RHIC ELECTRON DETECTOR SIGNAL PROCESSING DESIGN*

J. Gullotta†, D. Gassner, D. Trbojevic, S. Zhang
Brookhaven National Laboratory, Upton, NY 11973, USA

Abstract

The RHIC gold beam intensity is presently limited by pressure rise at some warm sections, and the main cause is thought to be the electron cloud. For the FY2003 RHIC run, a system has been installed to characterize the electron cloud, if it exists. The system is comprised of electron detectors, high voltage bias supplies, signal amplifiers, and data acquisition electronics, all integrated into the Controls system. The 11 detectors are grouped into four locations, one in an interaction region and three in single beam straight sections. This paper describes the signal processing design of the detector system, and includes data collected from the FY2003 run.

INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory has eleven electron detectors installed for measuring the electron cloud density in the beampipe. This paper will describe the construction, specifications, and tolerances of the RHIC electron detector system. Actual results are presented and discussed as a verification of the system's usefulness as a tool to measure the electron cloud.

OPERATIONS

During the FY2002 RHIC Au-Au run, intensity was limited to $5 \times 10^8\, ions/bunch$ while running $110\, bunches/fill$. The limiting factor was vacuum pressure rises which caused the beam to abort. These pressure rises were linked to beam intensity and thought to be caused by the beam interacting with electron clouds in the beampipe. Design intensity of RHIC is $10^9\, ions/bunch$ at $110\, bunches/fill$. This limitation caused the machine to run at just over 50% of design intensity.

We are currently running deuteron on gold(d-Au) collisions in the FY2003 run. For the FY2003 d-Au run, intensity has been lowered to avoid electron cloud limitations, so there have been considerably less pressure rise events. However, during a dedicated beam studies period, intensity was maximized to induce pressure rises. A single event that resembled electron cloud multipacting occurred coincidently with a major pressure rise.

Machine Timing

At 100GeV, RHIC has a revolution period of $12.789\, \mu sec$ and therefore a revolution frequency of $78.193\, kHz$. There are 360 RF buckets around the whole ring. While we are running 110 bunches we fill every third bucket, and leave ten consecutive spaces (30 buckets) empty for the abort gap. The length of one RF bucket is $35.53\, nsec$. The time from the head of one bunch to the head of the next is $106.575 nsec$, with a periodicity of $9.383 MHz$. The abort gap is $1.066 \mu sec$ long.

Electron Cloud Structure

Figure 1 shows RHIC electron detector signal corresponding to a vacuum pressure rise during fill 3107. Figure 2 is a wall current monitor trace showing the bunch structure for fill 3107. Notice the two groups of low intensity bunches which cause a weaker electron cloud signal. The wall current monitor signal is acquired by a scope sampling at 4GS/sec. Therefore the x-axis of figure 2 is $1/4 nsec$ counts. The y-axis of figure 2 is an arbitrary scale used for relative bunch-to-bunch measurements. The electron cloud signal is sampled at 1GS/sec, so the x-axis in figure 1 has units of nanoseconds. The units of the y-axis of figure 1 are millivolts, with an arbitrary DC offset.

The data in figure 1 shows the only time that electron multipacting is thought to have occurred during the FY2003 d-Au run. The beam was lost due to a vacuum pressure rise about 20 seconds after the data in figure 1 was taken. Evidently, the scope was set to too high of a resolution because saturation occurs before the end of a single turn. In subsequent samplings (not shown) during this fill, the scope is saturated as soon as sampling begins. However, the structure of the signal in figure 1 closely resembles previous research on this topic [4].

According to the physical models and simulation results, we were expecting to collect electron cloud current on the order of $50 \mu A$ during electron multipacting. The detector drives an amplifier input with an impedance of 50Ω. Therefore, the expected voltage to be seen on the output of our 32dB amplifier is 100mV minus cable losses.

During fill 3107, the scope saturated during the first turn in which data was logged, corresponding to at least 80mV of collected signal. We can only hypothesize that the maximum signal collected was much larger than 80mV before the beam was aborted 20 seconds later.

