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A programmable digital pulse generator for pulsed NMR spectroscopy

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Abstract. The pulse programmer generates highly stable pulses and is capable of producing various scheme of pulses (*i.e.* a given specific number of pulses with independently variable widths and separations) employed in pulsed NMR spectroscopy. The construction and working of the programmer is described with reference to the two most commonly used schemes, namely, a two-pulse sequence and the Carr-Purcell sequence.

Keywords. Pulse generator; pulsed NMR.

PACS No. 76·90

1. Introduction

In pulsed nuclear magnetic resonance spectroscopy one irradiates the sample with a certain specific sequence of rf pulses and observes the response of the nuclear spin system. It is, therefore, important to have pulses with well-defined widths and delays. This is easily achieved using digital techniques. Pulse programmers which make use of digital techniques have been described earlier also (Adduci *et al* 1977; Conway and Cotts 1977; Shenoy *et al* 1976). Simplicity of design and use of inexpensive ICs in the circuit are among the important features of the pulse programmer. The emphasis in designing this instrument has not been the versatility alone. In zero field resonance measurements, the most commonly used pulse sequences are the following:

A train of $\pi/2$ pulses to see the free induction decay, a $\pi/2-\tau-\pi$ pulse sequence for observing the echo and measuring T_2 and the Carr-Purcell sequence for measuring T_2. This instrument aims at providing all these types of pulse-sequences simply by setting the thumbwheel switches appropriately. We demonstrate the performance of the instrument by observing the zero field resonance in the sample $LaMn_2Si_2$ at 77 K using the $\pi/2-\tau-\pi$ and the Carr-Purcell sequences.

2. System description

The instrument consists basically of the following blocks: (i) The master clock (ii) The magnitude comparators and (iii) The interface. The entire circuit is fully TTL and is assembled on 5 cards as shown in figure 1.

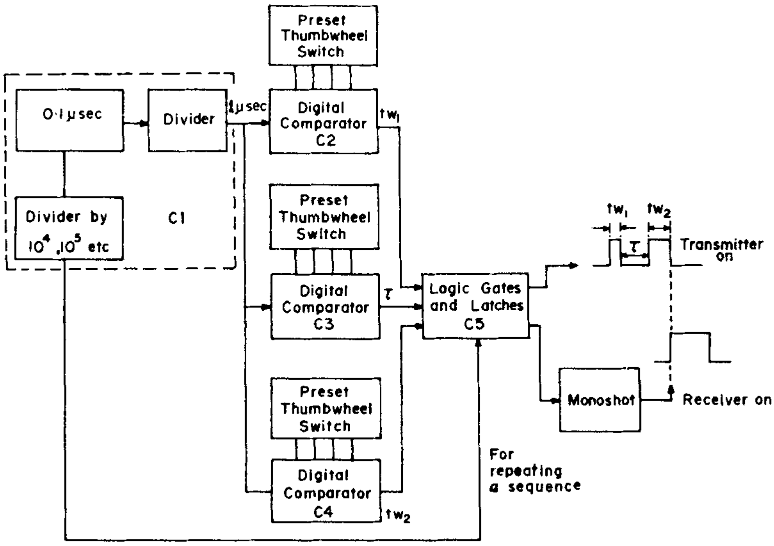


Figure 1. Block diagram of the preset table two pulse sequence generator. tw_1 and tw_2 are 90° and 180° pulses respectively. τ is the delay time between the 90° and 180° pulses. Logic gates and latches are used as an interface for generating a two pulse sequence.

