A Microprocessor-based Nuclear Magnetic Resonance Spectrometer

Y. Liu and G. Li
Shanghai Key Laboratory of Functional Magnetic Resonance Imaging
Department of Physics, East China Normal University
Shanghai, People's Republic of China

***Abstract*—A microprocessor-based Nuclear Magnetic Resonance spectrometer is proposed. This spectrometer, in which the microprocessor, pulse generator, RF waveform transmitter and digital receiver are integrated onto one card, can complete all tasks without the participation of the PC. Moreover, this spectrometer can be customized attributes for its variation applications by communication with a PC through USB connection.**

Keywords-microprocessor; Nuclear Magnetic Resonane; events; CPMG

I. INTRODUCTION

Although the standard commercial Nuclear Magnetic Resonance (NMR) spectrometers have many advantages, such as high precision and total function, the important drawbacks are associated with them, cost and complexity. To meet the needs of expanding application field of NMR technique, a low-cost and portable spectrometer is required for a particular purpose in many cases [1]. So the microprocessor-based NMR spectrometer is proposed and designed with the application of the latest digital integrated circuit technology. The hardware of this spectrometer is different from PC-based construction [2-3]. The microprocessor, pulse generator, RF waveform transmitter and digital receiver are integrated onto one card, and an integrated microprocessor and a field programmable gate arrays (FPGA) chip are utilized for complete all tasks including real time control of the spectrometer and data processing. The hardware structure is independent of PC and greatly simplified without the loss of flexibility and performance. In addition, a USB connection is designed to communicate with a PC for further particular applications, such as data storage and sequence customization. In this paper, we describe the method of this spectrometer and illustrate the performance with result using Carr–Purcell–Meiboom–Gill (CPMG) pulse sequence.

II. METHODS

The block diagram of this proposed spectrometer architecture is showed in Fig. 1. An integrated enhanced 8051 microprocessor (CY7C68013, CYPRESS) is employed to translate the input pulse sequence into a target binary data stream specified to the relevant hardware. Then the translated data can be decoded to control the pulse generator, RF waveform transmitter and digital receiver.

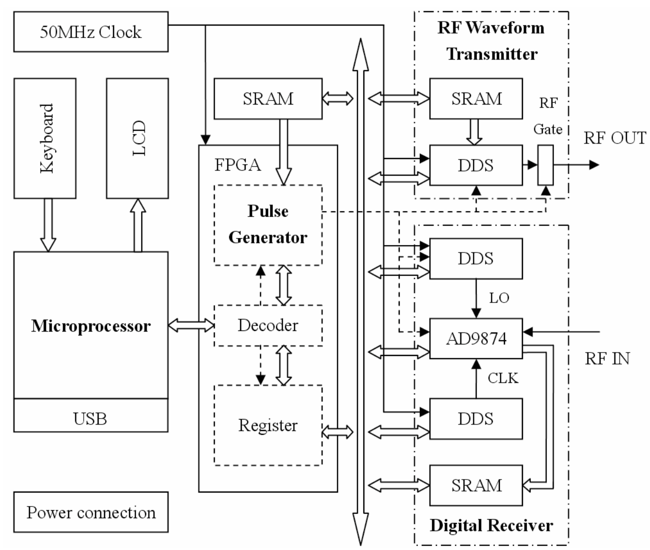

Figure 1. Block diagram of a microprocessor-based NMR spectrometer.

- - - - control lines, —— signal lines, ═══ data lines.

The pulse sequence can be considered as a group of events with duration. Taking CPMG pulse sequence as example, this sequence is divided into 6 events which are individually assigned with a delay period indicated in Fig. 2. The loop is utilized for multi-echo and the loop count is indicated by 'C1'. The repetition is employed for signal average. According to this, the microprocessor generate target binary stream including three parts. One part is about the events and corresponding duration. As far as the loop or repetition is concerned, the loop information can be a supplement of this data list for data compression. The second part contains the amplitude, frequency and phase information of the RF pulses. The third part is for data acquisition, such as number of data points (TD) and different spectral width value (SW) for the different acquisition.

