Third-generation electronics for on-line physics experiments (review of published materials)

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The third-generation electronics for physics experiments using scintillation counters and wire chambers is reviewed. Especial attention is devoted to the modules that provide the connection to a computer and the acquisition of information. It is shown that the CAMAC system is the basis of the third-generation electronics for physics experiments. Examples are given of electronic installations for physics experiments in this system.

INTRODUCTION

In computer language, transistor electronics for physics experiments can be characterized as second-generation electronics. The third-generation modules of units for physics experiments, built mostly with integrated circuits, are intended for use on line with a computer, whereas the second-generation units were used only occasionally on line.[1,2] The construction and circuit logic of the third-generation modules are based on the CAMAC system.[3,4] The CAMAC system was developed in the large West European physics centers in 1968-1969 and was adopted by the interinstitutional organ for the electronic standardization of physics experiments – the Committee of ESONE (European Standards of Nuclear Electronics). In 1970, the CAMAC system was adopted in the physics institutes in the United States. At the present time, the Central Institute of Physical Investigations (Budapest) and Institute of Nuclear Investigation (Sverk, Warsaw) have joined the ESONE Committee.

The third-generation modules are fitted into crates (Fig. 1) with standard format and autonomous power supply.[5] In the electronics for second-generation physics experiments, for example, in the NIM system, an autonomous bin with power supply is also used. The crate is characterized by the presence of a standard format for logic signals, the constructional orientation to the use of integrated circuits, the approximately tenfold greater power supply (250 W), and the obligatory ventilation. Each crate has 25 stations, that is, positions for plugging the modules into an 86-pin connector. The maximum number of modules in a crate is 23. The two extreme right-hand positions in the crate are intended for the controller module, which controls all the exchange of information in the crate. The increased power required is made necessary by the greater circuit density and number of functions fulfilled by one module. Essentially, the crate is a peripheral highway for exchanging information between the different modules used in the experiment and in the computer. Systems associated with the evaluation, acquisition and transmission of digital data are currently constructed as third-generation modular units.[6-13] The transition to the third generation is taking shape in spectrometric modules[14] and modules for acquiring data from filmless wire chambers.[7] The process is not so pronounced in counter electronics, although here, too, there is a tendency to use integrated circuits and to construct modules in the CAMAC system.[15]

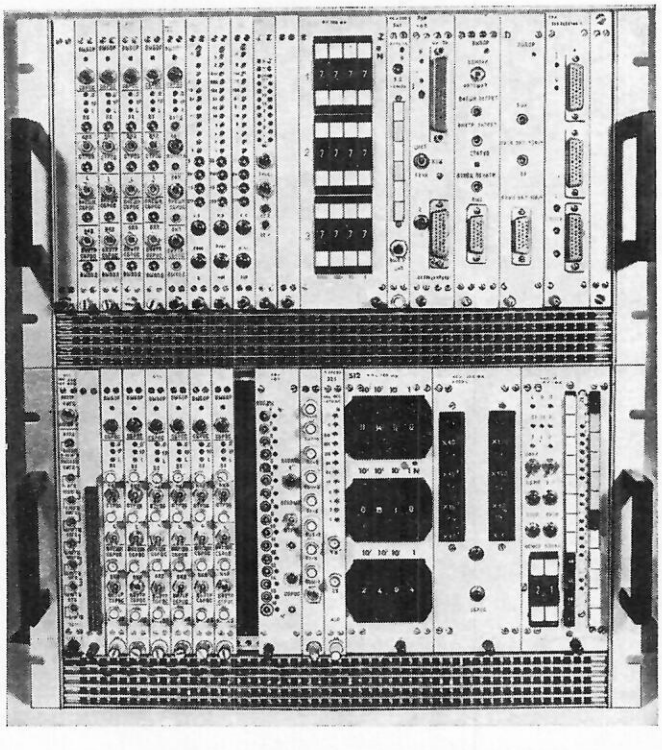

Fig. 1. Exterior appearance of crates with digital modules.

We shall consider the third-generation electronics as used in these main directions. Following the transmission of physical data in experimental installations, we shall first consider detector electronics, and then the modules for the linkup with computers.