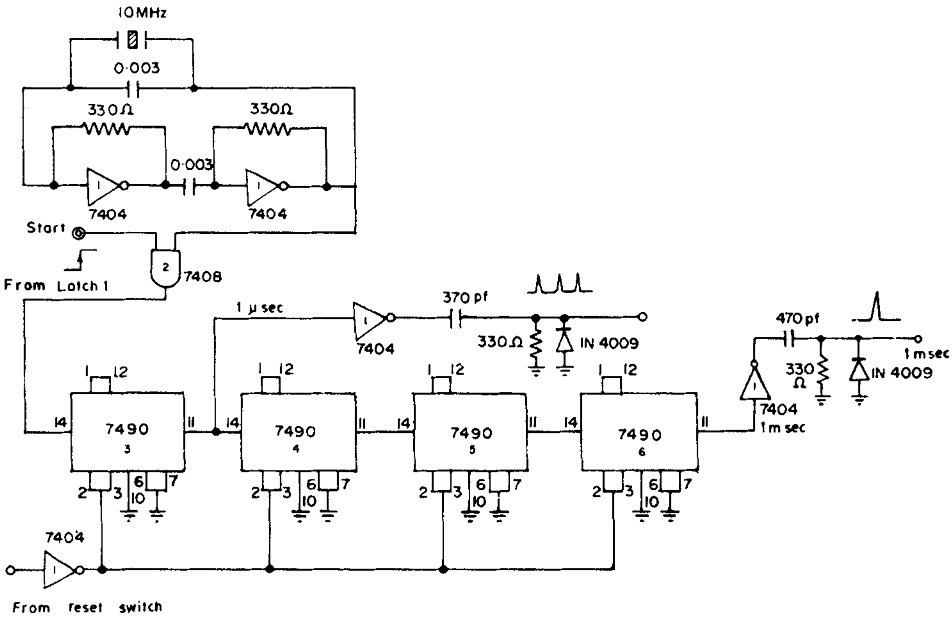


Figure 2. Schematic of 10 MHz clock pulses and generation of 1 μ sec and 1 msec timing pulses using dividers. 1 μ sec pulses are used as basic pulses for pulse widths and delay. 1 msec pulses are used for repetition rate.

2.1 *The master clock*

The master clock, shown in figure 2 and assembled on card C1, generates 0·1 μ second pulses using a 10 MHz quartz crystal. Using counters (type IC 7490) as dividers, one obtains 1 μ sec and 1 m sec pulses. The 1 μ sec pulses are used to control the width and the delay between the two rf pulses whereas the 1 m sec pulses are used for repeating a given sequence of pulses. It is clear that the basic time resolution of the instrument is 0·1 μ sec which can be made use of if necessary.

2.2 *Magnitude comparators*

The programmer uses three identical magnitude comparator circuits assembled on three cards C2, C3 and C4 to obtain the predetermined widths tw_1 and tw_2 of the two pulses and the delay τ between them. Two of the comparators control the widths tw_1 and tw_2 while the third one controls the delay. The detailed schematic of a comparator card is shown in figure 3.

The IC 7485 is a four-bit magnitude comparator having two sets of inputs $A(A_0, A_1, A_2$ and $A_3)$ and $B(B_0, B_1, B_2$ and $B_3)$. Two such ICs are connected in cascade with their inputs A already preset by a two digit switch brought on the front panel. The 1 μ sec pulses obtained from the clock are connected to the 7490 counter and the BCD outputs so obtained from 7490 constitute the second set of inputs B of the comparator. Whenever the two inputs A and B are equal a level change occurs at the $A = B$ pin of the comparator. This level change prevents further counting. Thus the time interval is a multiple of the basic time unit and the thumbwheel setting. As pointed out earlier, the comparators C2 and C4 decide the width of the first and the second pulse, tw_1 and tw_2

