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A Multiple Input Data Acquisition System Using a Small On-Line Computer

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The data from several independent multiparameter experiments at the Karlsruhe FR2 reactor are simultaneously recorded by an on-line computer system.

The system involves:
- remote control and buffer stations on each experiment,
- data communication lines for parallel data transfer from each individual experiment to the computer,
- a multiplexer unit, involving a 4 x 24-bit buffer store,
- a computer Control Data 160-A with 8K memory,
- two magnetic tape units,
- and a specially designed display system.

All operations are governed by one control program. After transferring the input data from the buffer store to the computer memory, they are checked and reduced using different data handling routines for each experiment. Finally the information is stored onto magnetic tape or directly accumulated in the core storage.

Design and performance of the whole system are discussed.

1. INTRODUCTION

This paper deals with a data processing system designed for the acquisition, control, and processing of the data obtained from nuclear physics experiments at the Karlsruhe FR2 research reactor. There are two groups of experiments: One group concerns the scattering of monoenergetic slow neutrons in solids and liquids by means of a multiple detector time-of-flight spectrometer. The other group deals with the determination of level schemes of deformed nuclei by neutron capture gamma-gamma coincidence measurements. The experimental facilities employed in the latter are a threefold sum-coincidence device, a five crystal pair spectrometer and an angular correlation spectrometer. Each experimental facility uses one reactor channel of its own, so that all of them may be operated simultaneously. All these experiments have in common that they are capable of simultaneously measuring several parameters in many channels. As the counting rate for each particular set of the parametric quantities is very low, only parallel acquisition of all useful information will allow good utilization of the experimental instrumentation. However, even with parallel acquisition the counting rates are so low that after setup of the experiments long measuring periods must be carried out in routine operation. Since the requirements for processing the data are similar in all experiments, we decided to build an integrated data handling system centered around a small computer, the Control Data 160-A.

2. DESCRIPTION OF THE SYSTEM

Fig.1 shows the overall design of the entire system. The experiments are physically located separate from each other and from the computer. All information important for further handling is converted into binary numbers by suitable types of digitizers, such as pulse height analog-to-digital converters, time-of-flight counters, and position encoders of different kinds. As soon as an event has been completely digitized, the master control of the experiment transmits a signal "end of conversion" to the remote buffer and control station which forms the input to the data taking system at every experiment. Each of these stations contains a 24-bit flip-flop register, along with other suitable control and adaptation circuits. 20 bits are available for storing binary coded experimental data, while the remaining 4 bits are intended for identification of the experiment. Thus, up to 10^6 channels are available for every experiment. Subdivision and assignment of the 20-bit word are random, so that the selection of parameters and the allotment of channels to the individual dimensions are entirely unrestricted.

When the digitized event has been accepted by the remote station, a "transfer ready" signal is supplied to the measuring device which thus becomes free for accepting a new event. At the same time the output control of the remote station puts the 20-bit data word plus the 4-bit identification and checking code onto the transfer line. All transfer paths join at the end in a main control unit at the location of the computer. Transmission time through 50 m of cable is about 5 μsec. The input control of the main unit checks every 1.2 μsec whether a 24-bit word may be accepted. In case several transfer signals appear simultaneously, a priority circuit in this control device makes sure that the data are accepted in a fixed sequence of priority. The data are temporarily stored in a 4 x 24-bit buffer storage. In order not to interrupt the computer for every incoming event, it is customary to first gather three or four events. Only then is data acquisition by the computer started by an external interrupt.

As the input-output systems of the 160-A are capable only of transferring 12 bits in parallel, the computer has to make access twice for every 24-bit word. Using our standard control program, which will be described later, the interrupt routine takes about 300 μsec to transfer four events from the flip-flop buffer of the main control unit. As input and output controls of this unit work independently of each other, buffer registers which have become free during readout to the computer may be immediately refilled with new input data.

