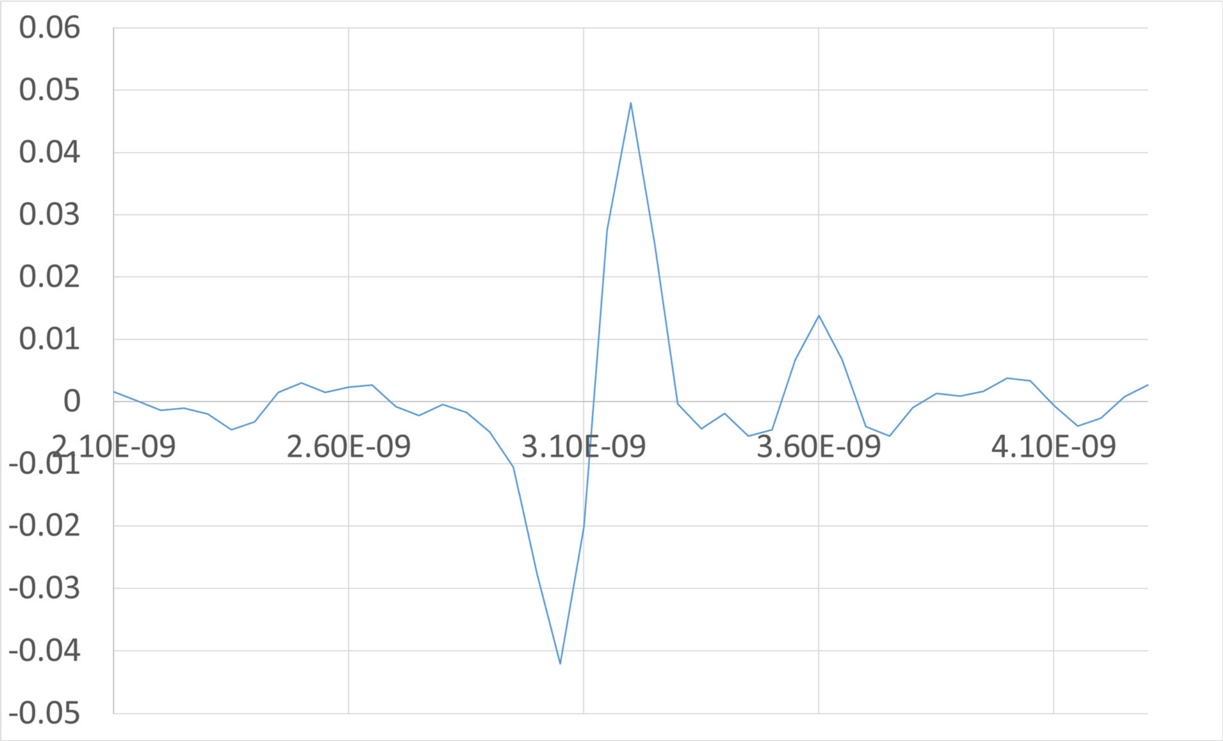

By replacing a resistor with inductors and shunt off the diode, we turned the circuit into a resonator based detector.

Resonator based circuit has strong response at where the diode based circuit near shutoff. For a ~380mV pulse, the resonator based circuit has an output of about 18mV. The circuit still response to input as low as about 100mV.

But again, there is still a limit at about 100mV which is still bit too high.