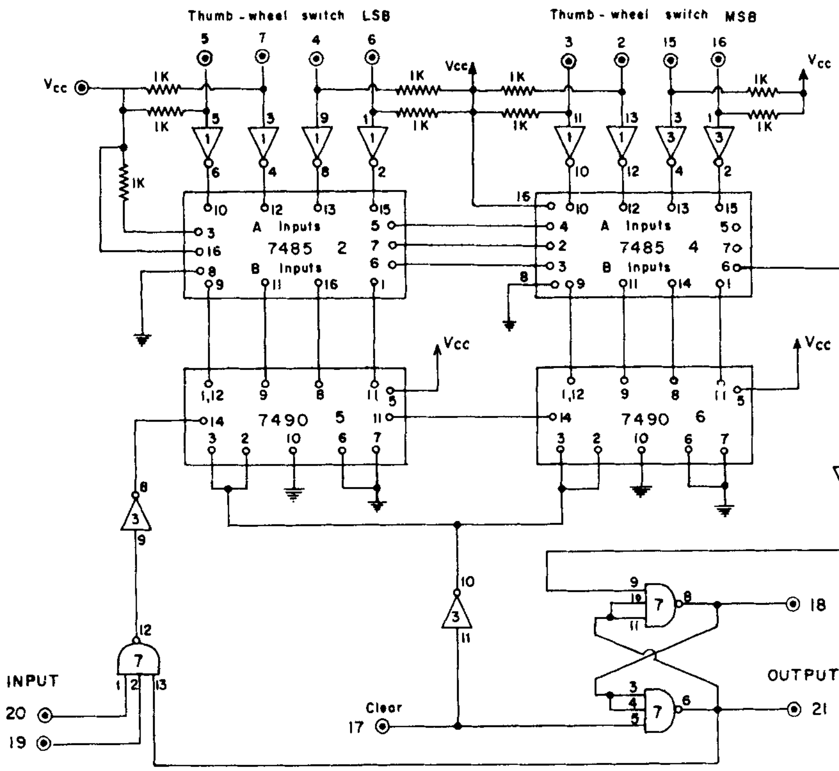


Figure 3. Magnitude comparator circuit. This is used for generating gating levels as per thumbwheel settings for tw_1, τ and tw_2 timings. IC 1 and IC 3 are 7404 and IC 7 is 7410. Pins shown are connected to pins in figure 4 with the same numbers.