The computer and the magnetic tape units are commercial equipment. The Control Data 160-A has a core storage of 8K 12-bit words. The storage cycle time is 6.4 μsec. Two independent input-output channels, one of which has a control of its own, and four interrupt lines of the same priority level are of particular importance for on-line use. Two magnetic tape units of the Control Data 603 type are used as auxiliary stores of large capacity. A paper tape reader, a paper tape punch, and an input-output typewriter supplement the peripheral equipment.

The efficiency of the system is considerably increased by two pieces of extra hardware. These are a real-time clock, and a two oscilloscope display systems which will be the subject of a separate paper in Session IV of this conference [1]. Like all equipment we designed ourselves, these devices have been made out of a digital module system with a clock frequency of 2.5 Mc/s. These modules are based on the logic concept developed by Control Data in the 160-A computer, but they were rebuilt in our laboratory using domestic hardware.

3. ORGANIZATION AND PROGRAMMING OF THE SYSTEM

The on-line operation programs are all written in the machine language of the 160-A. Numerous programs of widely differing scopes were employed in developing the system from a simple programmed multichannel analyzer [2], up to the present status, which employs several experiments, live display, data reduction, and control by a real-time clock. The program as now routinely operated, which controls the whole on-line processing of the system, consists of two parts. All routines responsible for the entire data flow independent of special experiments, for communications with the pheripheral equipment, and for automatic or manual control of the computer, have been combined into one fixed <u>control program.</u> Depending on the number of connected experiments and the special requirements of data handling, this program may be expanded by a series of special experiment-oriented <u>data reduction routines.</u> The control program assures the proper functioning of the system, while the easily exchangeable reduction routines permit flexible adaptation to changing experimental conditions. A large part of the control program is taken up by the interrupt routines. Depending on special external or internal conditions, the interrupt capability of the computer allows the interruption of the current program via the interrupt lines and requires the computer to carry out certain transfer or control operations.

Fig.2 shows some of the functions exercised by interrupt routines in our program. The input routine serves for accepting data from the external buffer store into an internal buffer region of about 100 words length. A range this long is necessary for balancing shorttime peak loads within the equipment. Examples for such transient loads are faulty writing on magnetic tape or a operator's intervention by a manual interrupt. When an internal buffer region has been filled, the program tries to switch over to a second region. This region had to be completely processed by the main program, while the first one was being filled. If this was not done, more data are supplied than the computer can handle. Practical experience has shown that, especially in the setup period of individual experiments, there is the danger of this occurring. In this case, program control is taken over by an "overload" routine, which warns the operator. This routine is also able to interrupt less important previously assigned functions, such as the display readout. In automatic operation without control by an operator, this disturbance will generally be caused by a faulty increase in the counting rate of an experiment. In both cases the computer, when controlled by the overload program, accepts only the number of events it really can handle. Since the data from all experiments are brought together in the main control unit, this behaviour affects the other correctly running experiments. To overcome this disadvantage of time-sharing, we are now developing a computer-controlled self-protective system which will enable us to switch off faulty inputs by electronic means .

The real-time clock interrupts the program at regular intervals.The routine released by this interrupt signal checks the stored monitor data and may, for example, suppress the storage of data from an experiment, when the neutron flux of the reactor decreases below a present level. As soon as the flux has reached its normal level again, processing is resumed automatically.

The most important task of data reduction routines is the preparation of raw data for storage. As the required number of channels normally exceeds the capacity of the core memory, most data are stored onto magnetic tape. For this purpose, the raw data are checked by the reduction routines responsible for each experiment. The accepted data then are combined and edited to a suitable output format. The reduced data word thus obtained is stacked in an output buffer region common to all experiments. When this region is filled, it is recorded on magnetic tape through the input-output buffer channel. A display readout occuring in this I/O channel is interrupted during the same time and resumed when magnetic tape operations have been successfully concluded.For practical reasons it was decided to have an output format of 18 bits per event . These 262,000 channels may be subdivided among the experiments at random. Processing of the data stored on magnetic tape is carried out on the Karlsruhe IBM 7070, as well as on the CDC 160-A during shutdown periods of the reactor.

