AN UPGRADE OF MAGNET-FIELD-DRIVEN TIMING SYSTEMS AT THE AGS*

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ABSTRACT

An upgrade of the main magnet-field-driven timing systems at Brookhaven National Laboratory's Alternating Gradient Synchrotron (AGS) and Booster accelerators will be described in this paper. A novel approach using content addressable memory (CAM) is applied to overcome a weakness in the previous systems, which required a reproducible dwell field for proper operation. Upgraded from a multibus-based system to a VME-based system, the new timing system also proves easier to maintain and to diagnose. Details of the system architecture, as well as its application in other timing systems will be discussed.

INTRODUCTION

A Timing system is typically required in an accelerator to synchronize all the components in the accelerator complex [1]. The task of the main magnet-field-driven timing system at Brookhaven National Laboratory's Alternating Gradient Synchrotron (AGS) accelerator is to generate 8-bit timing events at scheduled magnetic fields. These timing events are broadcasted to various accelerator equipment systems to control and synchronize their activities.

In a magnet-field-driven timing system, a table is used to define the output event codes at specific magnetic fields. The table is loaded before the start of an accelerator cycle. Once the cycle starts, the timing system follows the accelerators magnetic field and searches in its table to find if the field exists. If a match is found, the corresponding event code will be generated.

In the previous timing system, a pointer-based searching algorithm was used to find the match of a magnetic field. This approach required a good initial magnetic field, i.e., a reproducible dwell field, for proper operation. A shift of the dwell field could halt the search operation and therefore stop the timing system. Some adjustments were needed to restart the system. During our previous operations, such a situation occurred occasionally.

To overcome this weakness, a novel approach using content addressable memory (CAM) was applied to replace the point-based table-searching algorithm. The CAM-based algorithm is able to quickly search the entire table and is not dependent on the reproducibility of the dwell field. Therefore the drift of the dwell field doesn't affect the performance of the timing system. CAM-based timing systems have been implemented in the AGS accelerator for more than one year and have been running smoothly. In addition, the CAM-based timing system is a standard VME-based system and is easier to maintain and to diagnose than the previous multibus-based system. We have also applied the CAM-based design to upgrade the 60HZ-clock-driven and 1MHZ-clock-driven timing systems at the AGS accelerator. Similar upgrades have been done at Brookhaven National Laboratory's Booster accelerator.

SYSTEM ARCHITECTURE

Multibus-based timing system

The architecture of the multibus-based timing system is shown in Figure 1. There are four pre-defined tables. Each table represents a different accelerator timing cycle and can be individually loaded before the accelerator cycle starts. A table consists of up to two thousand scheduled entries. Each entry has a 24-bit setpoint and an 8-bit event code. The setpoint is the scheduled magnetic field value at which an event code should be generated. The setpoint least count represents 0.2 Gauss and 0.1 Gauss for the AGS and Booster accelerators respectively.

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The magnetic field of the accelerator is followed using up Gauss clocks and down Gauss clocks, which are pulses generated in increasing and decreasing magnetic fields respectively. A 24-bit counter is used to store the actual magnetic field value. Between each cycle, the counter is calibrated to the dwell field by a Hall probe, or to a preset program value.