After the above translation, a FPGA chip (XC2S200, Xilinx) is utilized for decoding and transferring. The data of the former two parts are stored in two static random access memory (SRAM) chips (CY7C1041B, CYPRESS) respectively. And the initial state of receiver should be set up according to the data of the third part. Furthermore, the pulse

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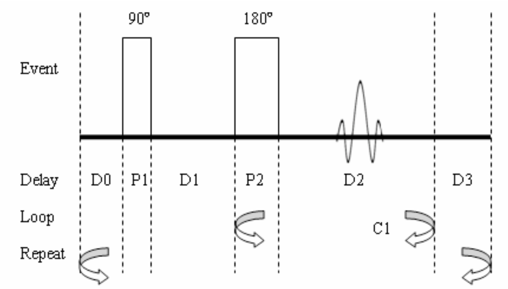

Figure 2. A scheme of CPMG pulse sequence which is divided into 6 events.

generator is built inside the FPGA and written by very high speed integrated circuit hardware description language (VHDL). This pulse generator has 16 independent channels (not all channels are used and just reserved) and each channel is used to control an event, such as RF updating (amplitude, frequency, and phase), acquisition triggering, and RF gating, etc. The state of each channel is identified by one binary bit as “events”, and its “delay” period is counted down by timer. For using a 50 MHz clock, the timing resolution is 20 ns. During running the pulse sequence, the control logic in FPGA will read each pre-stored element in order and output the corresponding pulses to the current element. By this means, the higher time precision and stabilization can be realized.

A direct digital synthesis (DDS) chip (AD9854, Analog Devices) is used as a radio-frequency source. This RF source is capable of generating a signal with frequency from dc up to 135 MHz directly and it has the ability to rapidly manipulate the instantaneous phase, frequency and amplitude of the RF pulse. Once the pulse generator set off the RF updating event, the control logic in FPGA will transfer current RF data (amplitude-frequency-phase) from SRAM to DDS registers and update the DDS output. The use of the complete-DDS and the FPGA makes the present design not only multifunctional to generate hard/soft pulses, but also easy to control and low cost.

We use a system-on-chip (SOC) IF digitizing subsystem (AD9874, Analog Devices) to simplify the digital receiver chain. It consists of a low noise amplifier (LNA), a Gilberttype active mixer, a band-pass sigma-delta analog-to-digital converter (ADC), and a decimation filter with programmable decimation factor. The state machine in FPGA transfers acquired data to SRAM as soon as an acquisition rising edge signal generated from the pulse generator. The microprocessor will read these data back for data processing after acquisition.

Other important features must be taken into account. Firstly, this is a complete digital spectrometer with great flexibility although its structure is simplified. Secondly, there are keyboard and Liquid Crystal Display (LCD) as accessories of the spectrometer, so we can input the parameters of a pulse sequence and the results can be displayed. All the tasks can be completed without the participation of the PC. That makes the spectrometer convenient and portable for particular applications, for example, rapid determination of content or product quality control.

III. RESULTS

The full size of our designed spectrometer board is 234×149 mm. To investigate the performance of it, the CPMG experiments were performed on our home-built 0.3T permanent magnet MRI system [4]. The sample employed in the experiment was a module (about 10 cm×10 cm×10 cm) filled with water doped with about 1% $CuSO_4$. Firstly, the single-pulse experiments were executed to get the main experimental parameters, such as RF frequency (SF) = 12.799 MHz and P1 = 25 µs, P2 = 50 µs. Then the delay times showed in Fig. 2 and acquisition parameters were set up. These experimental parameters were: D0 = 1.0 µs, D1 = 5 ms, D2 = 10 ms, D3 = 1000 ms, echo number (C1) = 16, number of signal averaged (NSA) = 2, spectral width (SW) = 50 KHz, number of data points (TD) = 8192. Fig. 3 shows the result in time domain obtained with this CPMG pulse sequence (Fig. 2). It is the normal method of T2 measurement, and usually used to analyze the relative content.

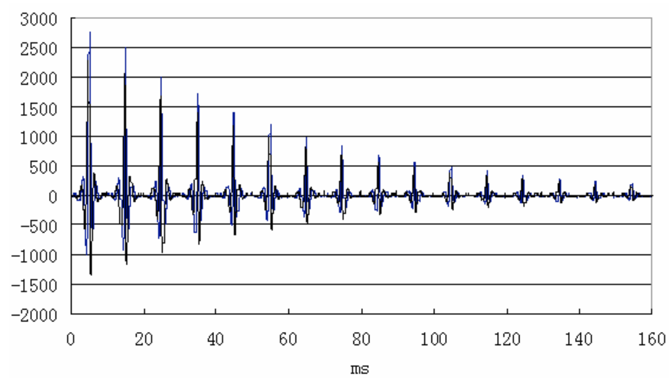

Figure 3. FID in time domain obtained with CPMG showed in Fig. 2.

So far we have demonstrated the proposed spectrometer. The simplified structure can reduce the cost, facilitate the debugging and improve the flexibility. We believe the good performance of our microprocessor-based spectrometer presented in this article may find many applications in NMR investigations.

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