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MILLION CHANNEL PULSE HEIGHT ANALYSER THROUGH PSEUDO-RANDOM DIGITAL TRANSFORMATION*

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In all nuclear spectroscopy experiments data are collected in the form as they come from the source. It would be very difficult and expensive to analyse such data in million-channel resolution.

A new technique is developed in which data from experiments are first digitally transformed into a new form and then analysed[1]). Digital transformation is applied on-line to each event (descriptor). Passing through a transformation box, each descriptor produces a pseudo-random address into which it is stored. Transformation comprehends a scattered multidimensional physical spectrum into a minimal space, enabling high speed, on-line, multidimensional, million-channel spectrometry.

The paper describes the computer system, which operates as a mega-channel, transformation mode analyser. Experiments with a real and computer simulated spectra show a very short dead time and high efficiency of the memory utilisation of the system.

Transformation can be realized by simple hardware between ADC's and computer, or as a part of a computer interrupt routine. Both solutions are described.

1. Introduction

In a multichannel analyser the input signal describing an external event is expressed as a digital number which we shall call a "descriptor". In a conventional analyser the descriptor defines the location in the memory at which the "count" (number of occurrences of the descriptor) is stored. Since the descriptor and the location are identical, the acceptable range of descriptors is defined by the size of the memory.

With increasing resolution of nuclear radiation detectors and analogue to digital converters the full range of descriptors may be very large. For example, in three-dimensional spectroscopy the possible range may be $1000 \times 1000 = 10^6$ different type of descriptors asking for a 10^6 channel analyser. In certain nuclear physics and biology experiments, particularly those involving coincident spectra, although the possible range of descriptors is very great, the number of different descriptors which actually occur during the experiment is much smaller. A few such two-dimensional spectra, displayed in a map form are shown in fig. 3. Such spectra in 1000×1000 resolution have a range of 10^6 possible descriptors, while only a few thousand of those actually occur in experiments (for example in fig. 3a, about 8000). If one uses a conventional multichannel analyser for the measurement of such spectra, one must provide a large memory (10^6 channels) of which only a small percentage of locations would be useful, and all

* This paper is the first part of a series "DIGITAL, ANALOG AND TIME TRANSFORMATIONS OF RANDOM NUCLEAR DATA".

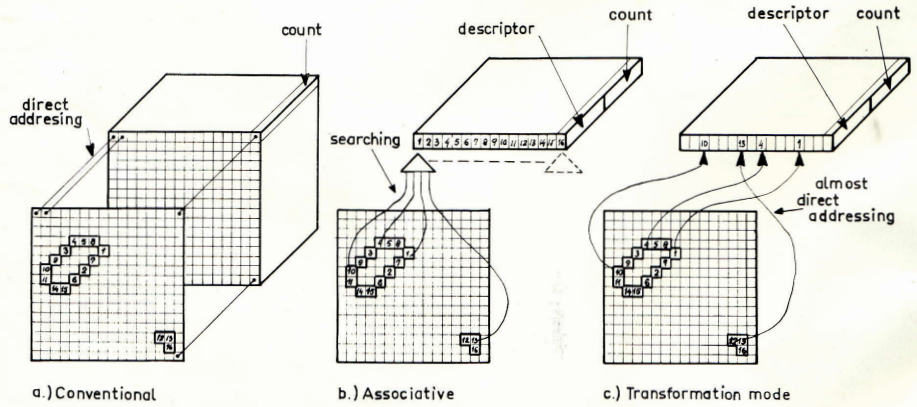

Fig. 1. Principles of conventional, associative and transformation mode analysis.

other locations would be empty (of 10^6 channels, only about 8000, or 0.8% would be useful). The principle of connection of the physical field of descriptors to the memory locations in classical analysers is shown in fig. 1a.

An alternative technique is to allow locations only to those descriptors which actually occur in the experiment. The memory size then limits the number of different descriptors rather than their range. Since the correspondence between the location and the descriptor is lost, it is necessary to store the descriptor as well as the associated count. These facilities are provided by content addressable or associative memories. Memory words are assigned only to those physical channels in which at least one count has occurred. Such assignment of micro-areas of interest cannot, in general, be done in advance of the experiment. The assignment of memory locations to physical channels is done dynamically – that is as the experiment proceeds. Hence the associative system is a sort of "learning or self-adjustable" system.

The principle of connection of the physical field of descriptors to memory locations in associative analysers is shown in fig. 1b. The numbers show the sequence of arrival of the first descriptors of different kind from experiment. The location given to a particular descriptor is not determined by coordinates of the descriptor as in classical analysers. The first descriptor will take the first available location of the memory, the next different descriptor the second location etc.

So far two computer oriented[2–4]) and one hardware oriented[5,6]) associative analysers have been built proving the high efficiency of the memory utilisation, but also showing some limitations: hardware systems are limited by size and high cost; computer-software systems are limited by increased dead time, since a comparison must be made between each input descriptor and the memory content to find the appropriate channel location. To overcome this limitations a new technique of pseudorandom transformation of data is developed.