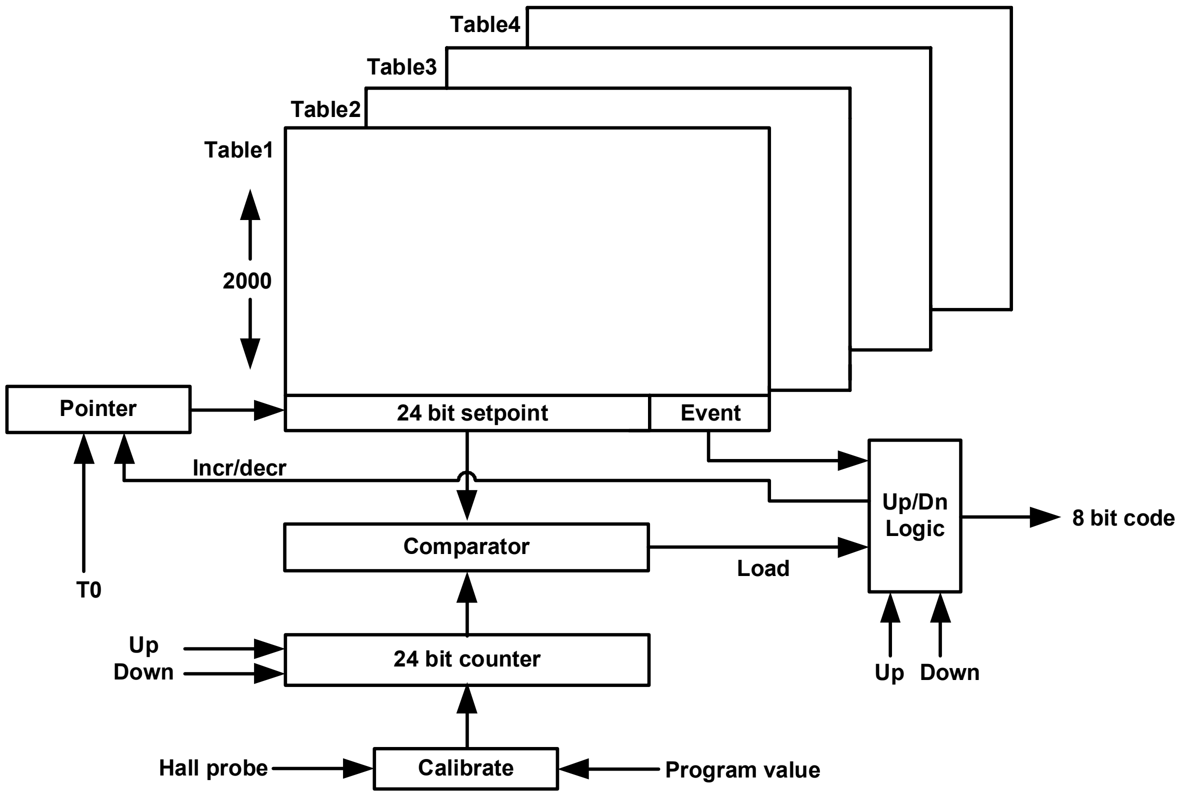

Figure 1. Multibus-based timing system

For each gauss clock tick, a pointer-based searching algorithm is used to find a match in the table. As shown in Figure 1, a pointer indicates the current search entry in the table. A comparator is used to compare the actual magnetic field with the 24-bit field value in the table. When a match is found, the comparator issues a load signal to output the entry's 8-bit event code. The pointer then moves to the next higher entry in the table if the field is increasing or to the next lower entry if the field is decreasing. Such a search is repeated until the end of the accelerator cycle.

Although the pointer-based searching algorithm works well, it can fail under certain conditions. The failure always happens at the beginning of an accelerator cycle. The following paragraph describes one such situation.

Assume a dwell field from the Hall probe is used to calibrate the 24-bit counter. When an accelerator cycle starts, the magnetic field gets stronger and thus the counter increases from the initial dwell field. Since the dwell field is actually the residual magnetic field after the previous cycle, naturally it drifts from cycle to cycle. If the dwell field drifts so high that it surpasses the scheduled magnetic field value of the first entry in the table, the counter will surely also surpass this value. Therefore, when the accelerator cycle starts, the comparator never finds a match between the counter and the first scheduled magnetic field. As a result, the pointer never moves to the next entry and the timing system stops generating any event codes for that cycle.

To make the timing system work properly, the dwell field, which drifts from cycle to cycle, must be smaller than the first field value in the table. In other words, reproducible dwell fields are required for proper operations. This weakness in the previous method calls for an improved design.

CAM-based timing system

To overcome the weakness of the pointer-based searching algorithm, a CAM-based design is applied. CAM is a special type of memory used in certain high speed searching applications [2]. Unlike a standard memory, which returns the saved data for a supplied address, a CAM is designed such that data is supplied and the CAM searches its entire memory to see if the data is stored anywhere in it. If the data is found, the CAM returns a list of one or more memory addresses where the word is found. Since a CAM is designed to quickly search its entire memory, it is much faster than a standard memory in virtually all searching applications. A typical application of CAM is in the design of communication router that can quickly search through its routing table to find a port for each IP packet, and that can also update its routing table rapidly.