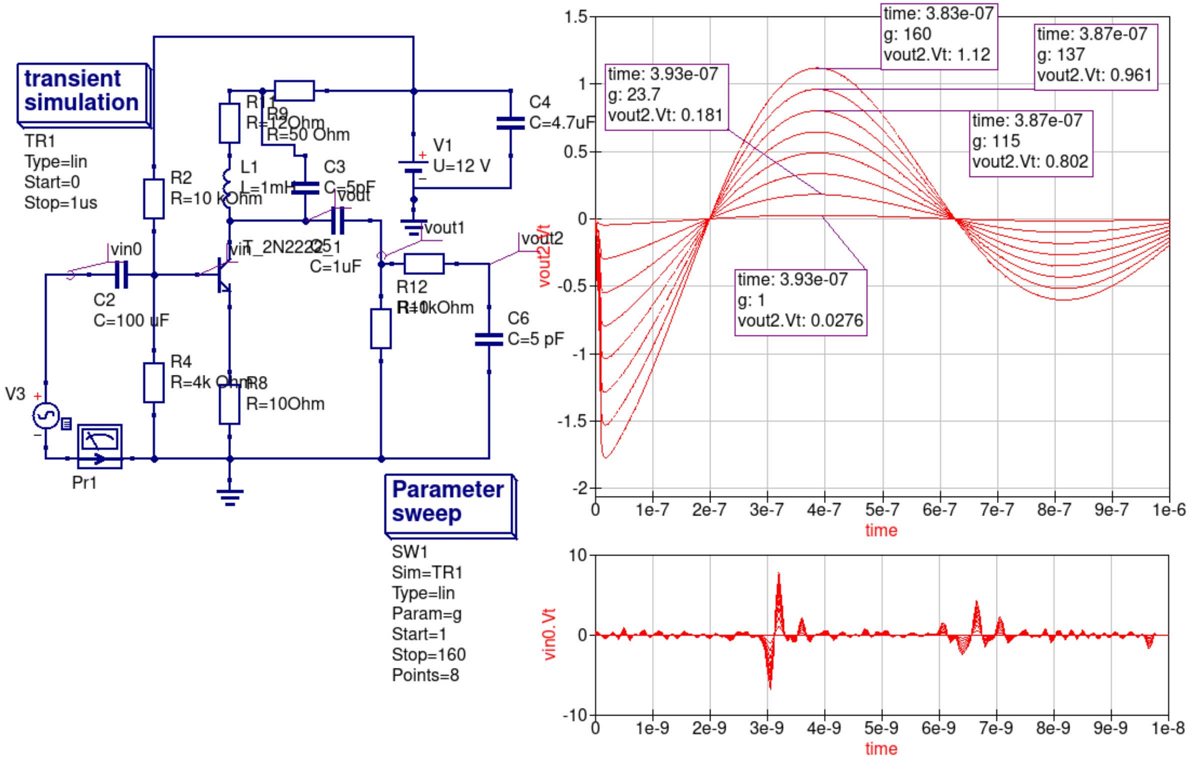
# BPM SIGNAL FROM LOW CHARGE BEAM (<100PC) WITH AN IN-FLANGE BUTTON BPM

- The signal from in-flange button BPM is really weak for low charge beam. The sum of all four channels is just about 50mV for about 100pC beam.
- Given the fact that there is a loss of about -7.8dB on the cable sending this combined signal back from BPM to the scope, the signal at BPM will be about 123mV /4 ~ 31mV per channel. And it is much lower than the detectable level of the prototype circuit.
- For electron bunch with few pC, the signal from in-flange button BPM will be in the mV to sub mV level.



# 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.

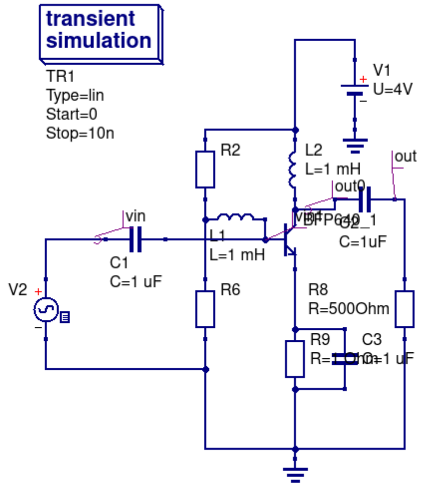


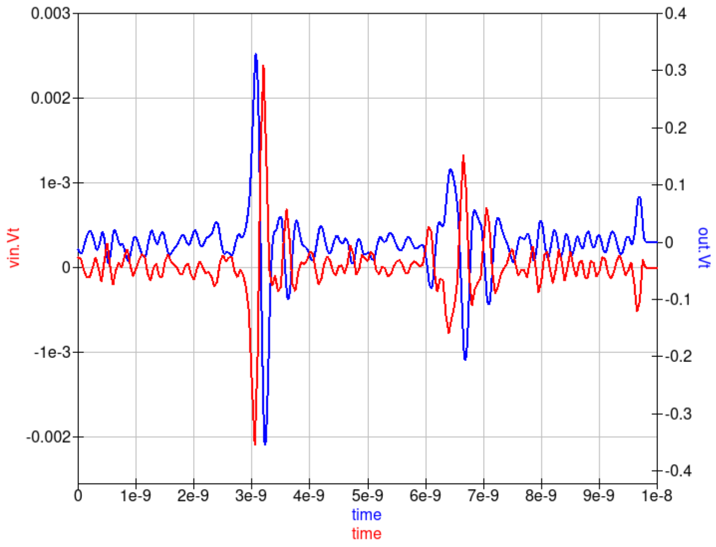

As showing in the simulation results using 2N2222, the circuit is good for BPM signals from 50mV up to about 8 volts.