2. List retrieval and pseudo-random transformation

When a new datum comes to the associative analyser input it must be sorted into its channel on a list by using the information provided in its descriptor. Hence some searching will be required to locate a descriptor in the storage system. The range of all possible descriptors, which we denote by $(a_1, a_2 \ldots a_n)$ is usually very large in comparison with the actual number r of descriptors $(a_{i_1}, a_{i_2} \ldots a_{i_r})$ that are to be stored in the i^{th} experiment. The storage procedure consists in assigning to each descriptor a_{i_k} a unique descriptor location number $A_{i_k} \in (0, 1, \ldots r-1)$, where r is the size of the memory. Typical values for associative radiation analysers may be $2^{20} < n < 2^{26}$ and $2^{12} < r < 2^{16}$. The problem is to device a procedure for assigning the descriptor location number so that the time needed to store or read out a descriptor is minimized. Next we shall discuss a few retrieval procedures.

Sequential method: An obvious routine for searching the list on the memory is to compare the descriptor for a new event with the descriptor in each location in turn starting at the first. When a match is found that is the two descriptors are identical, the associated count is increased by one. If all descriptors are equally probable, and the list is of length r, the average number of comparisons will be $c = \frac{1}{2}r$ (for $r = 4096$, $c = 2048$ comparisons). It is obvious that such a procedure cannot be accepted for on-line application.

Tree method: A marked reduction in access time to the required location may be achieved by using a tree search algorithm[7]). This procedure requires repeated comparison of pairs of descriptors. Each comparison yields one of three answers: (1) they match; (2) the first is greater than the second; or (3) the first is smaller than the second. According to the answer the comparison is either finished or proceeds on, to the left or right branch of a tree. The left address points to the location where the next larger descriptor is stored; the right address points to the location where the next smaller descriptor is stored. If there are r descriptors on the tree, the average number of comparisons is reduced from $\frac{1}{2}r$ to approximately $\log_2 r$ (for $r = 2^{12} = 4096$, $c = \log_2 r = 12$ comparisons).

The number of comparisons may be further reduced by splitting the list into several trees, growing simultaneously in the memory, as it was actually done on the first associative analyser[3]). The main disadvantage of this "forest" technique is its complexity.

Pseudo-random transformation: The problem is to device a procedure for assigning the descriptor location address so that the time needed to store or read out a descriptor is minimized. The procedure must be such that it works equally well for any shape or size of spectra. Hooton, Souček and Spinrad have suggested to look for a procedure of randomising type[8–10]), and Rosenblum[11]) has shown that Hamming's[12]) codes can be used for this purpose. Many procedures have been tried in our laboratory (Hamming's codes; residues; multiplication of polynomials; etc.) and the best results have been obtained by dividing polynomials[13]). The problem is similar to the file address problem by key-to-address transformation. The characteristic of nuclear spectroscopy is that it

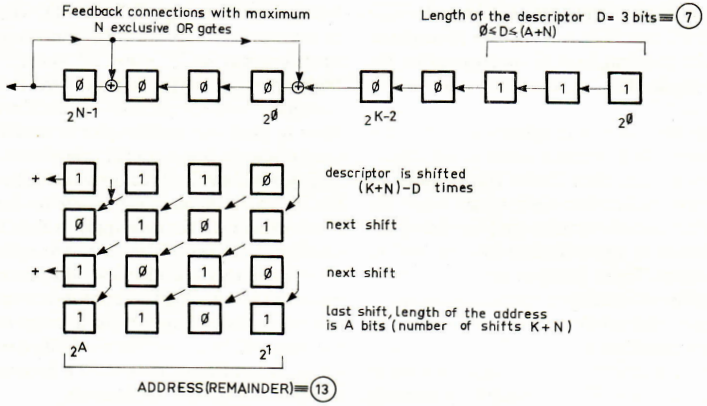

Fig. 2. Generation of pseudo-random address of length $A=k$ bits.

does not assume an a-priori knowledge of the key set (spectrum or descriptor set) and asks for a procedure suitable for high speed on-line application. Through transformation each descriptor uniquely derives its storage address. It is assumed that descriptors will be pseudo-randomly assigned to storage locations, hence the term "pseudo-random transformation". It would be ideal if any distribution of descriptors would produce a uniform distribution of addresses throughout the memory. For practical spectra there is, however, the possibility of two or more descriptors being transformed to the same address. To overcome this serious limitation, transformation is used only to generate an address on the list at which to start searching. This is the most probable address at which to find the descriptor, but it does not necessarily have to be there. The procedure can be explained by one example: Let descriptors R_1, R_2, S, U produce after transformation addresses r, r, s, and u, and no descriptor in a particular experiment produces the address t. If the descriptors come in time according to the sequence U, R_1, R_2, S they shall be stored on the list in the following way:

Location	Descriptor	Stored
⋮	⋮	
r	R_1	
s	R_2	
t	S	
u	U	
⋮	⋮	

By using this method, experiments have shown that the average number of comparison is only slightly bigger than one. The principle of connection of physical channels to the memory locations through pseudo-random transformation is shown in fig. 1c. Each descriptor, after transformation, is "almost directly" addressing the memory. The advantages are obvious: memory access time is short as in classical analysers, the efficiency of utilisation of a memory is big as in associative analysers.