Along with storage on magnetic tape, direct accumulation in the computer memory is used for monitor data, important partial spectra, or strongly "compressed" data regions. These "compressed" data regions are derived from the complete data by summing over several channels. The complete data are stored simultaneously in full resolution on magnetic tape.Some 6000 memory locations are available for accumulation of spectra.By means of a continuous display readout routine, which may be started and stopped by a manual interrupt, these spectra may be displayed "live" on our display unit. In this way it is possible to control the progress in all connected experiments continuously without interruption of the measurements.

In some cases we have to work with high counting rates in several thousand experimental channels. Then we concentrate all the efficiency of the system on one transfer path. In this case the remote station and the main buffer store act as a 5-word derandomizer. The fastest acquisition program needs only 64.2 /usec on the average to accept a 12-bit address and increase the contents of the corresponding channel number by one. Two storage locations are used per channel, so that up to 17 million events may be accumulated in every channel. Using fast digitizers, up to 10 000 events/sec may be processed, with dead time losses of a few percent.

4. CONCLUSIONS

The system described here has been in continuous operation in its first stage (without using magnetic tapes) since June, 1963 [2]. Often this operation was for 24 hours a day. Reliability of the electronic hardware - commercial units as well as those of our own design - was very satisfactory. There were minor troubles in the long-time runs of magnetic tape units, but we think these troubles have now been overcome. The system is now in full operation; performance and flexibility have fulfilled our expectations. It is possible to serve five independent experiments, each of a capacity up to 10^6 channels. The computer may select from these input data all useful information. For storage purposes there are magnetic tapes of nearly unlimited storage capacity, as well as core storage. The system may be operated at greatly varying counting rates. The range from 10,000/sec (without data reduction) to several 100/sec. At the latter counting rate the computer can generate a live display, analyze the data under various aspects and be controlled by interrupt actions of the experimenter.

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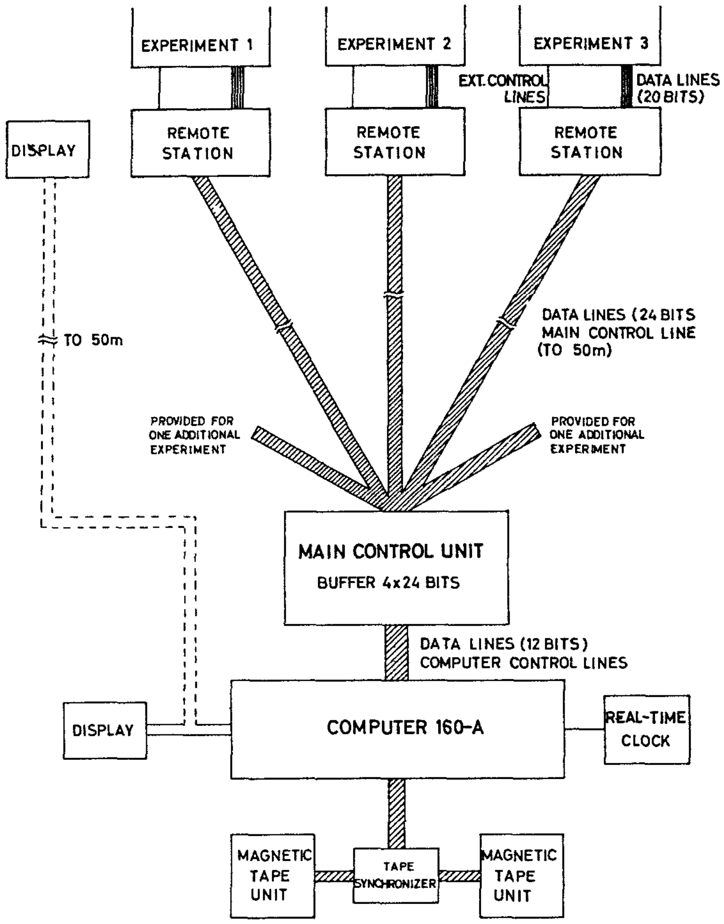

Fig. 1
Multiple input data acquisition system.