# SOLUTION FOR BUTTON BPM WITH EXTREMELY LOW CHARGE INTENSITY BEAM

- When charge intensity is less than 10pC, with the button BPMs, the signal will be mini volts to sub mini volts level.
- Signals from the circuit proposed in previous slide will also be very weak and it will be very hard to handle for down stream circuits.
- A high speed small signal voltage amplifier can be used to amplify the signal before using active filter to generate the associated low frequency signals.

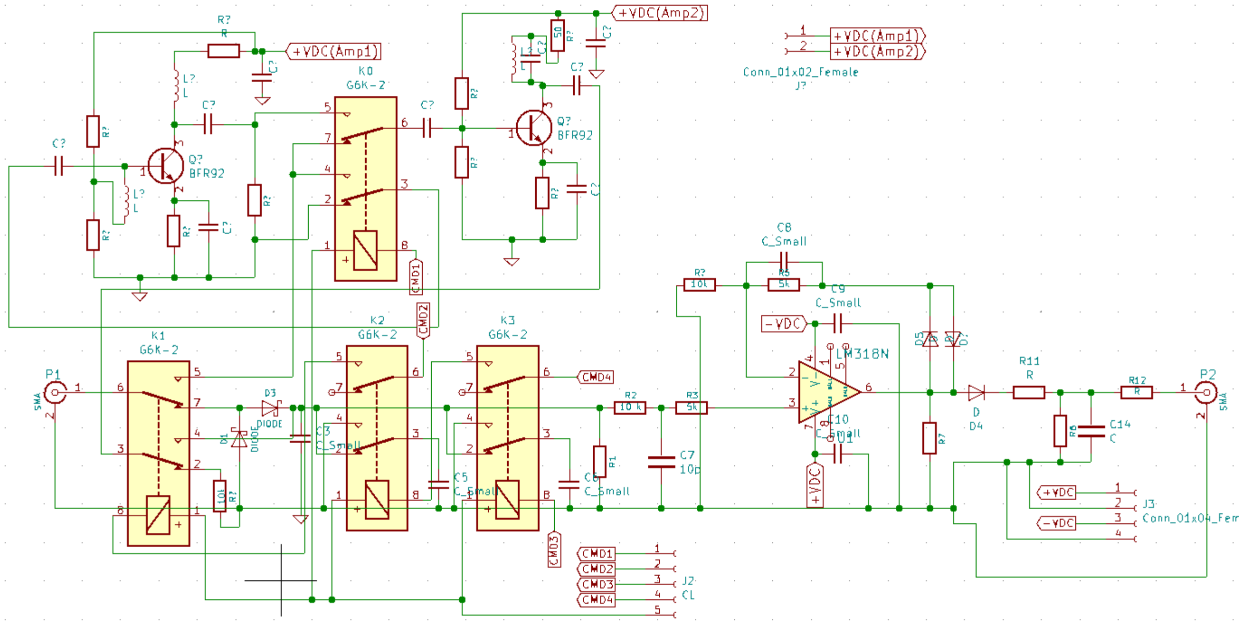
- A simulation using BFP640, a NPN RF transistor, has shown that a voltage gain of about 100 can be achieved with a load about 500Ohms. As long as we can get input impedance of active filter to about 500 Ohms, the circuit in the simulation should be able to properly amplify sub mini volts signals to a level good for active filter circuit to work on.