The principle of transformation through division by a polynomial is shown in fig. 2. Transformation is realized by a shift register with proper feedback through exclusive OR gates. If the shift register has $n+k$ stages, and the input descriptor D digits, the descriptor has to be shifted $k+n$ places. At the end in the register there will be the remainder. Experimentations with different spectra and different feedbacks have shown that the remainder might be used as a descriptor address on the list. Two adjacent descriptors in the physical field will give two remainders far away from each other.

In the example in fig. 2, the descriptor has 3 digits and corresponds to decimal 7 and a part of shift register on which a feedback is applied has 4 stages and can produce $2^4 = 16$ different addresses. The descriptor 7 will produce after 9 shifts the remainder 13, and will be stored in the memory address 13. This is also shown in fig. 1c.

The choice of feedback and properties of such pseudo-random transformation are given in the following paper[14]), this issue, p. 213.

3. Experiments

The transformation has been programmed for an SDS 930 computer and used for analysis of two-dimensional coincident spectra. Some of the spectra have been collected on-line from real experiments, while other spectra have been simulated. The transformation mode is specially suitable for spectra such as in fig. 3. Those spectra are simulated by a simple laboratory made CRT-light pen system with a PDP-8 computer, according to the known results of the experiments.

Each of those spectra contains 1000 different descriptors in the 128×128 field. The descriptors are transformed by SDS 930, always producing practically uniform distribution of 1024 different addresses, regardless of the spectrum shape. If there was more than one descriptor producing the same memory address, all except the first one searched for available space further on the list. Although each of those spectra has a range of $128 \times 128 = 16384$ possible channels, they have been measured with an instrument having only 1024 channels, owing to the digital transformation technique, which comprehends the size of the spectra into minimal space.

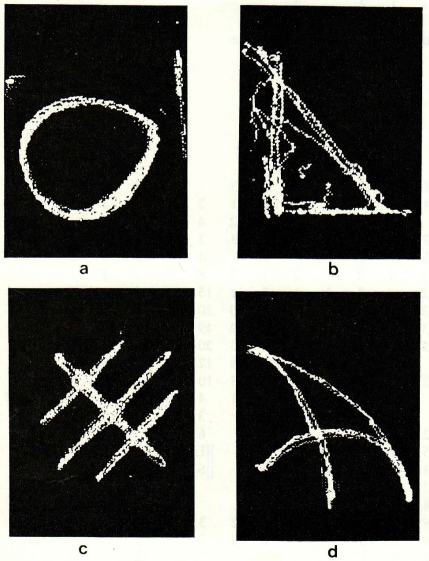

Fig. 3. Spectra with a great range but limited number of channels. a. Cyclotron experiment: d+p→p+p+n, 21.1 MeV, 34° ⌀, −34° ⌀; b. Van de Graaff experiment: ^{6}Li+^{3}He→p+α+α, 3.0 MeV, 35.7° ⌀, −37.5° ⌀; c. Biological spectra, Jahns line phantom; d. Two parameter spectrum ^{3}He(^{3}He,2p)^{4}He.

Those are typical spectra with a great range but limited number of descriptors.

The place where this kind of instrument will become of tremendous importance is in the more complicated experiments. Let us take one numerical example. Suppose we have 4 parameters at 1000 channels each – this is 10^{12} channels. Suppose we have a large experiment generating a total of 10^8 events, so we have 10^{12} possible channels and 10^8 events. In this circumstance, even if each active channel is occupied only one, we would still have only one count in each of 10^4 channels. If an experiment is really interesting at all, there will undoubtedly be more than one count in many of the channels, which would mean that the total percentage occupation or probability of occupation might be 1 in 10^5 or in 10^6. With more parameters this point becomes even more significant.

When one uses more parameters the background is cut out essentially so that there is a big probability that available memory locations will belong to events of interest.

Fig. 4 presents the part of ^{60}Co and ^{22}Na gamma-gamma spectra, analysed in 128×128 resolution in transformation mode. The memory size has been smaller than the number of different descriptors, and not interesting parts of spectra are stored on the magnetic tape and not in the fast core memory. These parts are marked on the spectrum.

