An Sampling Detector for the RHIC BPM Electronics*

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Abstract

The analog detector electronics for the RHIC BPM Instrumentation is described. The detector employs a self-triggered peak detection algorithm for single bunch acquisition of beam position. Optimization of the design for low noise gives excellent position resolution, an internal self-calibration system insures position accuracy to well within the RHIC instrumentation system specification, and switched attenuation and gain insures very broad dynamic range. Design history, current implementation, and test results are described.

I. REQUIREMENTS

The following points, as previously stated [1], summarize the specifications and design philosophy of the analog front end:

1. Single bunch acquisition - bunching frequency is 8.9MHz (112nsec period).
2. Maximum bunch acquisition rate: 78 kHz (the revolution frequency) (12.8µsec period).
3. Position uncertainty at center for entire system (BPM + electronics): <0.13mm.
4. Single bunch resolution for commissioning (single bunch, 10^{10} protons per bunch): <1mm.
   For operating storage (>10^{11} protons per bunch, or 10^{9} gold ions per bunch): <<0.1mm
5. Bunch-to-bunch coupling: < -60dB
6. Instantaneous Dynamic Range: >17dB.
   Programmable attenuation: >30dB.

II. DESIGN APPROACH

The specifications above, when examined closely, require a sensitive, fast and repeatable detector with broadband response.

Broadband response is necessary to obtain single-bunch acquisition with sufficiently small bunch-to-bunch coupling in the 112nsec period between successive bunches. Narrowband detectors are feasible only if a fast switch is used in front of the front end filters to select a specific bunch. However, the trade-offs between switch speed, cost, survivability, and maximum distortion-free amplitude make this impractical.

This presents a problem as most high sensitivity detectors, in fact most RF detectors in general, are narrowband. Most BPM Electronics schemes currently in use employ narrowband techniques: AM/PMs, the SPS Homodyne detector, and the SSC Log Ratio detector all rely on the ringing response of a narrow bandpass filter to obtain a CW signal for detection. While the output amplitude of these filters is small when compared to the peak amplitude of the BPM output, the reduction in input noise from both the narrow bandwidth of the front end filter and the detector output filter (usually lowpass, with a bandwidth equal to or less than the front end filter) keeps the SNR high.

However, these same filters, with their long ringing response, would induce too much bunch-to-bunch coupling in RHIC to be of any use for single bunch acquisition.

Two designs have been extensively developed for the RHIC BPM Electronics: a broadband synchronous detector, and a self-triggered peak sampling detector.

III. SYNCHRONOUS DETECTION

The synchronous, or homodyne, detector has a long history in RF engineering. The version developed by the RHIC instrumentation group [1] used matched 40MHz BW/70MHz center bandpass filters to condition the signal for the detector. These time response of these filters was carefully designed to reduce bunch to bunch coupling, with the bunches separated by 112nsec, to less than 60dBs. The BPM signals were then divided with RF splitters and half of each combined and input into the LO generator chain, which consisted of four Plessey SL532C limiters, a threshold comparator (to eliminate oscillation - a big problem in synchronous detectors, especially when the input signal is not continuous), RF amplifiers and a splitter whose outputs drive the LO of two double-balanced mixers. The filtered BPM signals, from the other outputs of the first two splitters, were connected to the RF mixer inputs through coaxial cable, matched in electrical length with the delay time of the limiter chain. The IF output of the mixers was then lowpass filtered (20MHz BW) and integrated over the length of the bunch response and then digitized.

This design proved to be impractical, inaccurate and expensive. Many problems were discovered trying to improve the linearity of the detector. For instance, we found that the reflected power from the lowpass filter was entering the mixer through the IF port and self-mixing, inducing a strong amplitude-dependent nonlinearity. This was corrected by terminating the IF mixer output and using a Harris high-frequency closed-loop buffer to drive the filters. Even at this point, our parts count was getting high (including 2 pairs of matched filters) and the per channel cost was becoming prohibitive. We then found the integrator was too sensitive to low frequency noise, and replaced it with a Track and

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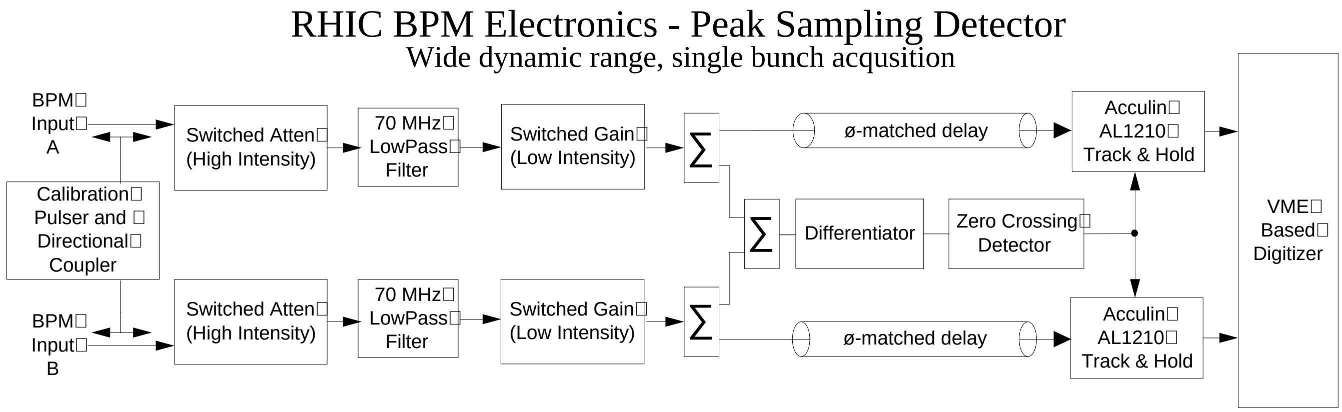