SYSTEM LAYOUT

The detectors are located in the ring at four major locations. One group, having two detectors, is at the 12 o'clock interaction region. The other three groups are located in straight sections in 12, 1, and 2 o'clock and are constituted of the other nine detectors. The signal amplifiers are all located in the ring within 5 feet of each detector. The

* Work performed under the auspices of the U.S. Department of Energy
† Email: gullotta@bnl.gov

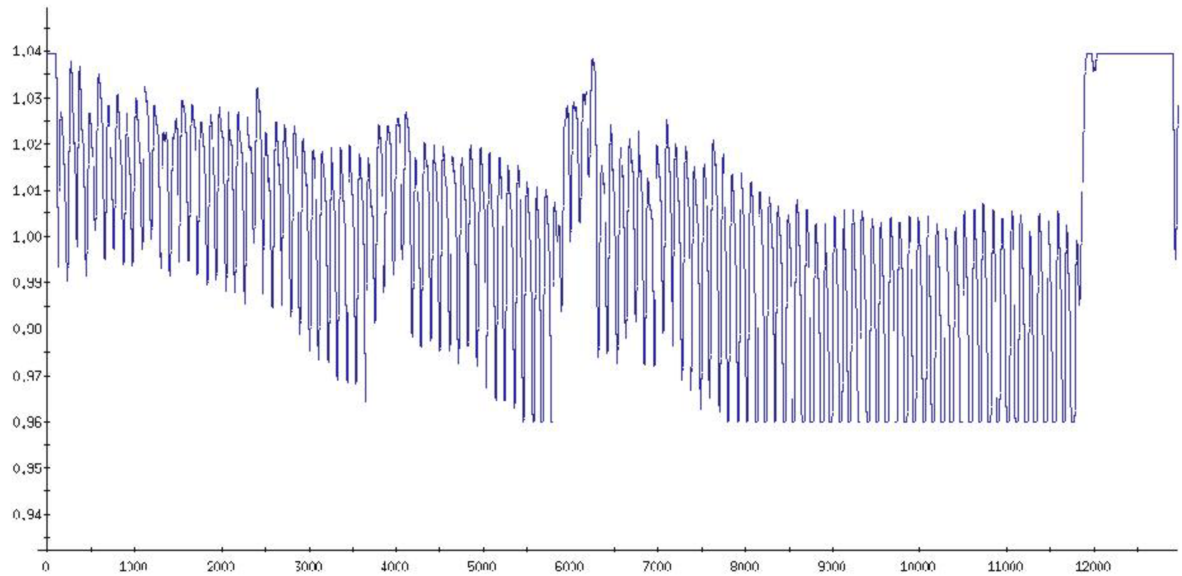

Figure 1: Electron detector signal for one turn during electron multipacting. FY2003 d-Au run, fill 3107

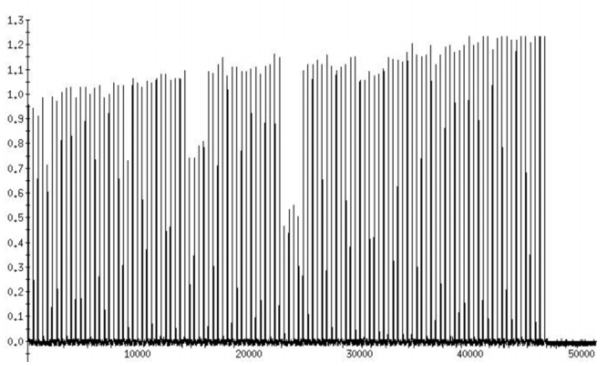

Figure 2: Wall current monitor for fill 3107, 110 bunches

high voltage power supplies, oscilloscopes, RF multiplexors, and trigger sources are all located in the service building. The signal is carried on $3/8''$ foam core Heliax, and the bias voltage is carried to the ring via RG-59 red 75Ω high voltage coaxial cable.

Scope and Trigger

To acquire the signal read back from the detectors, an ethernet ready scope is used. This scope is the LeCroy Waverunner LM354 2GS/s 4 channel scope. The scope is triggered on beam events using our VME trigger card, the V124.