4. Zone selection in transformation mode analysis

Transformation and associative mode analysers ask for a descriptor to be stored in the memory, as well as for an associated count. Hence about 50% of the memory would be occupied by descriptors. The situation has been improved in the associative mode by introduction of "zone selection", and the same technique can be equally used in the transformation mode. Here are the basic principles of zone selection, as proposed by Hooton[6]).

In many experiments information occurs in groups or clusters of channels. If the descriptor field is divided arbitrarily into a number of equally sized zones, each zone presents a small digital window. For each zone it is necessary to store only one descriptor. If data occur in any channel within a particular zone the descriptor describing the zone is held in an associative memory and a group of storage locations is assigned for counts for different channels inside the zone. For example if the zone is of size $4 \times 4 = 16$ channels, it is necessary to provide one space for storing descriptor of the zone, and 16 spaces for counts, which can be addressed inside a zone using 2 least significant descriptor digits. Hence

	16													32											
20		3	4	4	5	3	2	2	3		4		2		2	2	1	12	12	12			3	2	1	
	5		3	6	5	2	1	3	3	2	2	2			1	1	6	11	11	6			1	2		2
	3	1	5	1	2	4	3	1			1	2	4	1	1	3	7	8	8	6	2					
	5	1		1	2	3	2	3	1			1			1	1	6	12	10	4	3	2	1	2		
	2	2		2	2	4	1	3			1	3	2	3	1	2	3	7	15	15	5					1
		7	2	4	5	1	1				1	1		1	1	2		6	5	3	1					1
	2	1	2	7	1	5	2	1	1			1				2	3	6	4	9			1		2	
		1	2		2	1		2	1			1			1		3		3	2			1		1	
			4	2							2			2	1	1		3	3	3	L O		3	1		2
			1	2	3		1					2			1		1	3	2	2	S T		2		1	1
	2	1	4	1	3	2		2	1				1						3					1		
			1	2	1	1	1	2		2	L O			2	1	2	3	4	3	2			2			
	2	1	1			1	2	2		2	S T		2			1	2	5	2	2		1		1		1
		1		1	2	1	1			1					2	2	1	7	3	5	2		2			3
	1		2	2			1		1	2	2		1			1	4	6	11	7	3	1				
	3	3	1	5	4	6	2	4	2	1	2	1		2	1		12	15	20	18	4					
	6	6	9	4	7	9	3	3	2	2		2	3	1	1	2	18	30	43	18	11	4		1	1	4	3
	4	8	7	3	10	9	10	6	4	1	1	3	3	1	5	6	18	40	53	36	11	5	1	1		3	
	10	12	7	9	9	4	8	1	4	3	2	3	2	2	1	6	16	49	49	33	9	2					
	5	4	9	3	6	6	4	2	2	1	1	1	2	1	2	3	7	29	28	19	7	1					
40	5	3	4	6	2	4	3	3	1	3		2		1	1	1	4	13	15	9	7				2	1	1
	2	3		2	1	5		1		2		1	1	L O			1	2	6	4	11	2	3				
	1	2	1	1		2	3	4			1		1	S T				2	5	1	1			1	1		
	1	3	2	3		1	1							1	1	1		1	1	2			1				
				1				1		1				2			1	2									
			1					2	1		1			1	1	1		2									

Fig. 4A. 0.511–0.511 MeV annihilation quanta from ^{22}Na source.

	64															80										
72	1	1	3	4	3	2	2	1	1	7	14	5	5	1	3	1				3		2	3			1
	2	1	3	3	1		1	2	2	4	3	4	3	4	6		1		2	1	2	2	1	3		
	1	4	2		1	1			1		6	11	6		3				1	2	4	1		3		
	4	4	3	1	3	4		3	4	7	7	5	3	3				3	1	3	2	1	2	3	1	
	5	6	5	3	7	3	6	2	4	3	4	7	4	3	2	1	1	1	4	7	4	8	3	3	2	
	7	7	11	3	7	3	4	6	4	2	3	9	6	1	4	2		2	7	7	8	9	7	2	3	
	8	7	7	7	7	7	6	3	4	3	3	3	11	2		2	3	1	7	11	15	15	12		6	1	1
	9	6	8	7	15	3	4	3	1	6	3	3	4	3	6	2	1	8	7	10	20	15	10	13	7	2	2
	9	6	10	11	1	5	6	5	L O		4	3	3	3		1	1	6	5	14	19	21	17	14	7	2	
	4	9	5	2	4	2	6	2	S T		5	1		2	1		3	3	7	13	20	22	13	15	2	2	
	4	2			3	1	1	1	5	4	2	5	4		2	2	4	3	4	8	12	16	12	8	2		1
	1	2			5	1	2	2	1		3	1		2	1				4	3	10	10	5	2	4		1
	3		1	4	1	2	L O		2	3		4							1	1	4	3	1				2
			5	1	1	2	S T		4		8	7									3	5					
	2	3			2	1			4	8	9	7	14	2	3	1					6	4					
	3		2		1	3	1	5	5	11	16	15	7	5	3						L O						
	6	1	1				3	1	6	14	12	10	12	13	6	1	2				S T						
	5	2	2	2	2	2	1	3	7	11	9	24	12	12	4	1											
90	7	1			1	1	3	9	4	5	20	18	14	8	7	2	2	1									
	2					1	2	1	3	8	12	18	9	9	6	6			2	2	3	3					
							2	3	5	5	6	19	11	6	3	3			1	2	2						
	2	2					3	2	3	4	12	4	5	4	2	1							2				
			1				2	1	2	3	5	5	5	1									1				
							L O			2	1							2									
							S T										1										

