# ACCELERATOR TIMING AT THE RELATIVISTIC HEAVY ION COLLIDER *

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## Abstract

The Brookhaven Relativistic Heavy Ion Collider (RHIC) has just completed its commissioning run. This paper will discuss early experience with RHICs two timing systems, a beam synchronous system and a general purpose event system, during the commissioning period. These systems provide synchronization among the more than 500 waveform generators, distribute clocks and provide triggers for data acquisition to more than 27 locations. The Booster and AGS preinjectors each have their own timing systems. Some events are generated locally for use by a particular accelerator, and others must be distributed among all accelerators to provide the appropriate sequencing of the machines.

## Introduction

The RHIC Collider is a 3.8 km heavy ion machine just commissioned at Brookhaven National Laboratory. Equipment locations that require timing include 18 ring tunnel alcoves, six service buildings, four experimental areas and four buildings in the AGS to RHIC transfer line. Timing is distributed to these locations on three encoded serial timelines. One of the systems, the RHIC Event link operates on a 10 MHz carrier from a crystal clock. The other two are beam synchronous systems, one for the blue ring and one for the yellow ring each operating at approximately 14.07 MHz from clocks provided by the respective ring RF system. The beam synchronous carrier frequency sweeps during acceleration by about 0.5%.

## 1 RHIC EVENT LINK

Virtually all timing at the AGS Booster Linac and RHIC are transmitted on encoded timing links. The 10 MHz frequency and transmission format of the RHIC Event link was chosen to maintain compatibility with the existing timing systems already in operation. Any new modules developed for RHIC would then be usable in other areas.

The cyclic nature of the AGS and Booster operation require central timing event generators that are table driven. That is, the events to be transmitted on the event link during the machine cycle are monotonically ordered in a table that contains the time in the cycle that an event is scheduled to be issued, and the event code to be transmitted. The 10 hour store expected for RHIC as well as the need for software generated timing events required a different type of event link master be developed. A system similar to the Fermilab Tclock was chosen.

### 1.1 Distribution

The eventlink master is located at one of the ring service buildings. Timing distribution within a building is on shielded twisted pair copper cables. For longer runs between buildings, timing is transmitted on single mode fiber. There are no active elements in the distribution system until the signal is converted back to electrical from fiber at the alcove, service building or experimental area.

The distribution is arranged as a star with seven main trunks, one to each of the six service buildings and one for the AGS to RHIC transfer line. All transmitters are centrally located. In each service building, the trunk is optically split by a one by eight optical splitter. One of the splitter outputs is made available for the service building where it is converted from optical to shielded twisted pair for local distribution. The other splitter outputs are routed by a fiber optic patch panel to three of the adjacent alcoves and an experimental area. The one exception to this pattern occurs in the 10 o'clock equipment building where, due to the beam dumps, the alcoves are fed from adjacent service buildings to avoid running fiber optic cable past the dumps.

### 1.2 Event generation

During the commissioning period a little over 100 events were defined on the RHIC event link,. This is less than half of the 255 events that can be defined. Some of these are common to both rings, such as the standard clocks, 720 Hz, 60 Hz, and 10 Hz events, the timestamp reset other and events common to both rings. However, approximately 50 are specific to each ring. This number of defined events is consistent with the AGS and Booster accelerators which are mature machines that have approximately seventy five or eighty events defined for each.

In contrast with the AGS and Booster where events are exclusively generated by hardware delays, a significant number of RHIC events are software generated.

During RHIC fill operations, several events generated by the AGS timing system are needed on the RHIC event link to synchronize both accelerators in preparation for the transfer of beam. To encode AGS events on the RHIC event link the required AGS events are converted into TTL signal levels with a VME event link decoder module, then connected to one of the inputs on the RHIC event link encoder.