Detector Design

The detectors are installed in a vacuum tee in the beampipe on a 6.75” conflat flange. The signal is collected on a single collector anode, which is a flat metal plate that has a surface area of $78.5cm^2$. There are two suppression grids on the beam side of the anode which each have a transmittance of 80%. To attempt to shield the detector from RF noise and image current effects, the port is covered with a perforated steel sheet that has a transmittance of 23%. Therefore, the effective surface area of the collector anode is $11.75cm^2$ The two suppression grids and the collector anode are electrically connected to external electronics via feed-thrus in the flange[5].

Controls Architecture

Our “Controls System” consists of many VME chassis and the ethernet network that connects them. Included in the VME chassis are device cards which may be data acquisition devices, trigger sources, muxes, etc. The controls system allows for the remote control of these device cards and the logging and display of the data that is read back.

Biasing

The suppression grids and the anode need to have their electric potentials specified with respect to ground. Usually we desire these potentials to be variable. ISEG VHQ-202M VME based high voltage power supplies were used when a variable bias was needed. However, in the case that a fixed voltage is suitable, batteries were used to reduce the complexity and cost of the system. For nearly all measurements, we used 45VDC to bias the collector anodes, and grounded all of the suppression grids.

Signal Amplifier

Much work was done to choose the correct amplifier for the signal path. The signal is very small, and must traverse a large distance($\sim 175\,meters$) to our data acquisition electronics. Currently, and since the system was installed, the signal is amplified in the ring using an AC coupled amplifier. This amplifier is a wideband amplifier, the Sonoma Instruments 310-N. This is the amplifier that was used to collect the data in figure 1.

The 310 has a bandwidth of 10kHz-1GHz, and a gain of 32dB. It was thought that an AC coupled amplifier would be well suited for the task, but it seems now that lower frequency signals are present and are shrouded by the low frequency cutoff of the 310. Therefore, we are developing a new amplifier that is DC coupled, and can withstand a large input bias voltage. The details of this design follow.

DC AMPLIFIER DESIGN

The application specific amplifier is a DC coupled transimpedance amplifier which can withstand a relatively large input bias voltage, and has a bandwidth of 25 MHz(see Table 1). Since we assume there is a DC component of the electron cloud, we desire that the amplifier is DC coupled. However, we want to continue to monitor the high frequency components of the signal. Based on the structure of the electron cloud, 20 MHz is the lowest acceptable bandwidth.

Table 1: Amplifier specifications

Specification	**Value**
Bandwidth	DC-25MHz
Input Impedance	1kΩ
Voltage Gain	0dB
Max Bias Voltage	65VDC
Bias Volt. Rejection	103dB min
Output Impedance	50 Ω
Noise Figure	10mV
Power Supply	$\pm$12VDC,120mA

Electrical Design

To allow the front-end to withstand large bias voltages, an amplifier circuit that has active common-mode rejection was chosen. The circuit used is similar to the one in the literature [1], but has a few modifications to compensate for sensitivity on the output to bias voltages caused by currents induced in the input load. This was not a problem in the literature, but our application is slightly different. By using this amplifier, we are able to bias the detector up to 65 VDC, while DC coupling our signal path to the data acquisition electronics. The amplifier removes the DC bias from the output in a very robust way.

Frequency Domain Design

To attempt to extend the bandwidth of the amplifier, a dynamic model of the system was developed [3] [6]. The actual response of the system rolls off at lower frequency than the modeled system, but has a similar shape. A network analyzer was used to obtain the actual frequency response. The lower bandwidth of the actual system is most definitely the result of unmodeled parasitic elements on the prototype board. A compensation scheme was developed to increase the bandwidth[2]. For simplicity, a zero was added to the transfer function of the amplifier at about 10 MHz.

Testing

One of our spare detectors resides in an evacuated test chamber. Also in this chamber is an electron gun that we use to test our detector and amplifier electronics. We use a Kimball Physics fast pulsed electron gun, model EFG-7/EGPS-7. We pulse the gun at 1MHz between 1% and 20% duty cycle to test the high frequency characteristics of the amplifier. Tests were also conducted to verify the DC nature of the amplifier using constant electron current from the gun [5].

FUTURE WORK

At the time of this paper, the DC coupled amplifier had not yet been used in the ring. We plan to install one of our DC coupled amplifiers in the ring during our polarized proton operations this spring.

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