COUNTER ELECTRONICS

Fast counter electronics contains a set of standard modules for acquiring and monitoring time signals from scintillation and Cerenkov counters[16] and semiconductor detectors and for time-of-flight technique problems. The time characteristics of detectors having changed little in recent years, the time blocks and their characteristics have remained virtually unaltered. The time modules consist of logic blocks that include a multiplier, a mixer, a coincidence circuit, a delay circuit, and shapers of the amplitude of signals from a photomultiplier. The logic blocks receive and transmit signals with levels in the range 0-16 mA to 50-Ω resistors (in accordance with the NIM standard[17]) and have signal rise and fall times of 1-2 nsec. The timing is taken from the leading edges of the photomultiplier signals by the shapers. The time-of-flight technique modules include a time-to-pulse-height converter, nanosecond linear gates, and an amplitude shaper with slave threshold that takes the timing from the constant part of the photomultiplier pulse height. The changeover to the third generation in these modules in-

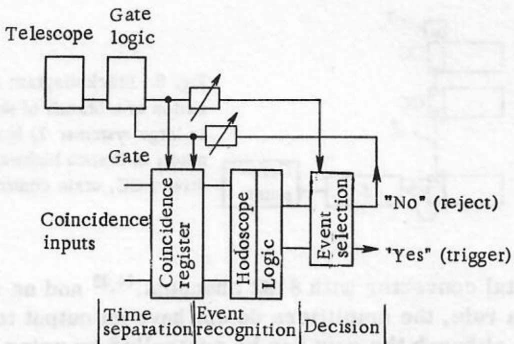

Fig. 2. Block diagram of the logic of physics experiments with scintillation counters.

volves the use of integrated circuits with 1–2 nsec rise and fall time of the type MECL II and MECL III, a decrease in the size of the modules, the construction of new functional blocks that unite several functions, and the introduction of digital control of the photomultiplier delay and power-supply blocks. The fast electronics blocks are programmed manually, by high-voltage cable connections in accordance with the configuration of the experiment, through sockets on the front panels and by switching of delays and changing of the power-supply voltages.

The transition to LEMO (RA 00250) sockets[1)] reduced the module width by a factor[18,19] 2–4. The width of the front panel is 34.4 mm and the height is 221 mm. The module size can be reduced by a further factor 1.5–2 if one uses the more miniature sizes, for example, of the type[20] SC 51-024-000 (Sealectro Con-Hex[2)]). At the same time, the density of elements in the modules remains low compared with digital units.

It is hardly practicable to use even smaller sockets. There are two ways in which these circuits can be developed: by dispensing with modular use and, thus, eliminating intermediate sockets and accelerating the processing of signals. Then a complete fast processor is collected in one block.[19–23] The second way is abandonment of manual programming of the fast logic, and control of the blocks by a digital code;[15,24] this makes it possible to free the front panel of switches.

The logic of many electronic physics experiments using scintillation counters is represented by the block diagram shown in Fig. 2. The telescope of the coincidence counters, which is set up in the ingoing beam of particles, transmits an enabling gate to the remaining part of the electronics, distinguishing the event in time. The gate is transmitted to the hodoscope gating system. Standard pulses are transmitted from the gate outputs to the logic part, which distinguishes the required event, after which the event signal is transmitted to the trigger of the system of spark chambers.

Thus, the logic is divided into two parts: 1) time, hodoscopic, and 2) the decision-making part.[25–29] The OMNI-logic system of the firm Le Croy[19] is based on just this principle. The hodoscope and processor can be made in the form of an individual module.[21]

In large experimental installations the time part requires laborious adjustment and calibration, which con-

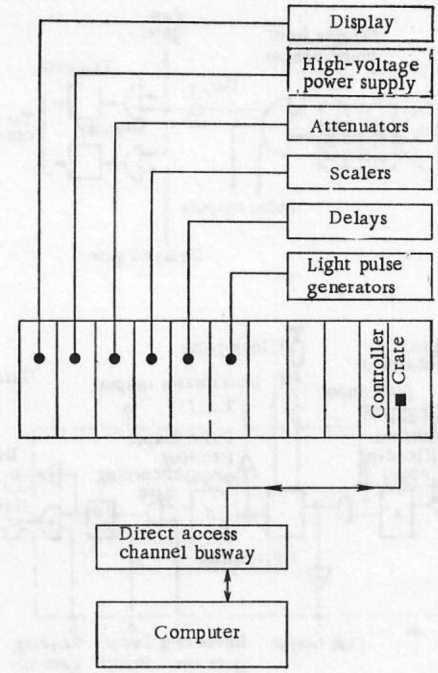

Fig. 3. Block diagram of a system of automatic calibration of counter experiments in a CAMAC crate.

sists of manual selection of the delays in each channel, the fixing of the voltages of the high-voltage power supply of the photomultiplier, the recording of calibration coincidence curves, the setting of the thresholds of the shapers, and the attenuation in the attenuators. For automatic adjustment of the system one requires delay blocks controlled by a digital code,[15,24,30] attenuators,[11,31] a high-voltage power supply,[24,32] and a source of pulses for the light-emitting diodes. For the controlled delay blocks and attenuators of the nanosecond range one requires a relay with small intercontact capacitances to ensure that the reflection coefficient for a 1–2 nsec leading edge is less than 5%. Miniature polarized relays, for example,[24] Infranor MR, are near these requirements. In the case of the delays of the time signals one also uses an active delay line with controlled transistor amplifiers. The high-voltage power-supply is controlled either through a relay or by stepping motors.[32]