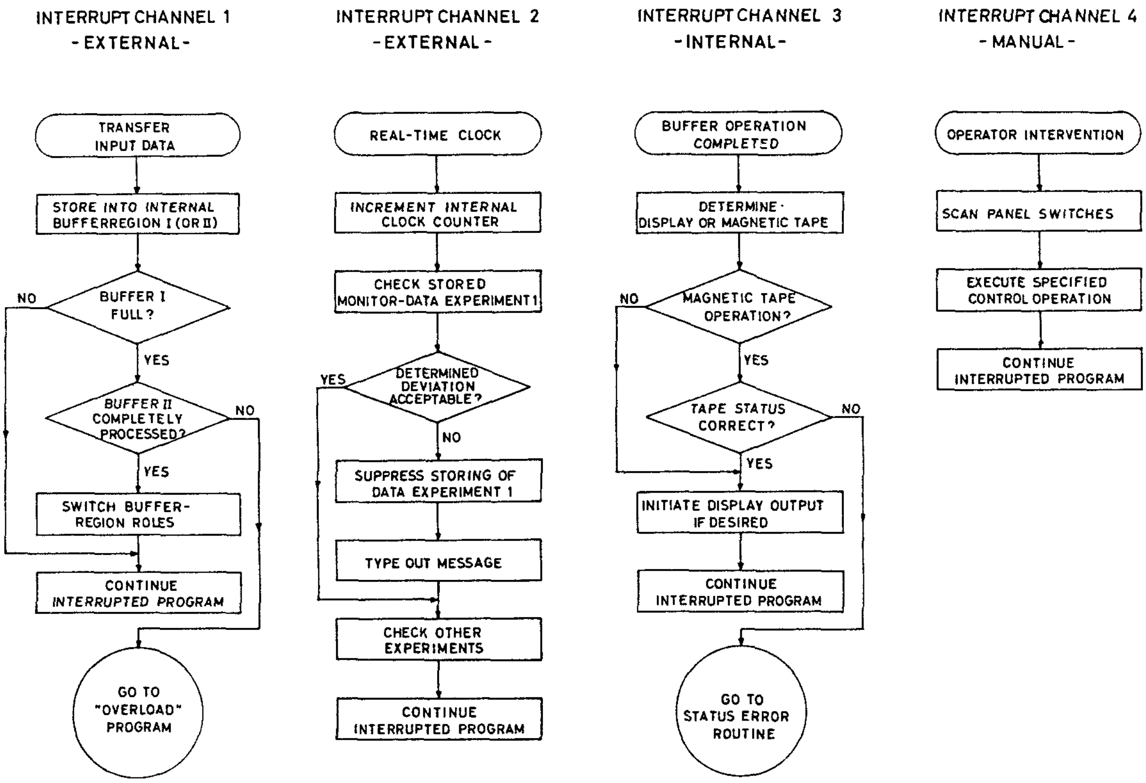

Fig. 2
Simplified flow charts of the interrupt routines included in the control program.

A Display System for Use with an On-Line Computer

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A flexible "automatic" display system for use with the Karlsruhe multiple input data acquisition system is described. The system provides the display of multiparameter spectra in two and three dimensional representation (e. g. brightness map or isometric picture). It involves two cathode-ray tubes, one for a general view, and the other for detailed examinations. The system can be operated in the computer-controlled mode. However, since in our on-line computing facility a small computer (CDC 160-A) is heavily loaded by simultaneous data acquisition from many experiments, storage capacity and computer time are very restricted, thus excluding a computer-controlled live display in most cases. Therefore, another mode of display operation has been set up in which the computer sends the previously selected part of the stored information to an external system which generates the display picture. Using digital switches the experimenter can choose a wide variety of different display patterns and can correlate the display pictures on the two scopes.

