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RECENT DEVELOPMENTS IN MULTICHANNEL PULSE-HEIGHT ANALYSIS*

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Summary

The state of the pulse-height analyzing art will be reviewed with particular emphasis on the developments of the past two years. The discussion will include consideration of multidimensional instruments, calibration-stabilizing techniques and some of the auxiliary features that are becoming increasingly available on commercial instruments. Possible future developments with respect to resolving time and memory organization will be discussed briefly.

Probably the most significant event in the development of multichannel pulse-height analyzers was the wedding, in 1951, of the linear sweep analogue-to-digital converter¹ to a computer memory by Hutchinson and Scarrott.² Most developments since then, while by no means trivial, have been more in the nature of improvements than of fundamental innovations. Faster and more reliable random access memories have come into general use and the digital and analogue circuits have been redesigned using transistors, but the basic organization - an analogue-to-digital converter addressing an accumulating memory - remains substantially unaltered.

Transistorized pulse-height analyzers with magnetic core memories have been with us now for several years and their virtues have become familiar. Probably most notable among these virtues is their relatively high order of reliability compared to vacuum tube instruments. An important corollary advantage associated with this improved reliability is that instruments can be designed and built with large memories and relatively elaborate logical organizations, with reasonable confidence that they will perform properly most of the time. Similar attempts with vacuum tube instruments were for the most part

badly received because the increased failure rate often more than offset the value of the added conveniences.

Some of the features available on commercial transistorized pulse-height analyzers include provisions for:

1) Memory splitting and selective storage. When the memory capacity is greater than that required for the resolution desired, the memory can be divided into two, four, or more sections and different spectra accumulated in each section. Several spectra can be accumulated in sequence and then displayed and compared on one cathode ray tube. Alternatively, data from one detector can be routed to different memory sections, depending on which of a set of coincidence conditions is satisfied (Fig. 1), or data from two or more detectors can be stored in the several memory sections, one instrument performing, on a time sharing basis, the function of several (Fig. 2).

2) Transfer of data between memory sections. This provides for the accumulation of a single set of background data in one section of the memory which can then be subtracted from a sequence of data runs accumulated in another section of the memory. Background information is stored in one memory section in a negative sense. It is then transferred to a second memory section and data is accumulated on top of it in a positive sense. The original background information is retained in the first memory section for subtraction from subsequent data runs.

3) Spectrum stripping.³ Standard spectra, obtained from known radioisotopes, stored on magnetic tape or punched paper tape, can be multiplied by a suitable adjustable weighting factor and subtracted from newly accumulated data. The weighting factor

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-- adjusted by trial until the characteristic features of the known spectrum are removed from the new data. The process is repeated until all the features of the data are accounted for. The weighting factors used are then a quantitative index of the relative amounts of the various radioisotopes in the unknown source. While several commercial instruments provide for a free choice of intensity weighting factors, to date none of them provides for adjustment of the energy scale. It is essential, therefore, that the standard and unknown spectra be accumulated under conditions of identical energy calibration. If spectrum stripping is to be accomplished with imperfectly normalized energy scales, it is necessary to make use of more sophisticated computers than are contained in present day pulse-height analyzers.⁴

4) Temporary analogue storage. This makes it possible to measure the second of a pair of closely spaced pulses, even though the analyzer has not completed the measurement of the first pulse when the second pulse occurs. The analyzer analogue-to-digital converter is preceded by a pulse-stretching circuit. Signals are passed immediately from the pulse stretcher to the analogue-to-digital converter unless the analyzer is busy, in which case the signal is stored in the stretcher until the analyzer is ready for it. This feature was first introduced in a vacuum tube pulse-height analyzer by Byington and Johnstone⁵ in 1955. The fact that it has only recently become available in transistorized versions^{**} is a result of the fact that pulse stretchers with very little droop are more difficult to make with leaky semiconductors than with high impedance vacuum tubes.

5) Live time measurement. Most commercial pulse-height analyzers provide for automatic compensation for counting

** The first transistorized instrument with a temporary analogue store was the Los Alamos Model 3A reported by Gilland, et al⁶.

losses due to the finite instrument dead time. A self-contained clock produces pulses that are tallied if they occur at a time when the analyzer is prepared to accept input signals and are rejected if they occur when the instrument is busy with other signals. The clock pulses may be tallied in the main instrument memory or in an auxiliary scaler. The count, in effect, represents a statistical sampling of the condition of the analyzer and gives a useful indication of the live time, provided that the sampling pulses are short in duration and that the data pulses are randomly distributed in time. Automatic correction for counting losses is achieved by accumulating data for a specified live time by controlling the data taking interval with the live time clock. It should be noted, however, that a live time clock is of no value when the analyzer is used with a pulsed source such as a high energy accelerator because it does not account for the substantial source dead time.

6) Integrating under peaks. At least one commercial pulse-height analyzer⁺⁺ can be instructed to add the counts accumulated in a selected set of sequential channels and print the resultant sum.

While these convenience features now available on commercial pulse-height analyzers will no doubt prove valuable to experimenters, the imminent availability of commercial two-dimensional instruments is probably of much greater significance. There are two basic approaches to the two-dimensional analysis problem, one using a large accumulating memory⁷, the other employing address storage in an open-ended tape memory.^{8,9,10} The accumulating memory (Fig. 3) is, in nearly all cases,

++ Nuclear Data Model ND130A

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considerably more convenient because it is possible the instantaneous display of the accumulated spectrum, while in an address storage system additional data processing is required before a display is available. On the other hand, the cost of an accumulating memory of sufficient capacity for high resolution two-dimensional analysis is considerable^{***} (one large enough for three-dimensional analysis would be prohibitively expensive at current memory prices); whereas the capacity of a moderately priced address-storage system is virtually unlimited. A wise choice between the two systems depends on a number of economic considerations including the cost of accelerator or reactor time and the extent to which experimental time is affected by the availability of an instantaneous data display.