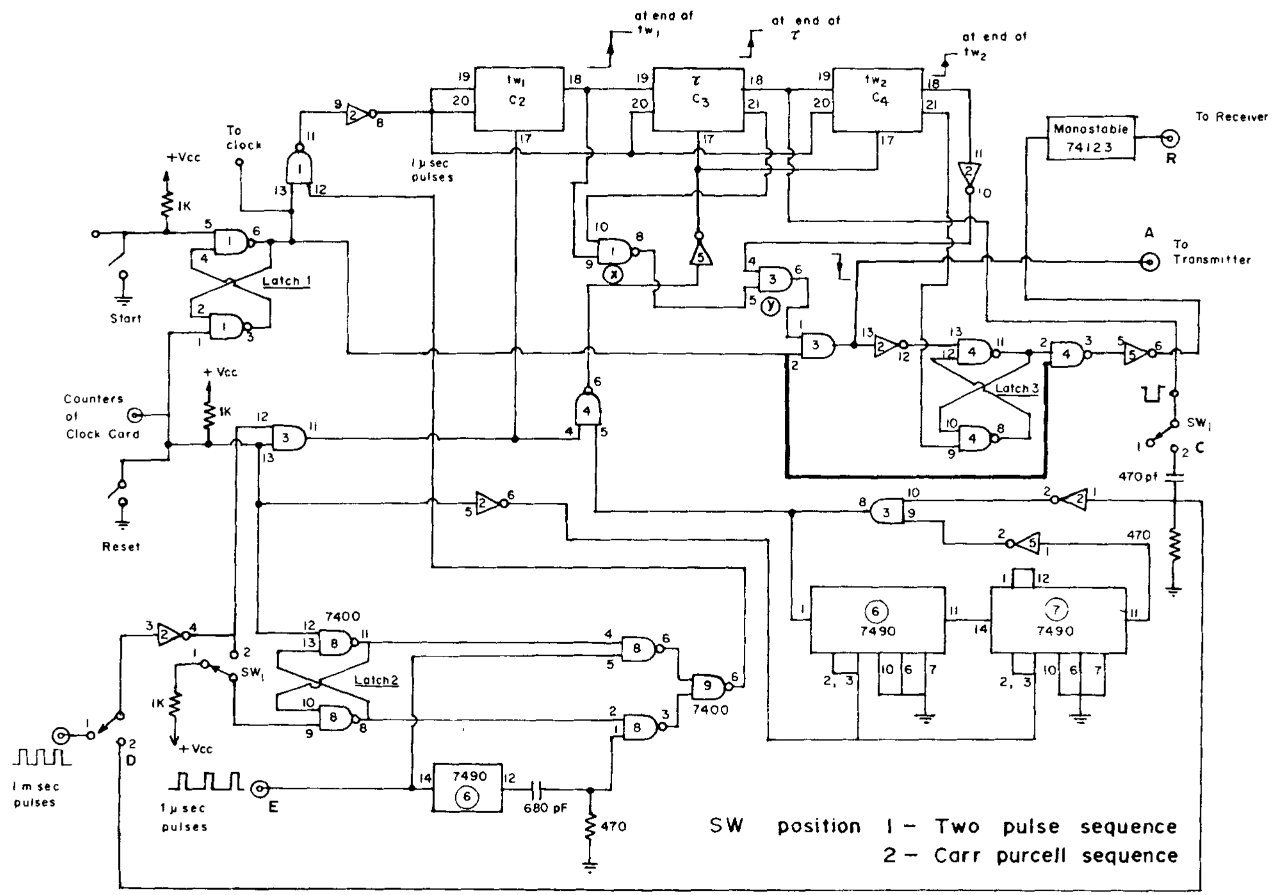


Figure 4. Interface card for generation of two pulse sequence and Carr-Purcell sequence. Point A is the output terminal for transmitter pulses. Point R is the output terminal for the receiver gating. Switch in position 2 generates Carr-Purcell sequence. IC 1 and IC 4 are 7400. IC 2 and IC 5 are 7404 and IC 3 is 7408.

respectively of the two pulse sequence whereas C3 decides the period between the end of the first pulse and the start of the second pulse. With 1 μ sec pulses as basic timing unit, all these periods can be independently set between 1 μ sec and 99 μ secs.

2.3 *Interface*

The interface card C5 consists mainly of logic gates and latches. It interfaces all the cards to produce a two-pulse sequence for the transmitter in normal mode and a Carr-Purcell sequence (Carr and Purcell 1954) in burst mode.

2.3*a* *Two pulse sequence mode*: With the selector switch in position 1 (figure 4), all the counters and the latches are reset by pressing the reset switch provided on the panel. Pressing of the start switch sets latch 1 which in turn makes: (i) 1 μ sec pulses to appear at the inputs of the three comparator cards C2, C3 and C4 (ii) the output point A feeding the transmitter to go to a high level and thereby initiate the first pulse of the predetermined width tw_1 and (iii) the latch 3 to be in set position.

As seen in figure 3, the outputs of the comparator circuits are complimentary to each other. In the reset mode the output pins (no. 18) are at a low level. Although 1 μ sec pulses are applied to all the comparator cards, only C2 starts counting and comparing whereas a low level at the inputs of the other two cards C3 and C4 prevents them from counting.

At the end of time tw_1, as per preset by the thumbwheel switch, output of C2 (pin 18) becomes high. This high level makes the output A to go low through NAND gate x and AND gate y. At the same time C3 starts counting and comparing which decides the period τ. At the end of the delay time τ, output pin 18 of C3 goes high and so the complimentary output (pin 21 of C3) goes low. Thus output point A goes to a high level again through the x and y gates at the end of the delay interval τ. Now because of the high input at C4 (pin 19), C4 starts counting and comparing. At the end of time tw_2, output pin 18 of C4 goes high which makes the output A to go low and resets latch 3 which in turn triggers a monoshot (IC 74123). The output of the monoshot puts the receiver on. Since all the three comparator cards are self-resetting type, at the end of their counting periods no further counting and comparison takes place until a next 1 msec pulse sets all the counters to start a fresh sequence (1 msec repetition pulse clears 7490 used in comparator cards and starts a fresh sequence).