1. INTRODUCTION

In planning the Karlsruhe miltiple input data acquisition system [1] we were faced with the task of developing a display system allowing for the peculiarities of integrated data handling of several experiments performed simultaneously. In order to convey an understanding of the special characteristics of the display system to be described, we have to give a brief review of the organization of data processing during measurements.

The encoded events fed into the computer from the input interface are roughly reduced by the program. The reduced data are either recorded on magnetic tape or directly accumulated in the core storage. In the case of multiparameter measurements mainly monitoring and control spectra are processed in the core storage. The spectra in the core memory are so arranged that there is an unequivocal relation between memory location and channel number of the multichannel experiment. The cell contents then represent the number of events. Now, it is the task of the display system to display these accumulated spectra on the screen of a CRT without disturbing simultaneous data acquisition.

2. DISPLAY MODES

In any case, a display system can only meet the experimenter's requirements, if it permits conversion of the collected information into comprehensible and easily interpreted display formats. Therefore, formats and scales of a display pattern should be selected under the complete control of the observer within a wide range of possibilities. The display may be controlled in two ways

(1) by computer program

(2) by a switch-controlled external device.

Our display system may be employed in either mode.

In the computer-controlled mode several display processing programs are contained in the computer. On an external instruction, e. g. a mnemonic code written on the I/O-typewriter, a special set of binary numbers is derived from the spectra to be displayed. By means of a set of digital-to-analog converters each number controls the deflection plates, or, in some cases, the brightness of a CRT. For every number supplied by the computer a spot is written on the screen.

The advantages of the computer-controlled mode are found in the practically unrestricted possibilities of display arrangements, even for very complex pattern and in the simple electronic set up of this part of the display unit. For on-line use with a small computer this mode has some disadvantages, because part of the storage is used up for storing the display programs and for holding the specially prepared data to be displayed. Moreover, execution of the display programs means an additional load on the computer during live display. This load is hard to determine and will vary with the way the experimenter handles the set.

For all these reasons it was our idea to design an external set controlled by switches which would permit a display of the whole core storage or parts of it. In this "automatic mode" of display presentation our Control Data 160-A computer has no active control functions. Its only task is to read out sequentially the accumulated data by its high-speed I/O-buffer channel into the display device. As this channel has a control of its own, the data flow to the display device occurs simultaneously with the normal computer program. For every data word to be read out the current program is interrupted for 6.4 µsec, but will be resumed in the following memory cycle. The rate of transfer, which is a maximum of 78 Kc, is controlled externally and may be selected at random. Normally, a lower transfer rate is used in the acquisistion phase so that about 15 % of available computer time is needed for output of data to be displayed.

3. DESIGN OF THE SYSTEM

Let us now go over a greatly simplified description of the display system.

The readout of a block of accumulated data is initiated by a short computer routine.The computer feeds a "functions code" into the display unit which determines whether the following data are to be presented in the "computer-controlled mode" or in the "automatic mode". In the case of "automatic mode", which will be discussed further, the "function code" sets all registers and control flip-flops to their starting positions. Each of the data words now following initiates the display control circuit for one cycle, which needs an execution time of about 6 µs. In this cycle the data word is taken up by the Z-Register. The X-Register containing the address of the spot in horizontal deflection is incremented by one. If a new trace is to be written, the Y-Register is also incremented by one. This register contains either the address of the trace or, in three dimensional patterns, the Y-parameter. With the three coordinate switches the user may arrange the spots to the desired pattern scale. The resulting analog voltages supplied from the D/A-converters are combined into a single, multitrace, isometric or map pattern by the mode switch and two analog adders.

By adding another couple of X- and Y-registers together with the corresponding coordinate switches and D/A converters we expanded the system to a correlated display with two CRT's.