# THE NEXT PROTOTYPE DETECTOR CIRCUIT

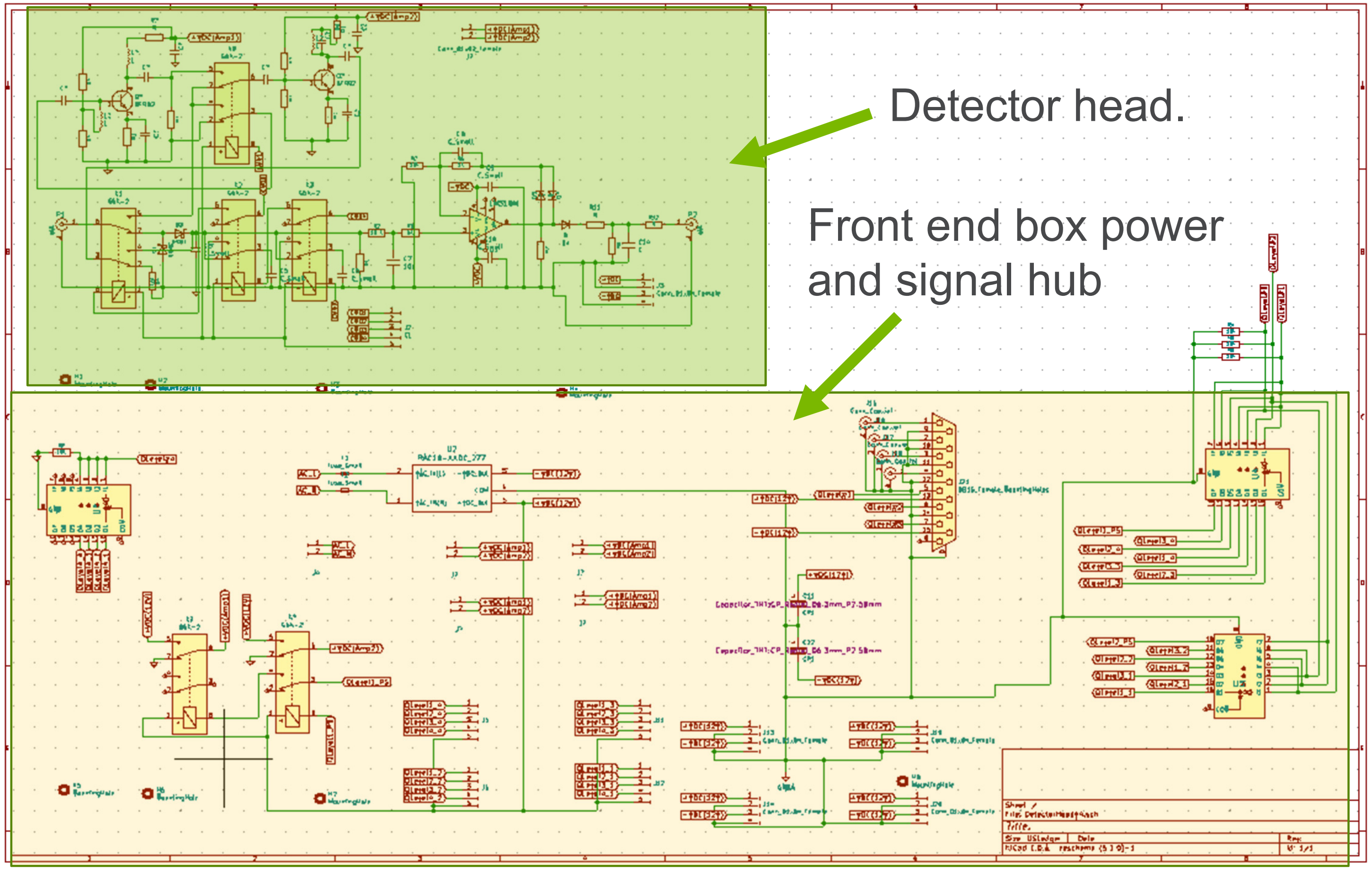
- An updated schematic for our next PCB prototype is attached.
- This version will have 5 selectable charge levels.
- For the lowest charge level, all 4 relays will need to be energized. Signal will first be amplified and then active filtering will be used before the modified peak detector.
- For the 2nd lowest charge level, the last relay, K0, will not be energized while all other 3 will be. 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 to get better signal resolution.




2n2222 will be used in the active filtering circuit while we will evaluate and test BFP640 or other RF transistors for the amplifier stage.