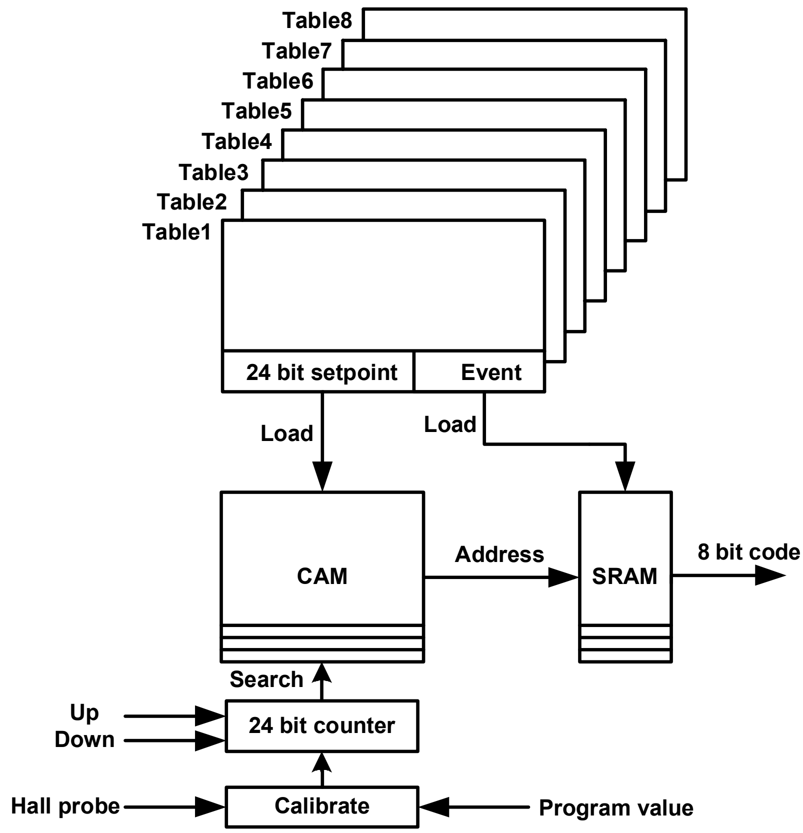

Figure 2. CAM-based timing system

Figure 2 shows the CAM-based timing system implemented in BNL's AGS accelerator. There are eight tables and each table can hold eight thousand entries. As with the multibus-based system, up and down Gauss clocks are used to follow the actual magnetic field, which is initially calibrated by a dwell value or by an estimated program value. Before an accelerator cycle starts, the scheduled magnetic fields in a table are loaded into the CAM and the corresponding event codes are loaded into a SRAM. During the accelerator cycle, the CAM constantly searches its entire memory for a match to each actual magnetic field. Each search of the entire CAM takes only 10ns, which is much faster than the period between gauss clock ticks. Once a match is found, the CAM outputs the matching address. This address is used for the SRAM to output the corresponding event code in its memory. Since all the scheduled magnetic fields are searched in the CAM, there is no special requirement for the dwell field and therefore the weakness of the previous pointer-based searching algorithm is eliminated. The CAM-based timing systems have been implemented and continuously running in BNL's AGS and Booster accelerators for more than one year. During this period of time, the systems tolerated different dwell field drifts and never stopped generating correct event codes.

Besides the reliability, a CAM-based timing system shows other improvements. It has eight different accelerator tables and each table is upgraded to hold eight thousand entries. These upgrades make it possible for us to deploy new accelerator control functions in the future.

In addition, since the CAM-based timing system is in VME form factor, it is easier to maintain and to diagnose. Many important timing system parameters, such as the actual magnetic field, event code output, table information and dwell value, can be easily read back from the new module. Also abnormal conditions can be detected and handled through standard VME interrupt mechanisms.