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Beam is extracted from the AGS on a bunch by bunch basis, so a timing event is generated for each bunch transferred. Separate events are defined for the yellow and blue rings. This event, called FEB_Req is used by the AGS and RHIC RF systems to synchronize the two accelerators and select the next RF bucket in RHIC to receive beam. This event occurs approximately 30 ms before each bunch transfer takes place. This limits the maximum transfer rate between the AGS and RHIC to approximately 30 Hz. The same event is also used in the AGS to begin charging the AGS extraction power supplies and appropriate injection power supplies for RHIC. The kicker firing trigger is generated by the RF system when the selected buckets are in position. The kicker trigger is also put on the RHIC event link to provide a warning to transfer line instrumentation to prepare the electronics for another bunch. The kicker firing trigger is transmitted as the two highest priority events on the RHIC event link.

## 2 Beam Synchronous Event links

The beam synchronous event links provide timing for distributed instrumentation and experimental area triggering. A reduced number of timing events are transmitted on these event links, although they share the same encoding scheme and data format as the RHIC event link. for commissioning, fifteen events were defined. The performance requirement for this system was to deliver instrumentation triggers with less than 2 ns. of short term jitter.

The most important information transmitted on the beam synchronous event links are the RF bucket clock, 28.15 MHz and the rotation clock, 78.196 KHz. The rotation fiducial is a clock pulse generated by the Rf system when RF bucket #1 passes a specific location in the ring. The rotation clock is transmitted as an event. This is the highest priority event broadcast and must be transmitted without contention to meet the jitter requirement.

The Beam Synchronous event system uses as it encoding clock, the 28.15 MHz Rf bucket clock. The carrier frequency of the Beam Sync system is one half the RF bucket clock. Locally, at the beam synchronous decoder, the RF bucket clock is recreated by a low jitter phase lock loop that doubles the carrier frequency. A beam synchronous decoder module developed for this system uses these clocks and information downloaded about the bunch fill pattern to provide flexible triggering on any RF bucket in RHIC.

### *2.1 Distribution*

The beam synchronous event links are distributed on single mode optical fiber using the same scheme as the RHIC event link. Locally however, the fiber runs are equalized in length by adding additional single mode fiber spools.

### *2.2 Beam Synchronous events*

There are more than five hundred beam position monitors distributed in the 3.8 km RHIC tunnel. To avoid having to distribute both the event link and beam synchronous timing systems in the tunnel, a number of events which are on the RHIC event link, including the standard clocks, and other informational events are also available on the beam synchronous timing system.

## 3 Timestamps

One of the features of the timing system is the ability to provide microsecond resolution timestamps around the RHIC facility. Many of the modules designed for RHIC provide timestamp registers to record when activity is initiated. The one microsecond clock used by these timestamp counter in these modules is derived from the 10 MHz event link carrier. The crystal on the event link master becomes a master clock used by all modules to count time. A line locked four second event is used to reset the timestamp registers on all modules assuring that they are counting in phase.

## 4 Conclusion

The decision to keep the Event link at 10 MHz and use the same frame format was a good one. VME waveform generators, event link decoders and analog data acquisition modules developed for RHIC are already in widespread use in the AGS and Booster. The event link encoder at the AGS has recently been replaced with the more flexible RHIC developed encoder. The 100 ns. timing resolution, 1.2 us event transmission time and 256 event limit have been adequate for RHIC timing needs.

When the AGS to RHIC (ATR) beam transfer line was built, the RHIC event link system being developed, was used to distribute timing to the beam line, in part, because some of the features needed for the ATR beam line equipment was not available in the AGS timing system. These features include being able to create timing events on the event link from pulsed signal sources and software.

The Beam synchronous timing system also performed well during commissioning. End to end tests on the jitter performance of the system indicate the peak to peak jitter with over 8000 feet of fiber easily met performance goals of less than 2 ns.

Managing three timing links, at times is confusing for operations. One question that could be asked is whether three timing systems are necessary. It would be better if events could be delivered by a single timing link, or, one event link per ring. The limited number of events on the Beam Synchronous event system suggest that it could serve as a general purpose timing system and provide jitter free triggering for instrumentation.