2.3*b* *Carr-Purcell sequence*: To obtain a Carr-Purcell sequence, the starting pulse of starting a sequence of two pulses as in the normal mode, generates a burst of pulses of predetermined width and delay. In this mode, the selector switch is kept in position 2. The operation is the same until C3 stops counting. At the end of the delay τ, the high level from the output of C3 passes through the points C and D to set latch 2 in action. The setting of this latch makes 1 μsec pulses at E to pass through a scale-of-two counter. Thus all the subsequent pulses will have twice the original periods *i.e.* pulse width $2tw_1$ and delay 2τ. The number of pulses to be generated in this mode are predetermined by the 7490 counters IC 6 and IC 7 (in the present case scale of 5 and scale of 10 respectively). At the end of the required number of pulses the output of the counter (IC 7) resets the total burst. One can start a fresh burst simply by pressing the start switch.

The scheme of pulses used in the spin echo spectrometer developed in our laboratory (Chaughule and Gupta 1982) is shown in figure 5. The receiver is turned on by applying an appropriate gate pulse, also shown in figure 5, only when one expects the nuclear

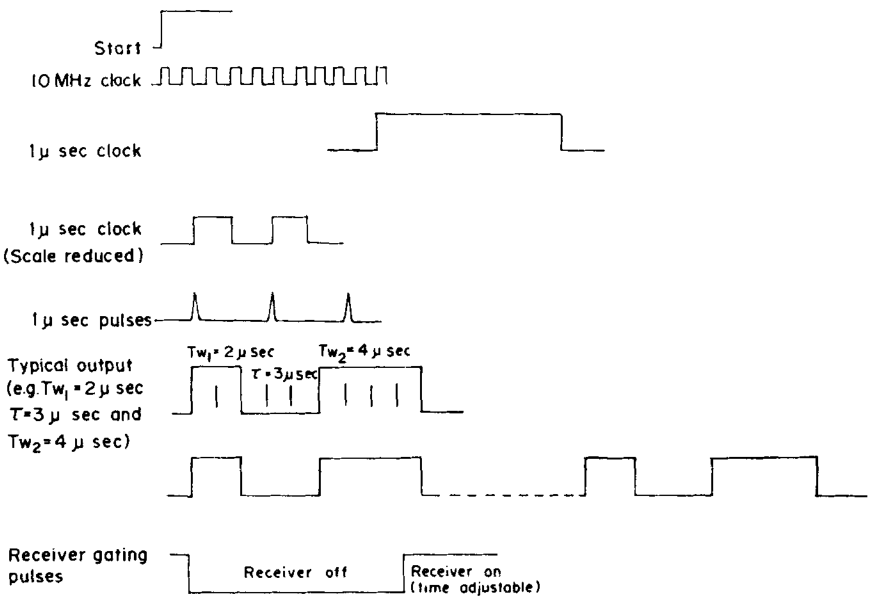


Figure 5. Basic clock and relative waveforms applied to transmitter and receiver.

resonance to take place in the absence of any rf fields. The gating keeps the receiver on only for the time adequate enough to receive the spin echo signals. This improves the recovery of the receiver.