APPLICATIONS IN OTHER TIMING SYSTEMS

The CAM-based design has also been used to upgrade the 60HZ-clock-driven and 1MHZ-clock-driven timing systems of BNL's AGS and Booster accelerators. These systems have similar architectures: they all have eight scheduled tables and a CAM is used to search for a match between pre-defined values and the actual ones. The only difference is the time reference used for the event codes schedule as shown in Figure 3. In a magnet-field-driven timing system, event codes are scheduled at different magnetic fields. In a 60HZ-clock-driven timing system, the schedule is based on ticks of a 60HZ clock, which is synchronized to one phase of the power line. A phase lock loop is used to generate a phase-locked 60HZ signal. In a 1MHZ-clock-driven timing system, a 1MHZ crystal is used to count the time elapsed since the start of an accelerator cycle. Event codes are scheduled based on the elapsed time.

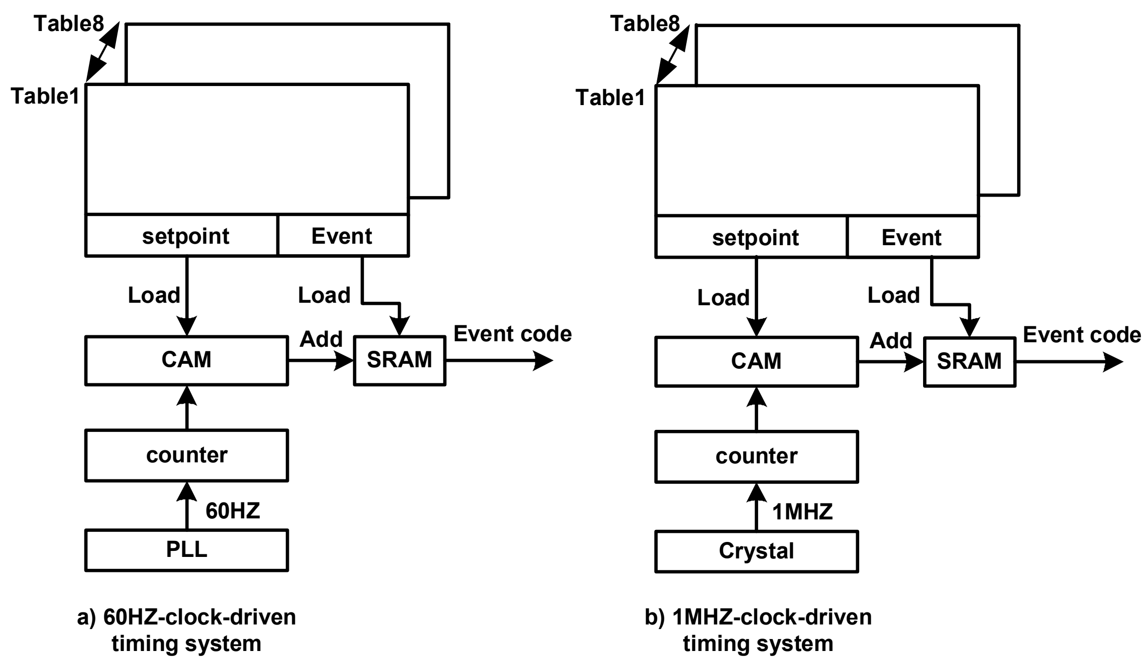

Figure 3. The other CAM-based timing systems in BNL's AGS and Booster accelerators

We have applied the CAM-based design in all the three timing systems. Benefiting from their similarities, we were able to reuse many designs during our hardware and software development. Now these timing systems are all implemented and have been running well.

SUMMARY

An advanced CAM-based searching algorithm is used to upgrade the magnet-field-driven timing systems of BNL's AGS and Booster accelerators. The requirement for a reproducible dwell in the previous timing system is eliminated. The CAM-based systems prove reliable under different operations. As standard VME-based systems, the upgraded systems are also easier to maintain and to diagnose. The CAM-based design has also been successfully applied to upgrade the 60HZ-clock-driven and 1MHZ-clock-driven timing systems.

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