Fig. 4B. 1.17–1.33 MeV gamma-gamma coincidence spectrum from ^{60}Co source.

in total it is necessary $1+16=17$ spaces and the fraction of memory containing the counts would be $f_1 = 16/17 = 94\%$. In the associative mode without zones it would be necessary to have 16 spaces for descriptors and 16 for counts, giving $f_2 = 16/32 = 50\%$.

Of course, high efficiency, f_1, would be achieved only if the clusters of the spectrum are much bigger than the size of the zones. In the case of spectrum with a very narrow line in comparison with the zone size, part of many zones would be empty and the efficiency might be even smaller than f_2. For realistic spectra and zones of 4×4 channels, the efficiency will be $f_2 < f < f_1$. The efficiency would tend more towards f_1 as the spectra would have more dimensions.

Transformation mode analysis can be applied to spectra composed of separated descriptors as well as to spectra split into zones. If zones are of 4×4 channels, determined by 2 least significant digits of X and Y (two-dimensional analysis), then those 2 digits are cut off the descriptor, and the rest of descriptor digits are applied to the transformation box to produce the pseudo-random memory address.

5. Selection of items of interest

In a transformation mode analyser as well as in an associative analyser, the number of memory locations M is much smaller than the total number of possible different channels or the descriptor range. The descriptor range may be split into two parts, a "region of interest" and a "background or noise".

Normally, the region of interest is a part of the spectral distribution in which a maximum of differential counting rates occurs. Associative and transformation mode analysers work so that the available M memory channels are given to the first M different descriptors arrived. Hence most of the memory channels will be given to the region of interest, but still some channels will be occupied by noise. To prevent this, a special procedure of automatic selection of items of interest is developed.

In many experiments the total number of channels containing an appreciable number of counts may be comparable with M or smaller. In such cases the memory effectively records the whole original spectrum, and there is no need for automatic selection of items treated here.

Let us suppose that the region of interest occupies N_1 channels, each having the frequency f_1, and the background N_2 channels, each with the frequency f_2 (N_1/N_2 might be of the order of a few times 10^{-3}, f_1/f_2 – a few times 10^3).

According to the Poisson distribution, the probable number n_1 of different descriptors out of the region of interest N_1, for which at least one count arrives during some time interval T (and will therefore occupy a channel in the memory) is

$$n_1/N_1 = 1-e^{-f_1T}.$$

Also, the number of n_2 of descriptors out of the background N_2, which will take place in the memory is

$$n_2/N_2 = 1-e^{-f_2T}.$$

Hence the ratio n_1/n_2 is

$$n_1/n_2 = (N_1/N_2)(1-e^{-f_1T})/(1-e^{-f_2T}).$$

If $T\to\infty$, $n_1/n_2 = N_1/N_2$. The whole spectrum would be stored, but the memory would have to be of a very large size:

$$M = n_1+n_2 = N_1+N_2.$$

If $T\to0$, $n_1/n_2 \approx (N_1f_1)/(N_2f_2)$.

The ratio N_1f_1/N_2f_2 might be of the order of 1. That means that the parts of the memory occupied by descriptors from the region of interest n_1, and by the background descriptor n_2, would be of a similar size.

To improve the ratio n_1/n_2, the following procedure is developed:

At the beginning of the experiment the memory is filled with descriptors, giving some ratio n_1/n_2. The descriptors from the region of interest would have bigger associated counts. If one divides all the counts by 2 (or 2^n, simple right shift n times), many locations occupied by the background would be cleared to zero. If one proceeds with experiments, many cleared locations would be given to the region of interest. Repeating this procedure a few times at the beginning of the experiment, one can increase substantially the ratio n_1/n_2, erasing from a list the descriptors belonging to the background.

The strongest selection would be, if one erases from the new list all descriptors, except the most probable descriptor.

Selection of items out of experiment presents in general an interesting problem[15–18]).

6. Dead time in transformation mode analyser

In classical direct addressing analysers, most of the dead time is due to the analog to digital conversion. In an associative analyser the dead time is substantially increased due to the number of comparisons necessary to find the descriptor on the list. In a transformation mode analyser, which is "almost directly addressing the memory", the dead time will be almost as short as in classical analysers. Fig. 5 shows the result of the experiments, proving this fact.

