THE USE OF DIGITAL SIGNAL PROCESSORS IN
LEP BEAM INSTRUMENTATION

P. Castro-Garcia, L. Knudsen, R. Schmidt

Abstract

At LEP, DSPs are used in the systems measuring the polarization and luminosity. In both systems the DSP receives the digitized information from a silicon strip calorimeter. With these calorimeters the position and the energy of electromagnetic showers are measured. The luminosity monitors measure the rate of Bhabha events which is proportional to the luminosity. The signature of such an event is one e^- and one e^+ measured in coincidence by 2 calorimeters left and right from the interaction point. After each bunch crossing signals proportional to the total energy from the calorimeters are recorded with the DSP to decide within 22 μ s, whether the event is a Bhabha event or not. The polarimeter operates at the repetition frequency of 30 Hz. Input to the DSP are 128 ADC channels, 53 for the silicon strips and 55 from other sources such as diodes etc. The output are mean and sigma of the electromagnetic shower distributions. The use of fast processors operating in real time is of particular interest for beam instrumentation in large accelerators : the natural repetition frequency of any circular accelerator is the revolution frequency. The use of DSPs allows to analyze data from turn by turn beam observations and replaces complicated electronic circuits.

*Paper presented at 1991 Accelerator Instrumentation Workshop, CEBAF, Newport News, USA,
October 28-31, 1991*

Geneva, 18 November, 1991

(SL/BI/Div.Rep. '91)

The use of Digital Signal Processors in LEP beam instrumentation

P. Castro, L. Knudsen, R. Schmidt
CERN-SL, GENEVA, Switzerland

1 Abstract

At LEP, DSPs are used in the systems measuring the polarization and luminosity. In both systems the DSP receives the digitized information from a Silicon strip calorimeter. With these calorimeters the position and the energy of electromagnetic showers are measured. The luminosity monitors measure the rate of Bhabha events which is proportional to the luminosity. The signature of such an event is one e^- and one e^+ measured in coincidence by 2 calorimeters left and right from the interaction point. After each bunch crossing signals proportional to the total energy from the calorimeters are recorded with the DSP to decide within 22 μs , whether the event is a Bhabha event or not. The polarimeter operates at the repetition frequency of 30 Hz. Input to the DSP are 128 ADC channels, 53 for the silicon strips and 55 from other sources such as diodes etc. The output are mean and sigma of the electromagnetic shower distributions. The use of fast processors operating in real time is of particular interest for beam instrumentation in large accelerators : the natural repetition frequency of any circular accelerator is the revolution frequency. The use of DSPs allows to analyze data from turn by turn beam observations and replaces complicated electronic circuits.

2 Introduction

DSP's are fast microprocessors used in various types of data acquisition systems, in particular in High Energy Physics experiments. However, in beam instrumentation they are not very common. To illustrate potential applications we discuss some examples for LEP, where DSPs are used in beam polarization and luminosity monitors [1] [2]. In this paper we do not intend to present an overview of the use of DSPs in High Energy Physics and Accelerator physics as it has been done elsewhere [3].

The monitors provide a large amount of data, between 10-400 kByte/s. The user is interested in the final result, the degree of polarization from the polarimeter and the luminosity from the luminosity monitors. DSP's are employed in the first level data processing to reduce the incoming data substantially. They are installed in an auxiliary building in a distance of some 100 m from the calorimeters.

Before discussing the data acquisition systems with the DSPs in greater detail, we describe the functionality of the two monitors.

Polarimeter For the polarization measurement polarized laser light is scattered off the electron beam. For each laser shot every 33 ms hundreds of high energetic photons are produced and reach a silicon / tungsten calorimeter 247 m

downstreams. The calorimeter consists of 4 strip planes and 5 full planes. The full planes have a size of about 40mm x 40mm, the strip planes 16 strips each 2 mm wide. With the strip planes the vertical and the horizontal distributions of the scattered light are measured and the full planes measure the energy of the electromagnetic shower. The degree of polarization is evaluated from the distributions : by changing from left to right circular polarized light the mean of the vertical distribution moves. The amount of the mean shift is proportional to the degree of polarization.