The block diagram of a system of automatic calibration of counter experiments with a large number of counters is shown in a simplified form in Fig. 3. This arrangement enables one to establish automatically, using a computer program, the optimal delays, attenuation coefficients and voltages of the photomultiplier high-voltage power supply, and to measure delayed coincidence curves.[15] The modules of the photomultiplier high-voltage power supply, the attenuator blocks, and the delay blocks are automatically controlled. Only two time channels were used, although in practice, using multiplexers controlled by a digital code, one can join any two pairs of channels. The circuit is controlled by a minicomputer through a direct access channel and corresponding crate controller. Each of the parameters that are to be fixed is varied in discrete steps by the computer program. In each step the scalers count the number of pulses from the photomultiplier and the coincidence circuit and also the number of pulses from

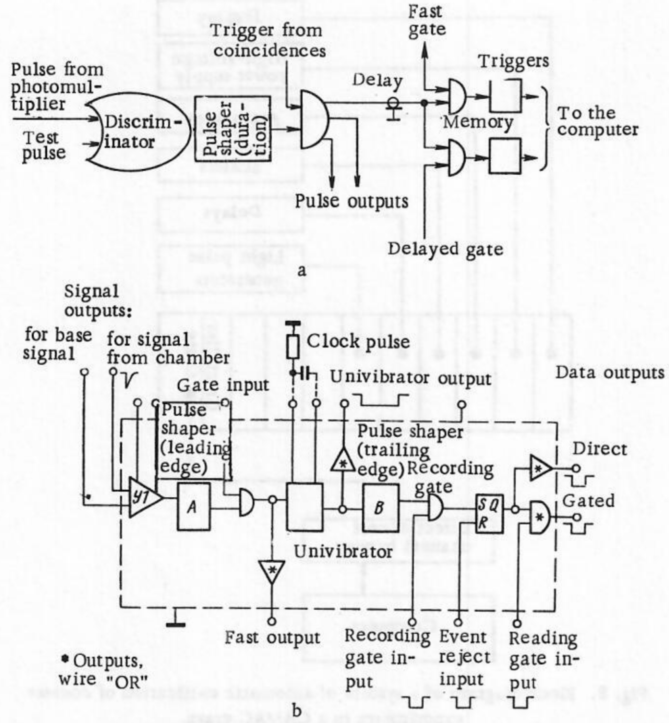

Fig. 4. Block diagram of the time channel of scintillation hodoscope (a) and proportional chamber (b).

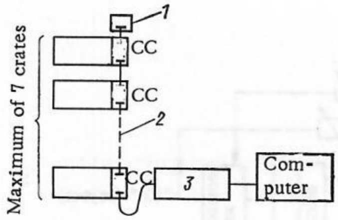

Fig. 5. Block diagram of the organization of a branch of several crates in large systems: 1) branch terminator; 2) branch highway; 3) branch driver; CC, crate controller type A.

the light-pulse generator, the counts being compared in the computer. The coincidence curve is displayed. The photomultiplier plateau with respect to the power supply is obtained by the program and the central point of the plateau is found. In a charge asymmetry experiment with the Bevatron,[25] a system of 144 scintillation counters was used; the system was controlled by a PDP-9 minicomputer. Basically, the logic of this experiment was similar to that of the hodoscope experiments (see Fig. 2). Figure 4a shows the block diagram of one time channel in the hodoscope.

The on-line connection of the fast electronics to the computer entails all the modules being made in the CAMAC system. When the width of the front panel is reduced to 34.4 mm, which makes it possible to put twice as many modules in a crate as in a NIM bin, the cost of the counter electronics modules in the CAMAC system becomes comparable with the cost in the NIM system. In addition, one can introduce digital control through a dataway to the counter electronics modules. Since there is already a large number of counter electronics modules in the NIM system, they can be joined to the crate dataway through an intermediate serial output register in CAMAC, which can transmit a 16-bit word from the dataway to one of the outputs. At each of the outputs a 16-bit serial code is received. The words in the module are selected in accordance with subaddresses. In its turn, each NIM module contains a shift register. Thus, one coaxial cable is required to transmit 16 bits.[26] Essentially, the serial output register is a NIM–CAMAC interface.