In principle, both tubes have their own switch controls and the data to be supplied from the computer may be processed into quite different pictures. Normally the two tubes are used in such a way that one tube shows the whole data material for purposes of an overall survey. Fig. 2, e.g. indicates a Co^{60} γ-γ coincidence spectrum arranged in a 64 x 64 matrix. Using the second switch control the experimenter may pick out any area of interest and display it in full resolution on the second screen. All spots appearing in this "detailed pattern" are intensified in the overall survey. Fig. 3 shows another example of pattern selection. One screen displays the Co^{60}-γ-γ coincidence spectrum in isometric mode, the other screen shows it simultaneously in map mode.

The ranges of the different switches are shown at the control panel of the "detailed display". The X-switch ranges from 8 to 4.096 spots, the Y-switch from 1 to 64 traces, and the Z-coordinate switch handles the cell content from 8 to 4.096 for full scale deflection. The switch "Z-deflection" permits limiting the full scale deflection to one half or one quarter of the screen or less in order to prevent overflow into the next trace in multitrace mode. The digital switch on the left hand side is for selecting the beginning address of the "detailed" pattern; the other digital switch is connected to a marker point circuit. Each displayed spot selected by the marker point switch may be intensified for determination of its address.

Fig. 5 shows the entire equipment with the two control panels and the two standard rectangular oscilloscopes of the Tectronix 561 type.

4. FUTURE DEVELOPMENT

We plan to expand our core storage by an additional 8K-memory with an independent timing control and an additional I/O channel with a maximum transfer rate of 125 Kc. The display system will then be operated mainly in conjunction with this unit. This takes care of one major disadvantage of the present assembly, i. e. the time sharing between computer program and core storage access of the buffer channel control. Once started, the readout of the additional unit occurs without interfering with the main computer, which itself interrupts the readout operation only for storage of a new event, i. e. an add one operation in a data channel.

REFERENCES

/1/ Krüger, G. and G. Dimmler: Proc. EANDC Conf. on Automatic Acquisition and Reduction of Nuclear Data, Karlsruhe, July 1964, Session II.c.

