Development of a Flexible Pulse Programmer for MRI Using a Commercial Digital Signal Processor Board

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INTRODUCTION

Recent sophisticated fast NMR imaging sequences require a high performance pulse programmer as well as a high speed gradient and RF system. However, to construct such a pulse programmer is not easy because many parameters including three channel gradient amplitudes must be controlled at a high time resolution .

One approach to the MRI pulse programmer is to use a hardware logic circuit consisting of a clock counter, address counter, digital comparator, and word memory. The logic circuit for such pulse programmer, however, becomes very complicated and the wiring increases explosively. Use of some computer system for the NMR pulse programmer is a well known solution. But PC or other usual board computers cannot be used to generate exact time sequences because these computers have system interruptions by the system timers and refresh cycles for DRAM devices. Most of digital signal processor (DSP) board systems are, however, made to give exact time sequences which can be used for NMR pulse sequences. We have thus developed a flexible pulse programmer for MRI using a commercial DSP board.

HARDWARE SYSTEM

The DSP board used is DSP6031 (mtt Instruments Japan) which has a 32-bit floating point DSP chip (TMS320C31, Texas Instruments) running at the 40 MHz clock frequency with the 50 ns instruction cycle. This board has four 12-bit ADC, four 12-bit DAC, and an 8-bit digital I/O port. All of them are assembled on a full size PC-AT extension card. This DSP board can be connected to other extension boards (full size PC-AT cards) using a 32-bit I/O bus. We used one extension card for 32-bit digital outputs. These two PC-AT full size cards connected with the DSP I/O bus were installed to a PC running under MS-DOS or Windows95.

The DSP has the internal 32-bit timer of which clock is synchronized with the DSP clock. Because the timer can generate interrupt signals to the DSP operation (50 ns cycle) and the minimum clock cycle of the timer is 100 ns, the DSP can generate pulses at 100 ns time resolution.

PROGRAM FOR THE PULSE PROGRAMMER

Figure 1 shows the overview of the program developed for the pulse programmer. This program consists of three major components.

The first component is the time table of the pulse sequence written with a text editor. The second component is the DSP program to generate pulse sequences. The key operation in the program is the timer interrupt operation: at first, the delay time is loaded to the timer register, then the interruption from the timer takes place after the delay time, and the event is output according to the event data in the time table. This DSP program was developed using the cross C compiler and the cross assembler for the DSP chip on the host PC running under MS-DOS version 6.2. The third component is the program to convert the time table to the timing and event data used for the DSP and to download the DSP code and timing data to the DSP memory.

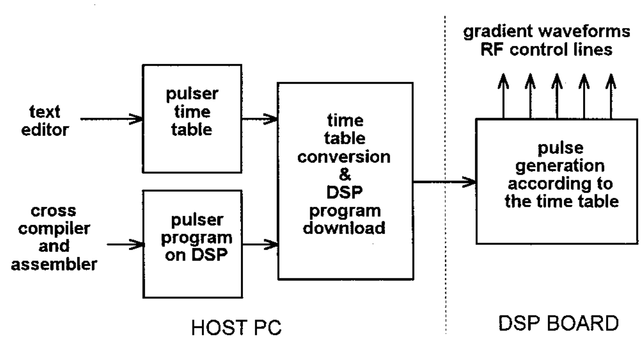

Fig. 1. Overview of the pulser program.

RESULTS AND DISCUSSION

The minimum time interval between two successive events was 3.7 μs. This was because the overhead time in the pulse output loop was 3.3 μs and some overhead time (400 ns) existed between the count down start and the idling loop waiting for the interruption. The 100 ns programmable time resolution was confirmed using a digital oscilloscope.

We have assigned 8 bits for the data-acquisition control, 8 bits for the transmitter RF phase, 6 bits for the selection of the tailored RF pulse stored in a ROM, and 2 bits for the RF pulse trigger. These bit widths are compatible with our analog RF system. Because the digital output width of the pulse programmer can be extended by the unit of 32 bits, the programmer can be connected to any advanced RF systems.

Because the word length of the DSP is 32 bits, the pulse programmer cannot change different kinds of outputs (RF and gradients) at the same time. However, amplitudes of three gradients can be changed at the same time because the event output loop includes four output commands and the DA converters for gradients have the common output trigger signal. The specification of the pulse programmer is summarized in Table 1.

In conclusion, we have succeeded in constructing a flexible pulse programmer that can be used for advanced NMR imaging experiments by using a commercial DSP board and without any additional hardware devices.

word length	32 bits
programmable time resolution	100 ns
maximum programmable time	99.9999999 s
minimum pulse (event) interval	3.7 μs
gradient channel	3 (+1)
gradient amplitude resolution	12 (16) bits
gradient signal switching time	10 μs
digital output ports	8 + 32n bits
number of loop counters	no restriction

Table 1. Specification of the pulse programmer developed using the DSP board. The word length is 32 bits but three gradient amplitudes can be changed at the same time. 16-bits DA converters are available as an optional I/O card.