SPECTROMETER ELECTRONICS

This consists of a set of blocks for pulse-height measurements with semiconductor detectors and scintillation counters. The set includes linear amplifiers, an analog-to-digital converter with 8192 channels,[14,33] and an integrator. As a rule, the amplifiers do not have an output to the dataway although the gain can be controlled by using a field-effect transistor as a regulated resistance.[34] A controlled attenuator can be made without difficulty, since the leading edges of the signals are 10 nsec or more.

WIRE-CHAMBER ELECTRONICS

The technique of wire spark chambers is based on the use of an on-line computer. Large wire proportional chambers are based on special integrated circuits. To extract coordinate and time information, one must connect an amplifying and shaping channel in each wire. Modern wire-chamber systems contain thousands of channels, which means that they must be cheap and very reliable. The block diagram of the time channel of a proportional chamber is shown in Fig. 4b. Its similarity to the scintillation hodoscope channel should be noted; this is due to the common logic of the time experiments (see Fig. 4a). The signal from the wire is amplified in the input amplifier-comparator with controlled threshold. The amplified signal is shaped to the amplitude of the logic level in shaper A and appears at the fast output, and is also shaped with respect to duration in the univibrator. The trailing edge of the signal from the univibrator is shaped in shaper B and sets the trigger. The total delay in the signal circuit at the fast output is 40 nsec. Standard 30-nsec pulses are taken from the shaper outputs. The delay of the univibrator is 0.1-100 μsec. One has the possibility of a fixed 300-nsec delay. The recovery time of the univibrator is no greater than the length of its output pulse. The threshold of the input amplifier is 1 mV. The input resistance is in the range 1-2 kΩ. A similar time channel has been constructed in the form of a single integrated module.[35,36] The cost of an individual channel is $40. When integrated modules are used, the channel cost is reduced by a factor 10-20 (microcircuits of the firms Texas Instruments and Fairchild). For combination logic one uses a fast output of an integrated module. The NIM logic level enters the multipliers, the mixers, and parallel registers already employed in fast counter electronics. Signals from the output trigger are transmitted to the parallel input registers connected to the CAMAC registers and hence to the computer.

DIGITAL ELECTRONICS

The task of digital electronics is to extract information from the installation and pass it to the computer. The individual devices in the installation– scalers, analog-to-digital converters (ADC's), and digital-to-analog converters (DAC's), etc. – are made in the form of individual modules with a minimal cell width of 17.2 mm. The signals are transmitted and the power is supplied through a two-sided edge connector on the circuit board of the module. The peripheral devices made to other constructional dimensions or nonstandard dimensions – digital voltmeters, digital printer, puncher, etc. – must have their "representatives" in the crate in the form of interface modules. The controller is the crate "despatcher," determining the sequence in which information is transmitted in the crate. If the installation is operated on line with a computer, the controller is made in such a way that it is simultaneously the computer interface. If there are more than 23 modules in the system that must be connected to the computer, a branch is formed that joins the crates (Fig. 5). The greatest number of crates in a branch is seven. For the organization of a branch one uses the so-called controllers of type A as crate controllers;[4] through these the branch highway passes. Information is exchanged along the branch highway with the branch driver, which is simultaneously the interface for the computer. Thus, in a many-crate system the branch driver is the equivalent of the controller in a single-crate system as computer interface. The system of digital modules forms a hierarchy at whose apex one has branch drivers (interfaces) and all the modules needed to organize the branch, a controller of type A, and a branch terminator. The next order in the hierarchy is the class of computer-interface crate controllers and simple crate controllers. Below one has the functional modules and the interfaces of the devices and peripherals plugged into the crate. The sets of digital modules in the CAMAC system were developed in a number of physics institutes[6,12,14,28,37-69] and firms.[8,9] At the present time they are manufactured by more than 10 firms.[8,10-12,19,30,31,70-78] These digital modules comprise all possible devices for connecting the measuring devices and detectors with the computer itself.[79] It is convenient to consider the digital modules in classes: 1) branch modules; 2) crate controllers; 3) converters; 4) registers and scalers; 5) device interfaces.

The modules can also be split into two larger groups: modules controlled solely by the computer and modules that require interaction with man. The latter group of modules is much more expensive (by 50%) because of the converters of intercourse with an operator; for example, a binary to binary-coded-decimal (BCD) converter, digital display, dialing and key switches and corresponding decoders, i.e., all the devices that facilitate the input and improve the presentation of information.