The DSP is used for preprocessing the data from the silicon calorimeter. It reads out 128 ADC channels digitizing the signals from the silicon strips, full planes and some other analog signals. The mean and sigma of the electromagnetic shower distribution and other statistical values are calculated with the help of the DSP. The DSP also tags the data in case of saturation of the ADCs. The data is written into a memory which is read out by a microprocessor (Motorola 68030) (see fig.1). The DSP reduces the amount of data by a factor of one to two orders of magnitude.

The polarization monitor has also been used to measure the turn by turn beam profile and the center of the distribution of the circulating electron bunches. The first strip plane of the calorimeter is illuminated by the synchrotron light from a wiggler magnet. The ADC's digitize the signals from the 16 strips of the first plane once per LEP turn every 88 μ s. It is possible to measure the whole profiles for 2000 turns or the mean of the distribution for 32000 turns.

Luminosity monitors At LEP the bunches collide at four interaction points (IP). For a fast measurement of the luminosity two monitors per IP are installed. One monitor is a set of two silicon calorimeters similar to the one used in the polarimeter. The calorimeters are installed at a distance of 8.5 m from the IPs, one calorimeter towards the inside of LEP and the other towards the outside (see fig.2). The luminosity is proportional to the number of Bhabha events. A Bhabha event is an elastic scattering of an electron and a positron. The probability for such an event is high for small angles (some mrad) and decreases strongly with increasing scattering angle.

The calorimeters are installed close to the beam at about 30 mm. The background from bremsstrahlung and other effects is high (between about hundred Hz and some kHz in each calorimeter. For accidental coincidences this yields a rate of up to 200 Hz, compared to about 20 Hz Bhabha event rate for a luminosity of $10^{-31} \text{ cm}^{-2} \text{ s}^{-1}$). With four bunches per beam the bunches collide every 22 μ s. In the near future LEP will operate with eight bunches per beam and the time between two crossings will decrease to 11 μ s.

After each crossing the DSP reads out from the ADCs a number proportional to the total energy deposited in each of the calorimeters. If the energy in both calorimeters is above a predefined threshold, a pair event is counted. If the energy in only one calorimeter is above the threshold, an event for the inside or outside

Figure 1: Data reduction by using the DSP

Figure 2: Schematic view of the Luminosity monitors

calorimeter is counted. To record the number of accidental coincidences the DSP measures coincidences between a particle in the inside calorimeter for one crossing and a particle in the outside calorimeter for the next crossing. In this case an accidental event is counted. Every 10 s the values of the counters is transferred to the microprocessors which averages for a time of 180 s to give the number of Bhabha events and therefore the luminosity.

3 The DSP in the data acquisition system

Overview : For the applications described above a commercially available VME-board is used, the DSP8150 from CES, Geneva, Switzerland [4]. It uses the Motorola DSP56001 and is designed to be used with an ADC board. In order to control the analog digital conversion the module contains a dedicated sequencer. The sequencer is a memory (RAM), its data is read out with a frequency of 5 MHz. One sequencer word is used as command for the ADC board, the sequencer executes a sequence of commands and works in parallel with the DSP. Therefore the entire performance of the DSP is available for data processing without having to wait for ADC conversions etc.

The DSP board is housed in a VME crate. In the same crate another processor (Motorola 68030) with a UNIX like operating system (Microware OS9) serves as a host for the DSP. The communication between host processor and DSP board is implemented by use of a memory buffer which can be accessed from either the DSP or from OS9 (dual port ram). This allows the read-out to be independent of the DSP processing. Fig.3 shows a general block diagram of the DSP8150 board and the host microprocessor. To carry out the synchronization of the different modules, several trigger pulses and control signals are required.