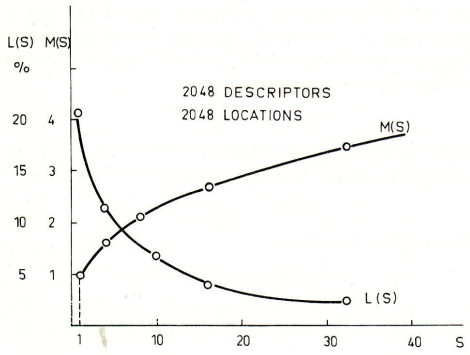

Fig. 5. Average number of comparison $M(s)$ and percentage of lost descriptors $L(s)$, as a function of maximal permitted number of comparison s.

The spectrum such as shown in fig. 3a, containing 2048 descriptors in a 128×128 field was analysed in transformation mode, in 2048 locations only. The average number of comparisons $M(s)$ and the percentage of lost descriptors $L(s)$ were measured as a function of the maximum permitted number of comparisons s.

If only one comparison is allowed, $s = 1$, of course $M(s) = 1$, but $L(s) = 20\%$, showing that there are about 20% congruent descriptors, addressing locations, already occupied by other descriptors. Allowing searching for a free place in a few subsequent locations, $s > 1$, $M(s)$ is increased, while $L(s)$ is decreased to only a few percent.

The experiment was performed under the most unfavourable conditions:

– memory space has exactly the same number of locations M as the number of descriptors N_1 in the spectrum. If M was larger than N_1 by a few percent, a negligible number of descriptors would be lost even for $s = 1$, giving $M(s) = 1$.

– all descriptors in the spectrum have equal counting rates, having equal chance to come first and occupy locations in the memory. Less strong experiments would produce an appreciable number of descriptors with high counting rates. Those descriptors will come first and take directly, in one comparison places on the list. Hence most of data will be analysed in one comparison, and only less probable descriptors will have to search for available places in a few comparisons. For such spectra, even with $M = N_1$, $M(s) \approx 1$.

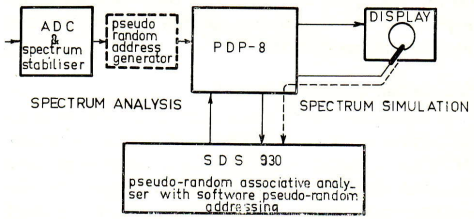

Fig. 6. Computer system for pseudo-random transformation of nuclear data.

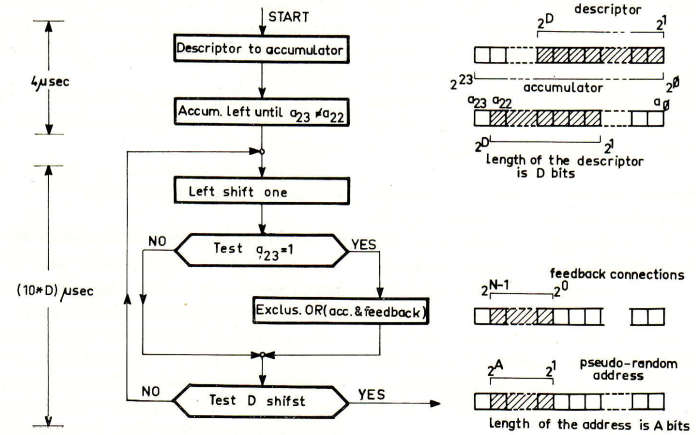

Fig. 7. Generation of pseudo-random address by computer.

It is obvious that in a transformation mode analyser, the dead time will be mostly due to the analog to digital conversion. With fast ADC's, transformation mode analysers can be used for high rate experiments.

7. Computer system for pseudo-random transformation

To investigate the properties of different pseudo-random transformations, and to use the transformation technique for analysis of nuclear spectra, the system shown in fig. 6 has been designed. The spectra from fig. 3 are simulated by the use of PDP-8, CRT, light-pen system, and then transferred to SDS 930. In SDS 930 software pseudorandom transformation has been applied to each descriptor. Software transformation has enabled us to change easily the transformation feedback, and other transformation features, and to make investigations using real-time FORTRAN. The transformation programme block diagram is shown in fig. 7.

The maximum length of the descriptor can be 23

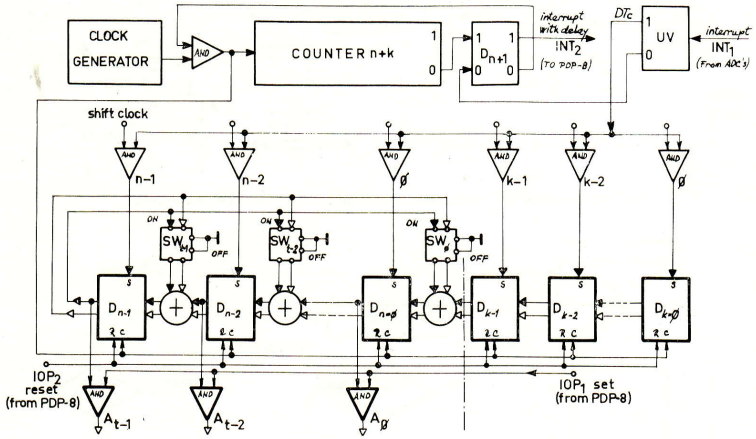

Fig. 8. Generation of pseudo-random address by hardware between ADC's and PDP-8.