Branch modules. These are controlled solely by a program. They include branch drivers, which are computer interfaces. A set of branch drivers have been developed and are manufactured for some modern minicomputers: PDP-11, PDP-15, PDP-9, HP 2114B-2116B.[39] Controllers of type A and branch terminators are also manufactured by a large number of firms.[10,30,38,70-74] A branch test box has been developed.[63] In a branch containing seven crates one can have 7 × 23 = 161 demands. Only 24 bits are used to transmit the demands to the branch highway, so that the demands must be coded. The demand coding block or LAM grader[36] establishes the priority of the modules within the crate. This module is not standardized, and the coding of the priorities can be chosen by the user. The branch is calibrated by a manual branch driver,[10,31] which makes it possible to control the information exchanged in it manually.

Crate controller. These have been developed and are manufactured by firms for almost all modern minicomputers: PDP-8,[9,30,80] HP2115B,[35] Nova,[70] DDP-516.[10] For systems that do not use a computer, specialized controllers that program the work of the system have been made. For example, if the aim of the system is to acquire information from scalers and transmit it to a digital printer or puncher (a problem that is frequently encountered in small-scale experiments), the sequence of operation of the system can be governed by a print controller.[44] If one requires the information to be passed only to digital display, this can be done through a display controller.[42]

Programming controllers or a program generator[9,10] are universal controllers of computerless systems. As a rule, the crate controller is usually autonomous, i.e., capable of generating a complete cycle of commands to the branch highway so as not to burden the computer with programming second-step operations associated with the CAMAC cycle. The controller is programmed through an auxiliary dialing unit and through an external fixed memory.[9,10] For testing and calibration a manual controller is used;[31,59,75] on its front panel this has a keyboard for number dialing, station addresses, subaddresses, functions, and a button for starting the cycle.

All the above modules are ancillaries that organize the exchange of information and determine its sequence. The measuring instruments that occur in an experimental installation or control system form the set of basic modules. These include scalers, input (output) registers, ADC's and DAC's, interfaces of nonstandard (in the sense of the CAMAC system) devices, and peripheral devices.

An individual group is composed of the modules for organizing the interaction with man: the dialing keyboard, the preset scalers, code converters, and display modules.

Scaler and register modules. These are the most common part of such installations. Since the majority of systems are designed to operate on line, binary scalers without display are used as a rule. Their data are transmitted to the computer outputs or to a display module (decimal display) through a binary to BCD converter module. In the second-generation systems, the scalers were, as a rule, decimal with display of each decimal. Because of feedbacks, the counting rate of the second-generation scalers did not exceed 10-20 MHz. In the third-generation scalers, MECL II and MECL III type circuits are used at the input; they are faster by an order of magnitude, so that the counting rate is 100-250 MHz. The scaler module has width 17.2 mm. The degree of integration of the microcircuits enables one to have in one module either four 16-bit scalers[10,53,70,73,75] or two 24-bit scalers.[31,48,72-74] Less frequently one encounters a 12-bit scaler,[9] which is convenient for a 12-bit minicomputer and is economical for acquiring data from ADC's. The scalers are 16-bit because the common minicomputers are. But because a 16-bit scaler is frequently inadequate when one is counting particles from a monitor counter in physics experiments with accelerators, for which one requires a capacity up to 10^7, one also uses 24-bit scalers (capacity $1.6 \cdot 10^7$). The scalers are sometimes called serial registers (which store data). In experiments with proportional and wire spark chambers and with hodoscope systems of scintilla-

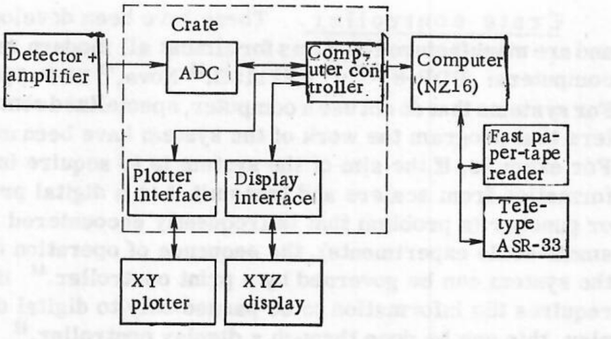

Fig. 7. Block diagram of multichannel pulse-height analyzer in the CAMAC system on the basis of a minicomputer.

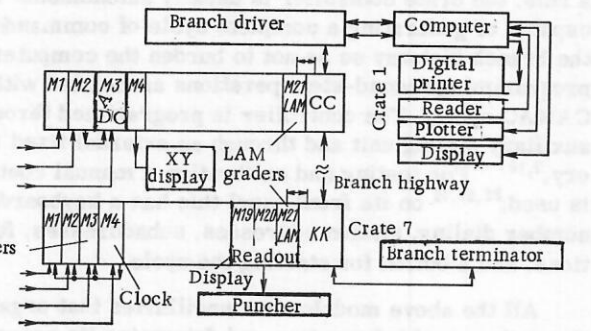

Fig. 8. Block diagram of an on-line CAMAC installation for experiments with high-energy accelerators (M is a module).