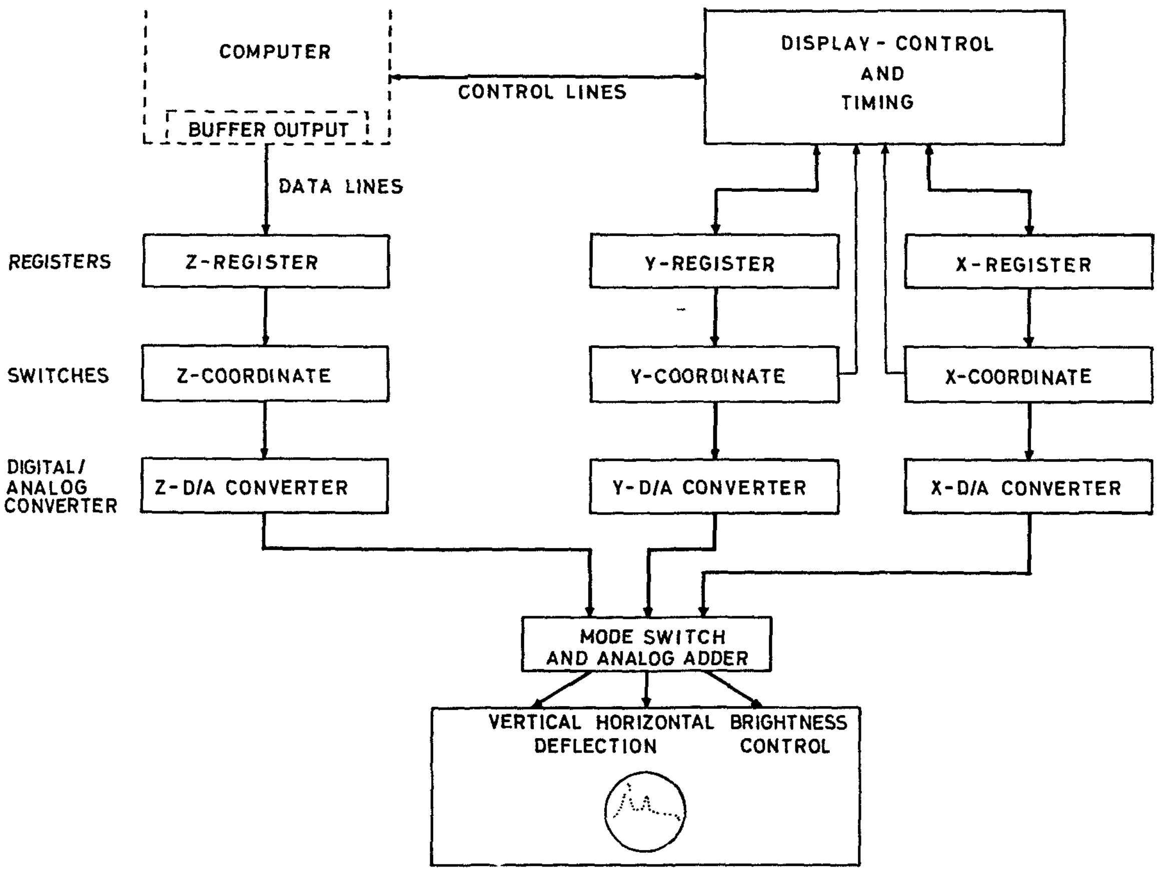
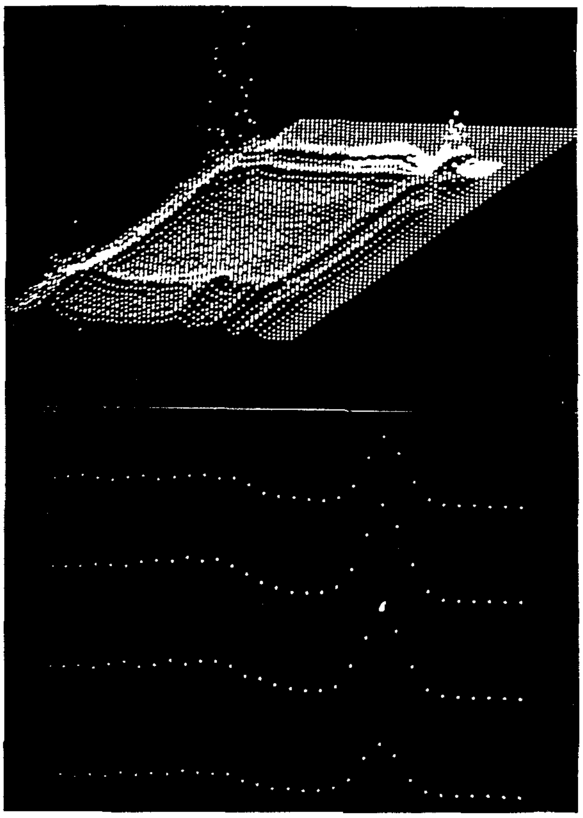


Fig. 1 Simplified block diagram of the display system.