Hold sampler. However, consistent operation of the sampler required some form of self-triggering, and at this point we wondered if a Track and Hold sampler could be found with better specifications than the mixer. Both the AD9100 and the Acculin AL1210 had far better linearity than any available mixer and both have sufficient bandwidth to use as the detection element in the BPM electronics.

The synchronous detector design was then abandoned, and we attempted to find a reliable way to use the Track and Hold samplers for peak detection.

IV. PEAK SAMPLING DETECTION

The decision was made to use a 70MHz Bessel lowpass filter on the front end. This reduced the number of matched filter pairs to one, from the two required for the synchronous detector.

Evaluating the Track and Hold samplers, we selected the Acculin. Although the linearity is not quite as good as the Analog Devices part, the AL1210 is much smaller, dissipates far less power, and has over twice the bandwidth (up to 400MHz small signal BW).

Once the samplers were selected, the main design challenge was the generation of a self-trigger signal time-aligned to the input signal maximum to drive the Track and Hold samplers. This is typically accomplished by differentiating the BPM signal (a pulse doublet) and using a zero crossing detector to generate a digital edge correlated to the first peak of the BPM signal.

Building an active differentiator presents several practical problems. Just as an integrator with gain is very sensitive to low frequency noise, a differentiator with gain is very sensitive to high frequency noise. Fortunately, there is sufficient signal amplitude out of the RHIC BPMs to use a passive differentiator and still maintain adequate instantaneous dynamic range. Our passive differentiator is simply a 16pF series capacitor followed by a 50 ohm termination to ground.

The zero crossing detector is made up of an SPT9689 ultrafast comparator wired in a schmitt trigger configuration with a chain of Plessey SL532C limiters on the input. The limiter chain keeps the same peak-to-peak voltage on the input of the comparator to avoid the dispersion in propagation delay as a function of input amplitude. The dynamic range of the self-trigger, in fact the instantaneous dynamic range of the entire detector, is thus determined by the limiter chain.

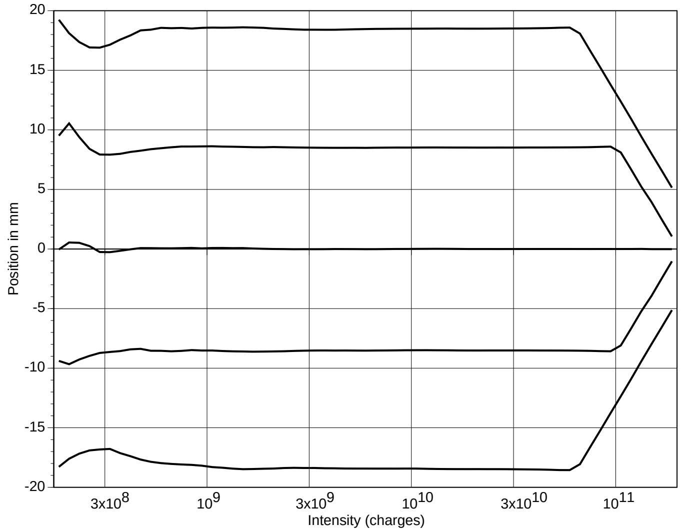
Further timing is performed with an array of one-shots, ECLinPS Lite gates and flip-flops. The circuit is setup to allow the ENABLE gate (all self-triggered detectors must be gated to prevent triggering on random signals) to trigger the Track and Hold samplers and concurrently the digitizer itself if no self-trigger took place within the gated period. In other words, the falling edge of the ENABLE gate will activate the Track and Hold samplers and the timing chain, but only if no self-trigger took place within the time that the ENABLE signal was high. A DATA VALID bit is included to differentiate between self-triggered data and data sampled by the falling edge of the ENABLE gate. This bit is high only if the timing chain was self-triggered by the input signal. The DATA VALID bit is latched and the ADCs are triggered by an ADC_TRIG output signal, also generated by the ECL timing.