Example : The following example illustrates the operation of the data acqui-

Figure 3: Block diagram of the data acquisition system

Figure 4: Timing diagram for the acquisition system

sition system for the luminosity monitors (see fig.4), dealing with an event every 11 microseconds (for a LEP operation with 8 e+ and 8 e- bunches). The analog signals from the calorimeter are integrated in an Integrate and Hold unit (I&H) during a gate pulse synchronized with the bunch crossings. Before the start of the integration the I&H requires a clear signal. A set of 32 I&H are multiplexed to one ADC. The ADC module is built up of 4 high speed CMOS 12 bits-ADC. The sequencer controls every function related to the analog/digital conversion. It requires an initialization from the DSP and a trigger pulse to start the command sequence for the A/D conversion. Once started it selects the I&H channels to be digitized, triggers the ADCs and transfers the data into a buffer (FIFO). The DSP waits for the sequencer to finish : it reads a sequencer status word and when the sequencer is ready it reads the data from the buffer. Then the DSP initializes the sequencer to prepare for the next event. The preprocessing of the data is done in parallel with the sequencer reading out the next event. The available time for the preprocessing is about 10 μ s. The processing has to be finished before data from the next event is available in the FIFO.

In total three external signals are supplied by the LEP timing system together a specific simple electronics module :

- A gate for the integration.
- A signal to start the command sequence.
- A signal to clear the Integrator&Hold (this signal can also be provided by the DSP program, as in the polarimeter).

So far we discussed the functionality of the DSP card together with the ADCs and the I&H unit. In the next section the communication between the host microprocessor (Motorola 68030) and the DSP card is described.

In fig.5 the timing of the system for some successive events is shown. The DSP processes a sequence of events in real time. After each event the result is stored in the DSP memory. When the DSP has processed the total amount of events required, it writes the data into an output buffer with two pages. At the same time one page can be accessed by the DSP and the other page by the host microprocessor. When the DSP finished writing the data. e.g. on page 1, it changes to page 2. Then host microprocessor can access page 1 and read the data etc.

4 Software for the DSP

The DSP56000 is optimized to execute algorithms in as few operations as possible. The whole architecture has been designed to ease the interface and maximize the throughput. No overhead is caused by an operating system and interrupts can be executed within a delay of a few hundred ns. The DSP is provided with 62 CPU

Figure 5: DSP and Sequencer processes and data transfer

like instructions [5] and contains on-chip two separate data buses together with the program bus. Certain instructions can be executed in parallel. Therefore with 10 MIPS the processor is a very fast tool in frontend data-acquisition systems. For using the DSP8150 board one has three levels of related software :

- The sequencer needs to be supplied with a sequence of commands to control the ADC card multiplexers, the analog-digital conversion and the data transmission to the DSP8150 input buffer (FIFO).
- The DSP5600 is programmed in assembler language. The program can have up to 512 instructions. As an example, within one instruction one multiplication and two data move commands are possible.

Apart from setting up the environment of the DSP (e.g. loading the command sequencer into the sequencer) a typical program has three parts : 1) read event, 2) process event, 3) store results.

- A program in the host microprocessor deals with the DSP (in our case the language C is used). It loads the DSP program into the DSP memory as well as the command sequence for the sequencer. When data from the DSP is available, it reads the data, does further processing and if desired sends the data to the workstations in the LEP control room.

The development environment for the DSP56001 exist on many different platforms, e.g IBM-PC/DOS, UNIX, VAX/VMS and Macintosh. We use an IBM-PC.

A C-compiler to write DSP programs is available although we do not use it. The reason are the relative few instructions in one program. For an optimized use of the DSP performance the assembler language is more appropriate.

The development path can be illustrated as following:

- After a DSP program is written it is running through an assembler.
- Linking the relocatable file with libraries (if any) and thereby producing an absolute load file ready for loading into the DSP-memory. This file is in ASCII format and is transferred to the VME crate with the DSP card via TCP/IP-FTP.
- At this stage a simulator can test performance of the program.
- Transfer of the program to the DSP external bootstrap program memory. This part is specific for the host computer environment. We use a C-program which reads the program from the file and writes it into the bootstrap memory of the DSP, which is memory mapped to VME.
- The DSP is ready to receive the bootstrap command for loading the program to the on-chip program memory.