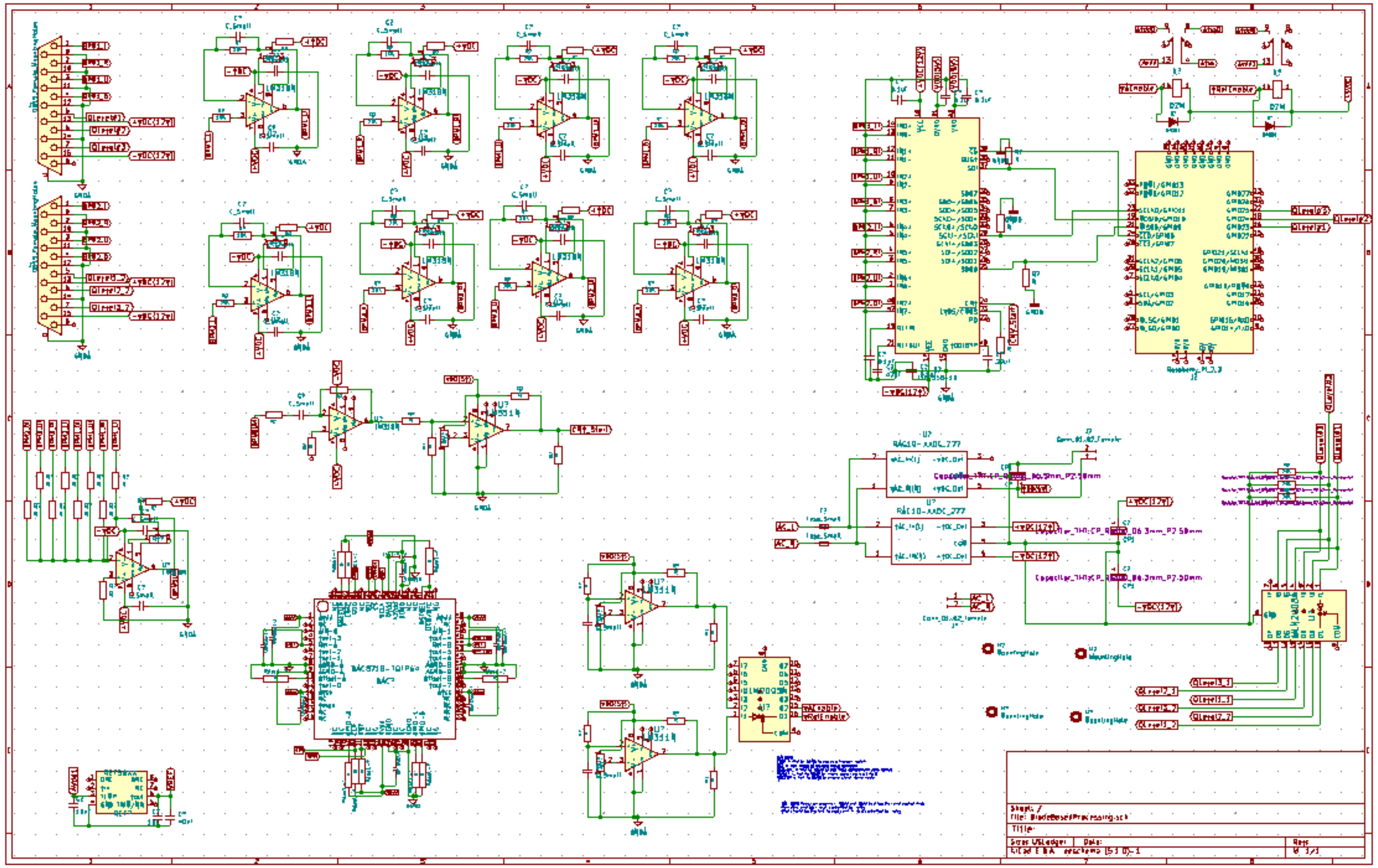
# UPDATED PLAN FOR THE BPM FRONT END.

- Each BPM will be connected to one front end box
- Each front  end box has 4 detector head circuit.  One for each channel.
- Each front end box  has 1 power and signal hub circuit.
- BPM signal from detector head will be gathered from detector head 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



# THE PLAN FOR CONTROLLER BOX

- Each control box will serve two BPMs through two DB15  cable.
- BPM signals from front end box are all connected with a voltage follower.
- The output from voltage followers will be routed to an 8 channels 18 bit simultaneous sampling ADC, LTC2358-18.
- We have two trigger options:
    - Self trigger: all 8 channels BPM signal will be summed and passed to a differentiator followed by a voltage comparator to generate the trigger
    - External trigger: Using 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.



# SUMMARY

- The low cost BPM signal processing circuitry development for AWA successfully prototyped the BPM signal detector head for charge intensity ~nC and above.
- The prototyped detector head circuit can turn the fast BPM signals into a very slow signal suitable for low speed ADCs to read them out.
- The circuit is designed to be able to switch between different signal dynamic range/ charge level with digital control signals from a controller.
- Sensitivity enhancement circuit has been designed and will be tested after the new PCBs are made.
- Preliminary design of controller circuit is done and prototyping controller circuit will be made when resources are made available.

# THANK YOU


Double Emittance Exchange Beamline (longitudinal bunch shaping)
L-band 20 MW RF power station
ACT
Cathode R&D
RF Breakdown
Plasma Wakefield Acceleration
Structure Wakefield Acceleration
65 MeV DRIVE BEAM
Bunch trains of up to 32 bunches
Maximum charge in single bunch 100 nC
Maximum charge in bunch train 600 nC
15 MeV WITNESS BEAM
single bunches: 0.05 to 60 nC
Staging (Two Beam Acceleration)