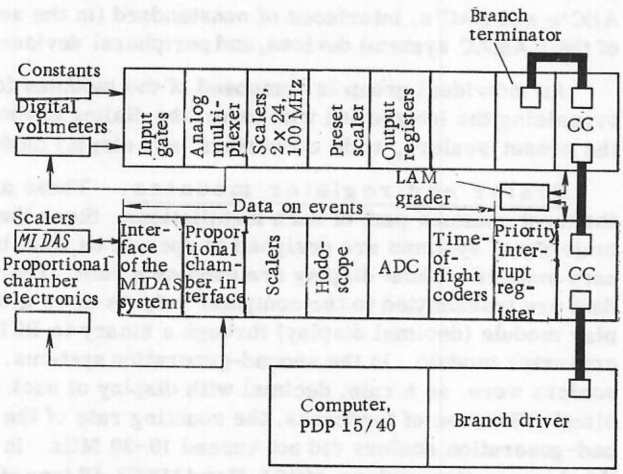

Fig. 9. Block diagram of on-line CAMAC installation for experiments on hyperon beams of the Brookhaven synchrotron.

the dataway. For the organization of a display on a cathode-ray tube from the dataway one uses a display interface module, which is called a display driver.[9,11,73] The blocks needed for display on the cathode-ray tube such as character and vector generators, and DAC's[58,59,72,73] are also manufactured as CAMAC modules.

The readout to a digital printer is organized similarly. Modules whose data are read out to the digital printer (scalers, ADC's, registers) are questioned by a special crate controller, which is a print controller. First, the binary codes from the modules come to a code converter and then to the interface of the digital printer and hence the printer itself.

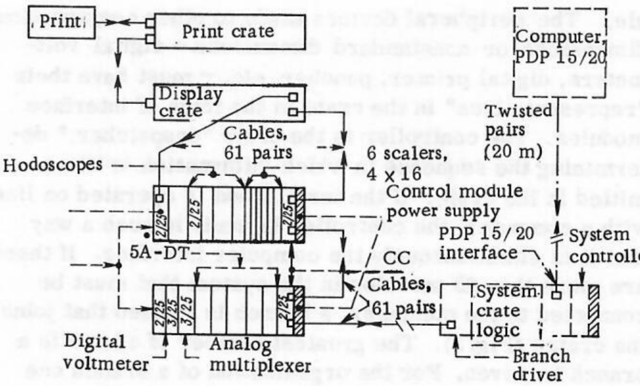

Fig. 10. Block diagram of on-line CAMAC installation for studying elastic scattering of pions by hydrogen nuclei at Saclay.

The block diagram of a pulse-height analyzer constructed from a set of ADC modules, interfaces, a plotter and display, computer controller, computer, paper tape reader, and teletype[82] is shown in Fig. 7.

The ADC modules, the interfaces, and the controller are made in the CAMAC standard and are in the crate. The remaining devices are outside the crate. The computer memory plays the role of the memory of the analyzer. In principle, the system can be multidimensional if additional ADC's are put into the crate.

A more detailed on-line multicrate system[83] is shown in Fig. 8. The peripheral devices – the digital printer, the punched-tape readers, the plotter, and the display – are connected to the computer's IO bus. The remaining units are constructed in the form of CAMAC modules (ADC's, scalers, decimal display, LAM graders, clock) or are connected to the crate through corresponding interfaces, also made in the CAMAC system (display, puncher).