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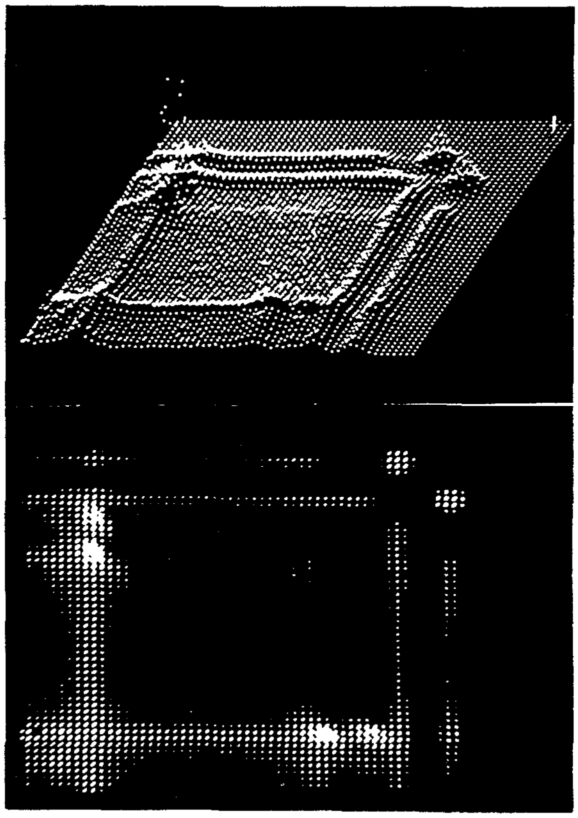

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Fig. 2

Example of a correlated display. One screen shows a Co^{60}- γ - γ -coincidence spectrum in isometric mode as an "overall survey", the other screen simultaneously shows part of it in multitrace mode as a "detailed pattern". The intensified spot in the "detailed pattern" illustrates the effect of the marker point circuit.

Fig. 3

The same spectrum as in Fig. 2 in a different arrangement. One screen shows an isometric display, the other screen simultaneously a map display.

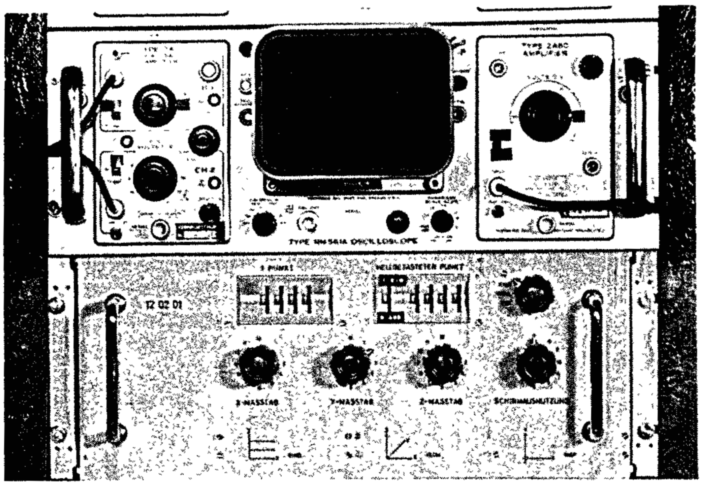

Fig. 4

Control panel of the "detailed display".

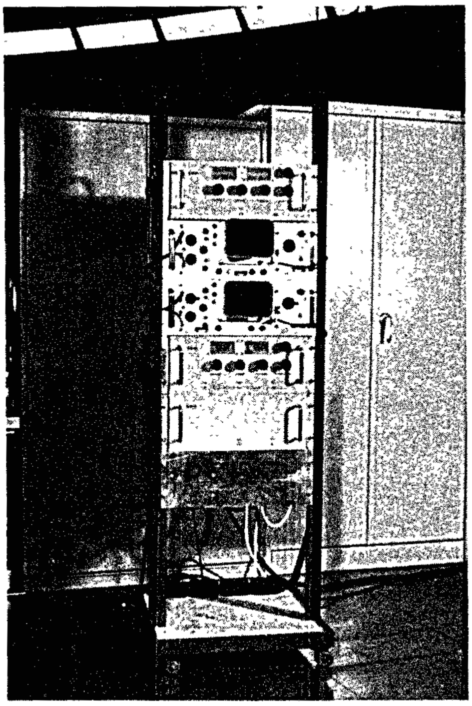

Fig. 5

The entire equipment. The different rack-mounted parts, as seen from the top, are: Control panel of "overall survey"; oscilloscope for "overall survey"; oscilloscope for "detailed display"; control panel for "detailed display"; plug-in for logic cards; power supply.