V. ADDITIONAL CIRCUITRY

In order to increase the dynamic range of the detector above and beyond the instantaneous dynamic range, switched gain and attenuation have been added to the front end. While -10dB, -20dB and -30dB of attenuation can be switched into either channel independently, due to phase matching constraints the +10dB, +20dB and +30dB of available gain can only be switched into both channels simultaneously.

A pulser and stripline coupler have been designed into the circuit to allow for in-place calibration of the electronics. The coupler allows a matched, pulsed signal to be generated either into the detector or out of the detector into the BPM cables. The “inward” going pulses will permit continuous calibration of the circuit to verify and maintain the position accuracy, while the “outward” going pulses can be reflected off the BPMs and their return can be measured by the detector, which will allow continuity and loss checks of the cabling to be made periodically.

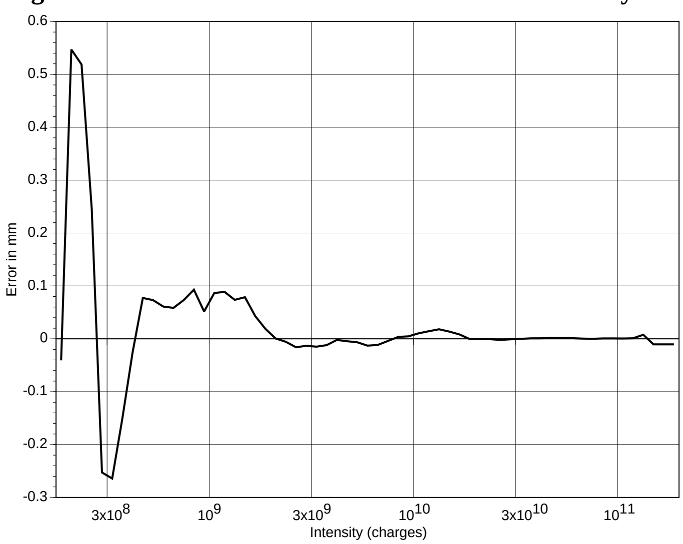
Figure 1. Position Response vs. Intensity



VI. PERFORMANCE

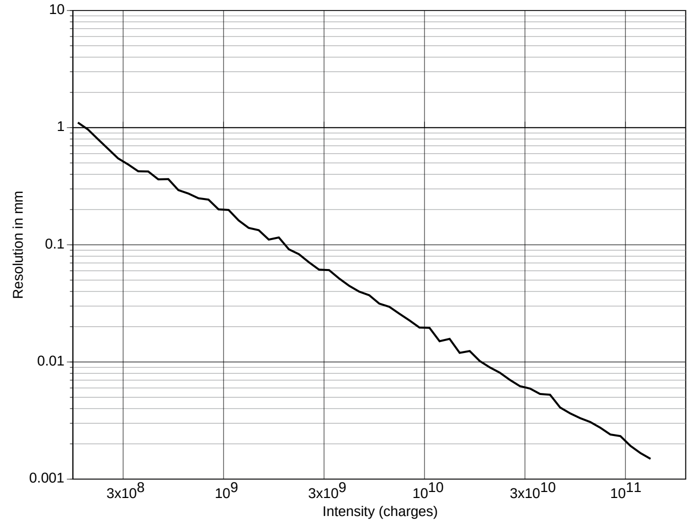
Position response of the detector is shown in Figure 1. The detector shows excellent precision over the RHIC dynamic aperture (+/-20mm) and has a accurate, full aperture instantaneous dynamic range of greater than 35dB. Combined with the switched attenuation and gain, this would give the detector a full dynamic range of approximately 90dBs, although the accuracy will suffer at higher levels of added gain.

Figure 2. Error on Centered Beam vs. Intensity



Error for centered beam is shown in Figure 2. As can be seen from the graph, the accuracy over the top 30dBs of dynamic range for centered beam is better than +/-.025mm. As the beam offset from center increases, this accuracy will decrease, but will remain within spec (+/- 0.1 mm) over the full dynamic aperture.

Figure 3. Resolution vs. Intensity



Resolution in mm RMS for centered beam is shown in Figure 3. The obvious linear response without saturation or rolloff indicates the presence of a constant noise source unrelated to the input signal. This source is in fact the injected noise inherent in the track and hold amplifier, which we were unable to reduce. Input noise will only approach this injected noise power when the switched gain is set to it's maximum (+30dBs).

VII. FUTURE DIRECTIONS

Calibrator coupling is balanced but amplitude is not as good as predicted. This is most likely due to the small trace size of the coupler striplines, the high sensitivity of the coupling to errors in size and separation of the traces, and the poor homogeneity and accuracy of the dielectric constant of the PCB substrate (FR-4). In future designs, we would like to build the coupler on a separate RT-Duroid substrate.

VIII. ACKNOWLEDGMENTS

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IX. MORE INFORMATION

For more information, including schematic copies and extended report on this circuit, please contact:

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X. REFERENCES

[1] W.A Ryan and T.J. Shea, A Prototype BPM Electronics Module for RHIC, Proceedings of the 1995 Particle Accelerator Conference, pp.2310-2312.