5 Experience with the DSP

The use of a DSP requires a certain expertise because three levels of software are involved. The documentation for the DSP8150 board is insufficient, i.e. examples are missing. Therefore it took some time to understand the detailed functioning of the board. Once this was accomplished, it was relatively easy to develop DSP programs. An essential part of the time is devoted to the test of the program. In particular the execution time must be smaller than the available time for data processing between two events. The DSP board works very reliably. Because of its architecture the execution time is determined and for one program always the same. No software maintenance is required because the DSP board is independent from the environment. No interrupts between the DSP board and the Motorola 68030/OS9 are used. The program in the DSP is written in a way to be independent from the Real Time operating system in the VME. If the host micro-processor or its operating system are changed, the DSP program does not have to be modified. However, it might be required to rewrite the program running in the host computer. A disadvantage of the DSP56000 is the lack of floating point arithmetic which complicates the program development.

For both, the polarimeter and the luminosity monitor it is important not to be limited by any dead-time due to the data acquisition system. This aim could be accomplished by the use of the DSP without building complicated electronics circuits.

For the luminosity monitors the processing time between two events is about 10 μ s. A typical application program with about 30 to 50 instructions can be executed withing this time.

6 Conclusions

For beam instrumentation equipment most data acquisition systems are operating synchronously with the revolution frequency or their harmonics. A typical application is the digitization of a signal for each revolution. Two methods can be employed:

- The signals can be digitized each turn and stored in a large memory. This technique has been employed for the BOSC system [6]. The analysis of the data is done offline. This method is limited by the size of the available memory.
- A second possibility is the use of a DSP : the time between two successive signals is available to perform the data processing to reduce the amount of data. For instruments monitoring instruments this technique is very attractive.

The use of a DSP is very flexible. Similar programs can be used for different applications. The reliability of the DSP is high. We expect that with the development of the new generation of DSPs with floating point arithmetics the speed will further increase and the program development will become easier. Because of the increased level of complexity a programming in the language C will be essential. The first LEP instrument using a DSP of the next generation will be the Q-meter.

7 Acknowledgement

The authors would like to thank J.d.Vries, B.Dehtning, G.P.Ferri and M.Placidi for their contributions to the use of the DSP. We also thank C.Bovet for his continuous support and W.Herr for reading this manuscript.

References

- [1] J.Badier et al., Part.Acc.Conf.,San Francisco 6-9 May 1991
- [2] G.P.Ferri, EPAC 1990, Nice, June 12-16
- [3] D.Crosetto, Digital Signal Processing in High Energy Physics, CERN Computing School 1990, Ysermonde, Belgium, CERN Yellow Report
- [4] DSP8150 User's Manual Creative Electronics System S.A., Geneva, Switzerland, 1990.
- [5] DSP56000/DSP56001 Users's Manual, Motorola, MOTOROLA INC.,1990

[6] A.Burns et al., EPAC 1990, Nice, June 12-16

[7] H.Schmickler, private communication

Scientific
Information
Service

SIS / F15

1989.01.12

Information to TH/SIS about
CERN publication or Divisional report

From Division

Date: 18.11.1991

The following paper has been authorized by the Division Leader.

6 copies are attached. (*Amend if six copies not available*)

First author: R. Schmidt, P. Castro, L. Knudsen

Author to be contacted: R. Schmidt

Title: "The Use of Digital Signal Processors in LEP beam instrumentation"

Number of pages: 11

Report number: CERN SL/91-46 (BI)

Experiment number (*whenever relevant*):

☒ This paper is submitted to a conference (*please give exact title, place and dates*).
1991 Accelerator Instrumentation Workshop, CEBAF, Newport News, USA,
October 28-31, 1991

☒ It will be published in the Proceedings, as noted below:

☐ This paper is to be published (*please give details indicated as far as possible*) in a:

☐ Periodical (*title, vol.*):

☐ Book (*title, editor, publisher, date*):

☒ This paper is a Divisional report not to be published:

☐ No further copies are available for distribution.

Signature:

CERN SCIENTIFIC INFORMATION SERVICE (TH/SIS): Preprints Section

Address
CERN
CH-1211 Genève 23
Switzerland

Telephone
+41 22 83 2867 (Direct)
From 22 Apr. 1989:
+41 22 767 2867

Telegrams
CERNLAB-GENEVE

Electronic Mail
LIBDESK@CERNVM.CH

Telex
country code +
419000 CER CH

Telefax
+41 22 82 3914 (Internat.)
(022) 82 3914 (Switzerland)
From 22 Apr. 1989:
+41 22 782 3914