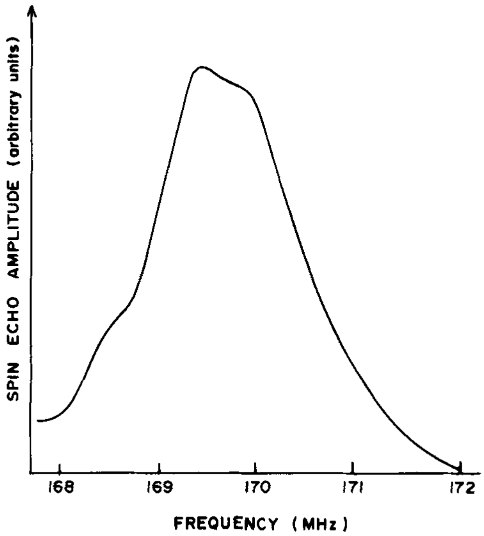
2.4 *Performance*

Figure 6a shows the spin echo of ^{55}Mn zero field resonance in $LaMn_2Si_2$. The parameters of the pulse sequence $\pi/2 - \tau - \pi$ used here are *tw* (width of pulse) $= 2$ μsec, $\tau = 7$ μsec, $\pi = 2$ μsec. Figure 6b shows the response of the system to the Carr-Purcell sequence of pulses. The parameters here are the same for $\pi/2$, π pulses except that there are a train of pulses seen on an oscilloscope with 10 μsec per cm sweep. These spectra clearly show the ease and flexibility obtainable with this pulse programmer.

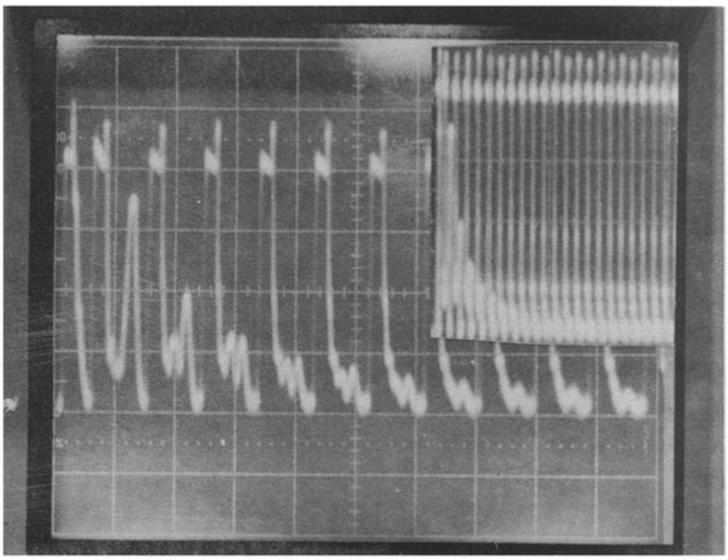
We are currently using this instrument in our studies of zero field resonance measurements in materials having rare earth(s) in mixed valence state. The emphasis would be to study the influence of mixed valence state on the zero field resonance properties of Eu in these materials.

3. Conclusion

We have described the functioning of the pulse generator that has been developed in our laboratory during the course of our work on zero field resonance in ferromagnetic materials. This pulse generator has been used in our recent work on $LaMn_2Si_2$ and related intermetallic compounds (Chaughule *et al* 1983). Spectra have been observed illustrating the usefulness of the pulse programmer.



(a)



(b)

Figure 6a. The line-shape of the echo ^{55}Mn signal in $LaMn_2Si_2$ at 77 K is generated by measuring the echo intensity as a function of frequency. **b.** Carr-Purcell sequence of echoes using $\pi/2, \tau, \pi, 2\tau, \pi, 2\tau \ldots$ pulses. $\pi/2$ pulse is 1 μsec and $\tau = 4$ μsec. The inset shows a large number of Carr-Purcell echoes to show clearly the exponential decrease of the amplitude of the echoes.

Acknowledgement

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References

Adduci D J, Homung P A and Torgeson D R 1977 *Rev. Sci. Instrum.* **48** 661

Carr H and Purcell E 1954 *Phys. Rev.* **94** 630

Chaughule R S and Gupta L C 1982 *Rev. Sci. Instrum.* **53** 1738

Chaughule R S, Radhakrishnamurthy C, Sampathkumaran E V, Malik S K and Vijayaraghavan R 1983 *Mater. Res. Bull.* **18** 817

Conway J L and Cotts R H 1977 *Rev. Sci. Instrum.* **48** 651

Shenoy R N, Ramakrishna J and Srinivasan R 1976 *J. Phys.* **E9** 779

Erratum

"Accelerator development in India" by A S Divatia and C Ambasankaran, Pramana 24 pp. 227–244 January & February 1985

i) Page-2, para-1, line-8: replace 'IISc' by 'TIFR' and

ii) Table-1, last line: replace 'sections' by 'sectors'.