A two-crate electronics system of a spectrometer with counters and wire chambers for on-line experiments on hyperon beams of the Brookhaven synchrotron is shown in Fig. 9. Data from the spark chambers are read out by time-to-code converters in the MIDAS system[84] and reach the crate dataway through a MIDAS–CAMAC interface. A separate interface module is used to read out data from the triggers of the proportional chambers. The data from the scintillation counters are registered by 24-bit 100 MHz scalers, hodoscope, 8-bit ADC's (time frequency, 40 MHz), and 8-bit time-of-flight to digital code converters.[72] The priority interrupt module accepts up to 12 NIM pulse inputs giving rise to external interruptions. The constants of the experiment and the readings of the digital voltmeters are read out to a 48-bit gated register. The constant voltages and the currents of the magnets are transmitted to the digital voltmeters through a 15-bit relay multiplexer. The output-register module is loaded from the crate dataway. From its output NIM gates that control the gates of the scalers, the ADC's, and the hodoscopes are taken. The electronics has much in common with that of a spark spectrometer on line with a PDP-15/20 computer used on the accelerator at Saclay for experiments on elastic scattering in hydrogen[85] (Fig. 10). The information is read out from the magnetostriction chambers by the SPADAC system,[73] which has an output on the crate dataway through the SPADAC–CAMAC intertion counters one uses modules of parallel input registers.[8,10,19,62,72,73,76] These registers are usually 16-bit, but one occasionally has registers that are 8-, 12-, and 24-bit. The second purpose of the parallel registers is that of input–output registers for transmission lines. An 8-bit register is used to receive and transmit information along communication lines with bites (one bite = 8 binary bits). Parallel registers have 16 or 24 bits and frequently a high-current relay output,[8,10,76] by means of which one can control high-power circuits. Such a register is needed for problems of automatic control of systems with feedback to a computer. During the operation of an on-line installation, the operator periodically displays information about the event recorded at the given instant, for example, through which counters did particles pass, through which wires in the spark chambers do interaction tracks pass. For this purpose one usually employs a 16-bit fast coincidence register that has a gate input (latch register),[72] or as one says, pattern module (pattern unit).[19,28,62,73] At its input, this register has 16 gates that are controlled by a gate pulse; the signals from them are transmitted to a 16-bit output register. The time scale is given by a clock pulse generator, which is a combination of a quartz-stabilized generator and a decimal scaler. Usually, at the input of such a generator one can obtain signals[5,9–11,31] from 1 MHz to 1 Hz at intervals of 10. The real-time generator or the programmed timer contains a binary scaler set by a code and has a time range from microseconds to hours specified by a program from the dataway.[9,73] The real-time generator, with controlled input, can be used to measure time intervals and convert a time code to a digital code.

The set of analog-to-digital and digital to-analog converters ensure a close control cycle. The time-to-digital-code converters are binary scalers with gates at the input that are opened for a measured time interval.[19,70] The ACD's have an accuracy of 10-12 bits and are used for pulse measurements and as digital voltmeters of intermediate accuracy.[8–10,19,31,72–73] As a rule, they are constructed on Wilkinson's principle with conversion of a linear discharge of capacitance into a series. The series frequency is usually 100-200 MHz and the conversion time is $\sim 10\ \mu$sec. The DAC modules are needed to control the actuating devices and for display readout on a cathode-ray tube, for which the accuracy is 10^{-4}. Hence, the DAC modules usually have an accuracy of 10-12 bits and a conversion time of a few microseconds.[9–11,58,59,72] As a rule, a matrix of accurate resistors of the type R-2R is used for conversion.

Interfaces of the measuring instruments and the peripherals. The measuring instruments and input–output peripherals are not made in the CAMAC system and require individual interface modules. These modules include print interfaces,[10,45] punchers,[10] teletype,[10,19,31] stepping motor,[10,66] digital voltmeter,[81] interface for a block of ferrite spark chambers,[55,31] and a light pen.[73] The interface modules reconcile the signals of the peripherals with the signals on the IO bus, and they ensure intercourse between the peripherals and the controller through the crate dataway. The interfaces take account of and match the individual features of the peripherals to the CAMAC requirements.

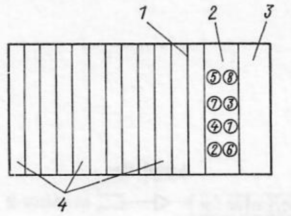

Fig. 6. Block diagram of digital readout system: 1) binary to BCD converter; 2) digital display; 3) display controller; 4) scalers, ADC's, registers, and interfaces.

Modules that ensure intercourse with man. These are intended to introduce information in a comprehensible form (decimal numbers) to the crate dataway and extract information in a form convenient for reception on a number display (decimal numbers) or for display on a cathode-ray tube (numbers, symbols, graphs). The information is introduced manually through a controller, branch driver, through a module for introducing constants (parameter unit)[5,9,10,46,61,73,81] and preset scalers.[9,10,30,31,52,70] The parameter unit enables one to dial manually the necessary numbers, for example, operating information for the experiments, which must be introduced into the crate dataway in a regular cycle. For dialing numbers in decimal code, dialing switches are usually fitted on the front panel; these enable one to dial four-bit words. The preset scaler has a number of switches on the front panel for dialing beforehand of a number to which it is necessary to count (filling of the scaler). In the preset scalers one can simultaneously introduce numbers through the dataway, and in this respect they do not differ in any respect from real-time pulse generators. The preset scalers may be binary or binary–decimal with decimal and binary data input. In the case of decimal input any number can be specified with an error of 1%, i.e., one can dial any number from 1 to 99 and of any order.