Commercial instruments of both types are now, or will shortly be available. One concern[†] offers a two-dimensional analyzer with 4096 words of coincident-current-addressed magnetic core memory while another[#] offers 10,000 or 20,000 words of "linear-select" magnetic core memory. A third concern⁺⁺ offers a compromise instrument which combines some of the advantages of both the accumulating memory and the address-storage schemes (Fig. 4). The instrument includes a magnetic tape memory with a derandomizing buffer, to reduce counting losses associated with the start time of the

^{***} A one-dimensional analyzer memory with 1% resolution must have capacity for 100 words (channels); whereas a two-dimensional analyzer memory with equivalent resolution must have capacity for 10,000 words, and a comparable three-dimensional analyzer must be able to store 1,000,000 words.

[†] Technical Measurement Corp., North Haven, Connecticut

[#] Victoreen Instrument Co., Cleveland, Ohio

⁺⁺ Nuclear Data, Inc., Madison, Wisconsin

tape-drive mechanism, and a 1024 word accumulating memory which can be used either for low resolution monitoring of the entire two-dimensional spectrum or for high resolution analysis of a selected portion of the spectrum. Data recorded on the tape can be reduced to spectra by accumulating the recorded addresses, in pre-selected blocks, in the internal 1024 word memory, or it can be done in an external digital computer.

In addition to its multidimensional applications, address storage on tape has also been applied to one-dimensional analysis at very low counting rates.¹¹ Low counting rate experiments are often plagued by bursts of stray counts of unknown origin. In an accumulating memory, the stray counts can swamp the true detector signals. However, when the events are recorded on tape in order of their occurrence, it is often possible to eliminate non-statistical artifacts. This is particularly true if the tape is advanced periodically, even in the absence of input signals. Non-statistical clusters of events in short bursts are then easy to recognize and discard.

The development of semiconductor junction radiation detectors with thick depletion layers is presenting new challenges to designers of pulse-height analyzing systems. To exploit the high resolution now attainable (of the order of 0.1% with 40 Mev protons), the analyzing system must be unusually stable both with respect to zero intercept and energy calibration. By employing a servo-stabilizing technique¹² we have recently succeeded in reducing the long term drift in a linear amplifier pulse-height analyzer combination to substantially less than 0.1%. Two accurately controlled reference signals are periodically mixed with the detector signals at the preamplifier input. The amplified reference signals are measured in a high resolution linear discharge analogue-to-digital converter and the digital discrepancies between the intended and observed measurements are used to correct the zero bias and

the clock oscillator frequency of the inverter. Although experience with the instrument is still rather limited, it seems reasonable to expect that the drift will remain less than one part in 4000 for periods of weeks and perhaps months.

Based on instruments now, or soon to be, in existence we see that pulse-height analyzers can be made with nearly any combination of such desirable characteristics as reliability, data-reducing capabilities, large memories, multidimensional conversion capability and extreme stability. Notably absent from the list, however, is high speed. Except for the almost obsolete multidiscriminator instruments, all of the instruments in current use require tens to hundreds of microseconds to measure a signal amplitude and at least 10 microseconds for a memory cycle. This is a serious limitation when they are to be used in association with pulsed particle accelerators where it is important to be able to measure a large number of signals during the short particle bursts. Temporary analogue storage does not offer much help unless the temporary store has a large capacity. Electrostatic storage tubes have been used as high capacity analogue stores¹³⁻¹⁷ with some success. It would seem, however, that by directly applying high speed computer techniques, it should be possible to produce a fast pulse-height analyzer without having to resort to the complexity associated with large analogue stores. The problem is somewhat simplified by the fact that high energy detectors do not have high resolution, so that 50 channels are more than enough. With a 100 Mc clock and a suitably fast address scaler, the conversion time need not exceed 0.5 microsecond. Thin film and tunnel diode memories have cycle times well under 0.2 microsecond, so that the overall instrument resolving time need not exceed 1 microsecond.

Future developments can also be expected with respect to the logical organization of multidimensional experiments. Experiments involving large arrays of detectors currently employ address recording techniques^{18,19} because an accumulating memory, employed in the conventional way, would be unreasonably large and expensive. In large arrays, however, the number of detectors that may

be triggered in coincidence is usually only a small fraction of the total. If reasonable restrictions are accepted with respect to the coincidence multiplicity, accumulating memories of reasonable size would be suitable even for large detector arrays, provided that optimum addressing techniques are employed. The design of an adequate addressing system, however, presents some difficult problems which must be solved before accumulating memories can be used with large counter arrays.

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Figure Captions

- 1 Coincidence controlled selective storage. Signals from detector A are directed to different memory sections depending on which, if any, of the other detectors produced time coincident signals.
- 2 Split memory analyzer serving several detectors on a time-sharing basis.
- 3 Typical experimental setup with a two-dimensional analyzer of the accumulating memory type.
- 4 Illustration of the address recording system and the partial accumulating memory in the Nuclear Data two-dimensional pulse-height analyzer. The switch selects 10 of the 16 address wires and connects them to the accumulating memory.

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