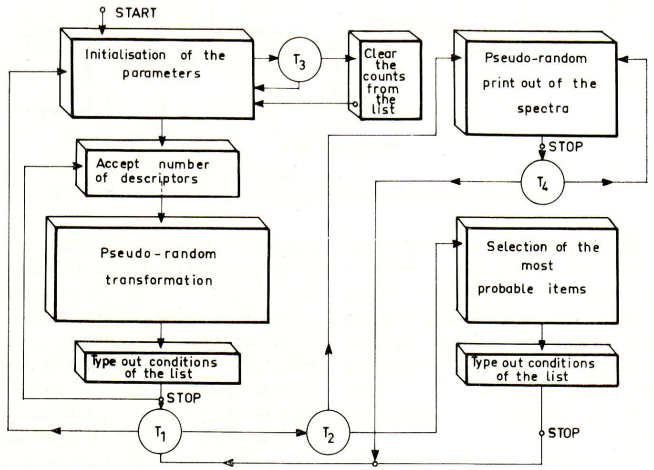

Fig. 9. Main program of transformation mode analyser.

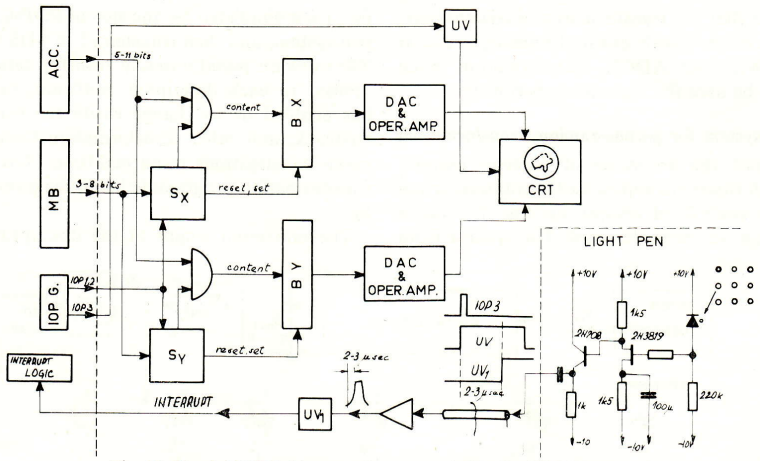

Fig. 10. Simple CRT light-pen system connected to the PDP-8 computer.

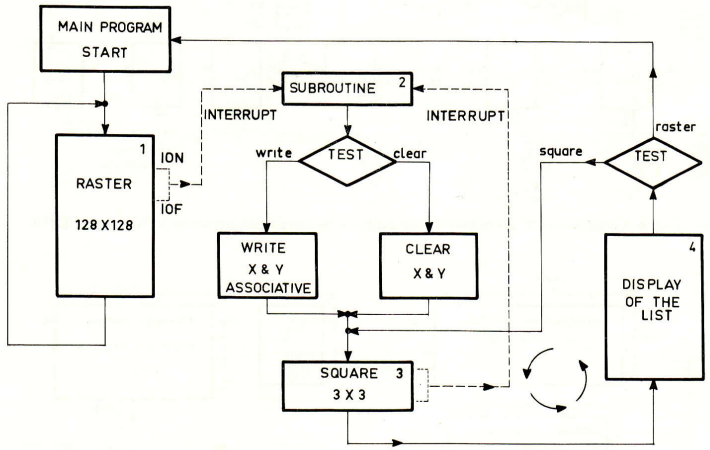

Fig. 11. Software organisation for CRT light-pen system connected to PDP-8.

bits. The descriptor first comes to the accumulator and then it is normalized by left shifting $(k+n-D$ times), until bit a_{22} becomes one. After that exclusive or takes place between the accumulator and a location keeping the "feedback wiring". The existence of the feedback (fig. 2) for a particular bit is indicated by a stored one in a given bit. After additional D left shifts, in the accumulator will be the remainder, presenting the pseudo-random address.

Fig. 9 shows a block diagram of a whole SDS 930 programme. The programme enables one to initiate the parameters of the transformation and the number of descriptors (total number of events). The next step is the actual pseudo-random transformation, shown in more details in fig. 7. After the transformation of a given number of events, the programme prints out the condition of the list (number of occupied zones, total number of empty locations inside all zones, average number of comparisons, number of lost descriptors etc.). In the programme there are indicated also parts for the selection of most probable items, clearing the memory and print out of the spectra.