The clearest way to represent the output data is in the form of decimal numbers, whereas the majority of data sources (scalers, ADC's, and registers) contain binary codes. To read out information to a digital display and output peripherals (digital print or teletype) one requires a binary to BCD converter module.[8–10,50]

If mechanical output devices are used, one must have a converter from binary code to the ASCII code.[19] Essentially, the code converter is a miniprocessor with fixed program and, were it made with second-generation circuits, would be a rather large installation. The code converter module based on microcircuits has a width of 34.2 mm. Conversion by the direct combination method by means of a decoder is cumbersome, and conversion by the serial method of a parallel scaler in binary and decimal scalers is frequently slow (conversion time up to 1 sec). Therefore, the conversion is usually made by a code shift in an output 24-bit register and by correction.[50,69] The conversion time is a few microseconds.

Figure 6 shows the crate organization for a digital readout system. Data is read out from any module (scaler, ADC, etc.) on the commands of the controller, first to the code converter block and then directly to the display. The controller is either the controller of the computer or a special display controller,[42] or simply a manual controller. The digital display module is made of Nixi digital display lamps. It contains between six and eight displays[5,9,11,30,31,43] and a register for word acquisition from

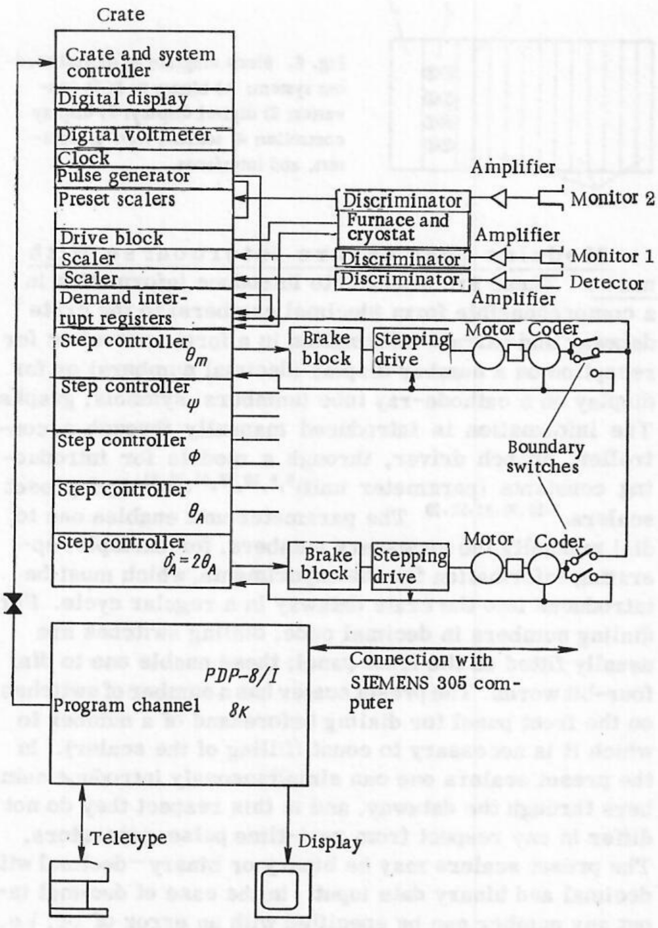

Fig. 11. Block diagram of on-line CAMAC installation for the electronics of a triaxial neutron spectrometer at a reactor.

face. The remaining modules, i.e., scalers, ADC's, and multiplexers, serve the same purpose as in the foregoing system.

The electronics of a triaxial neutron spectrometer used for solid-state investigations in the reactor center in Jülich[86] is shown in Fig. 11. The installation uses two CAMAC crates and is on line with a PDP-8/I computer. The investigated sample is irradiated with monoenergetic neutrons at a definite angle and the sample is rotated by a stepping motor in accordance with commands from the computer. The angle of rotation is coded by means of an angle-to-code converter. Optical step coders are used (10^4 pulses per revolution of the shaft). The stepping motors give 200 steps per revolution. The step controller block (see Fig. 11) transmits pulses to the stepping motor, start–stop signals, and direction-of-rotation signals. The time sequence of the spectrometer operation is controlled by a clock and a demand interrupt register from the temperature control instruments, the boundary switches, etc. Interruptions can also be initiated by 24-bit preset counters.[11]

The principle of a peripheral unified dataway in CAMAC can be used not only in investigations related to nuclear physics and high-energy physics, but also in all fields in which one must read out digital data and operate on line with a computer. In particular, CAMAC modules have been used in medicine to analyze electroencephalograms,[87] in meteorology to measure air pollution,[88] and in marine investigations to analyze underwater sound vibrations.[89]

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1) MK-1A is a zech variant of LEMO.

2) The similar socket 50-2-XI is produced in the DDR (VEB Elektronische Bauelemente, Dorfhain, Betriebsteil, Glashütte).

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