Print-out is also organized using pseudo-random transformation technique, for finding the items to be printed. A part of the printed spectra is shown in fig. 4.

Fig. 8 shows a block diagram of a hardware for pseudo-random transformation. Such a "transformation box" can be inserted between ADC's and PDP-8, as indicated in fig. 6. Hardware solution is very simple and fast.

After the conversion is completed ADC's send interrupt INT1, which fires the transformation box. The signal DT_c transfers the descriptors via $(n+k)$ AND gates $n-1,n-2,\ldots 0,k-1,k-2,\ldots 0$, into a shift register $D_{n-1},D_{n-2},\ldots D_{n=0},D_{k-1},D_{k-2},\ldots D_{k=0}$. The counter and clock generator produce $(n+k)$ clock-shift pulses. Each pulse left-shifts the content of the shift register. Different feedbacks can be achieved by hand switches $SW_{t-1},SW_{t-2},\ldots SW_0$. If the most right switch is on (SW_0 in fig. 8), that means that $t=n$. The index t can be decreased by 1 by switching off the most right switch, and giving index $t=0$ to the second switch from the right, etc. The number of different addresses is always 2^t. After $n+k$ left-shifts in the shift register there will be the remainder, i.e. one pseudo-random address. Now INT2 will interrupt the PDP-8 computer. PDP-8 will send IOP1 pulse and accept t-bit address $A_{t-1},A_{t-2},\ldots A_0$. After that IOP2 reset the shift register. The next step is to accept the original descriptor from the ADC's buffer into the computer. Having the address and the descriptor, the interrupt routine can easily find the place on the list and add one to the stored count.

8. Laboratory made light-pen – CRT system for PDP-8

For display and simulation purposes, a simple laboratory made light pen – CRT system for PDP-8 computer is designed. The block diagram of the system is shown in fig. 10. Hardware consists of standard and-gate device selectors, 7-bit buffers and digital to analog converters with operational amplifiers for X and Y deflection of CRT (X,Y Tektronix 536).

IOT instructions, through the memory buffer register MB select either the X or the Y buffer, and transfer to it 7-bit content of the accumulator. IOP1 and IOP2 are used to reset and set the buffer condition. IOP3 fires one shot (univibrator) UV2, whose pulse is used for unblanking the CRT when transients in X and Y deflection are over.

The light pen is very simple and consists of a photodiode, FET amplifier and emitter follower. Through amplification of the received light signal from the screen of CRT and through proper shaping, the delay of the light pen is reduced to 2–3 μsec. The light pen triggers the univibrator UV1, which interrupts the computer.

Fig. 11 shows the software organization for the light pen – CRT system. The programme RASTER (1) generates a field of 128 × 128 spots on a CRT. This programme makes it possible to interrupt the computer only during the unblanking period on a CRT. If one touches any part of this field with a light pen, the interrupt switches the programme to SUB-ROUTINE (2). This subroutine tests the break point and write/clear the coordinates X,Y of the spot which was the cause of interrupt. Around this spot a SQUARE (3) of 8 spots is generated. This square is used as a "drop of ink" which one can move with a light pen and make a drawing on a CRT. The digitised picture is stored on the LIST (4), and displayed on the CRT. The system was used for display of the results of analysis and for simulation purposes. The spectra in fig. 3 were simulated using this simple system.

9. Conclusion

To increase the resolution of pulse height analysis from thousands to millions of channels, it was necessary to introduce a completely new technique. This was achieved through digital pseudo-random transformation. Transformation can be realized by simple hardware between ADC's and the computer, or as a part of the computer interrupt routine.

Transformation mode analysers differ from classical instruments in the following:

The information from the experiment is first transformed into a new form and then processed. Good results obtained indicate that it might be of

TABLE 1

Method of analysis	Number of descriptors	Memory utilisation	Descriptor field	Number of comparisons
Conventional	4096	100%	4096 max	1
Associative	2048	50%	2^{24}	11
Associative with zones	819 × 4 = 3276	80%	2^{26}	10
Transformation mode with zones 2 × 2	819 × 4 = 3276	80%	2^{26}	≈1

interest to try a similar approach to other fields (control, pattern recognition, digital filtering, etc.).

— The instrument is probabilistic in a sense that the memory channels and the physical channels are connected through the pseudo-random relationship, but in such a way that there is a nearly uniform distribution of descriptors through the addresses, regardless of the spectrum shape.

— In case there is a larger number of descriptors than the number of places in the memory, the system shows a self-adaptable feature, giving the available space to the most frequent information.

Table 1 compares the features of conventional analysers, associative analysers with and without zones, and transformation mode analysers, for a memory of 4096 words of 24 bits.

The pseudo-random technique has been recently used in many diverse fields. Here is described an adaptation of this technique for nuclear pulse spectrometry applications.

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