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INSTRUMENTATION SYSTEM FOR PULSED NEUTRON GENERATOR

PART 1: ELECTRONIC CONTROL AND DATA ACQUISITION

**Jacek Burda, Andrzej Igielski, Wladyslaw Janik,
Mariola Kosik, Arkadiusz Kurowski, and Tadeusz Zaleski**

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INSTRUMENTATION SYSTEM FOR PULSED NEUTRON GENERATOR

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ABSTRACT

The paper presents an electronic instrumentation system which is successfully applied for pulsed neutron generator and measurements. In the paper there are described in details all modernised parts of the system as well as new designed and applied ones. The set of diagrams is enclosed. An important part of the system has been designed and built in the Neutron Transport Physics Laboratory.

STRESZCZENIE

W pracy opisano system aparatury elektronicznej, który z powodzeniem zastosowano w impulsowym generatorze neutronów i pomiarach neutronowych. W pracy opisano szczegółowo zarówno zmodernizowane elementy systemu pomiarowego jak i zaprojektowane, zbudowane i zastosowane z powodzeniem jego nowe części (bloki funkcjonalne). Dołączono również komplet schematów szczegółowych. Istotne elementy systemu zaprojektowano i wykonano w Pracowni Fizyki Transportu Neutronów.

1. INTRODUCTION

The 14 MeV pulsed neutron generator has been constructed in the Institute of Nuclear Physics in sixties as the stationary neutron source. In seventies the pulsing system for the ion extraction voltage has been built which gave a possibility to use the generator as the pulse neutron source.

In the last few years the electronic systems have been almost totally modernised and reconstructed. Modernisation includes: computerisation of data acquisition and data processing, control and registration systems, and accelerator high voltage supply and control systems. Also sample environment control and number of neutron detectors have been enhanced.

The 14 MeV fast neutrons are produced by a linear accelerator in the $^3H(d,n)^4He$ reaction. Solid tritium targets $^3H/Ti$ of activities from 70 Gbq to 180 Gbq are used. The accelerator works in a pulsed regime by pulsing the extraction voltage of the ion source. The pulsing system is characterised by the following parameter:

- width of the fast neutron bursts: from 5 μs to 999 μs, adjustable,
- repetition time of neutron bursts: from 0.1 ms to 99.9 ms, adjustable,
- maximum neutron flux during the neutron burst: $5x10^9$ n/(s 4π).

A demonstrative general view of the neutron generator is shown in Fig.1. Gas deuterium is produced from the electrolysis of heavy water and dosed to the quartz bulb of the ion source by the palladium valve. Gas deuterium is ionised by the electromagnetic field of high frequency, next is extracted (continuously or pulsing) from the source volume, and accelerated along the vacuum tube. The water cooled solid tritium target is mounted at the end of the tube.

The generator can be used directly as the 14 MeV neutron source and/or as a tool for a thermal neutron transport research. A lot of research made in the Laboratory belongs to the neutron diffusion in finite media. The special experimental set-up is built for that purpose. Thermal neutron experiments are sensitive on an environmental temperature. The experimental hall where the neutron beam is focused and where the experimental set-up is arranged is air-conditioned to keep a temperature 20 °C. The new experimental set-up for experiments in wide range of temperatures is under construction.

The measured system is irradiated by neutron pulses. After each fast neutron burst the neutrons are slowed-down in the system and time-dependent thermal neutron flux can be observed. The correct registration of the thermal neutron die-away curve is the main effort of the instrumentation system. A simplified diagram of instrumentation system for a die-away measurement of thermal neutrons is shown in Fig.2. Two ^{3}He detectors are used to register thermal neutron escaping from the measured system. The two independent registration lines with two fast multiscalers are used to register the neutron die-away curve. It is equivalent to the two independent experiments given at the same time if the proper geometrical conditions of the system are fulfilled. The proper synchronisation both of the registration lines is required. The time diagram of pulsed neutron measurement is shown in Fig.3. The details of such a kind of measurement when the Canberra 35+ multichannel time analyser is used is described by DROZDOWICZ *et al.* (1993).

The measurement should be done in well known stable conditions. Both the accelerator, the electronic instrumentation systems, have to be under control. A constant average neutron flux, a proper counting statistics, a low neutron background are required to reach a high accuracy of final results of experiments. The most important parts of the instrumentation system of the pulsed neutron generator are presented in the paper. Many of electronic devices have been designed and built by the authors.

2. ELECTRONIC SYSTEMS OF THE PULSED NEUTRON GENERATOR

Due to technical reasons the electronic systems of the neutron generator are distributed over several locations with distances of tens of meters. It is mainly because of a high voltage and a radiation security. The main electronic functional nodes and their distribution are schematically shown in Fig. 4. In the accelerator hall there are situated:

- high voltage supply units of the linear accelerator (125 kV and 50 kV),
- high voltage supply units for extraction and frequency power (HF) generator (5 kV and 3 kV, respectively),
- fast high voltage electronic switch (extraction pulse),
- electrostatic deflection system of the residual beam (not shown),

- deuterium supply system (electrolyser and palladium valve),
- high frequency power generator,
- mains transformer with high voltage insulation,
- control and supply unit for the two-step vacuum pump system.

In the air-conditioned experimental hall there are situated:

- ion current detector and preamplifier (not shown),
- four neutron detectors with associated electronics,
- auxiliary electronic equipment which consists of a vacuum meter, a radiation hazard alarm, temperature stabilisation systems, and a test generator (part b).

In the control room there are situated:

- remote control systems with the optofibre HV isolation for the all HV supply units situated in the accelerator hall, for the palladium heater supply and for the extraction pulse,
- ion source glow indicator,
- auxiliary electronic equipment which consists of a master control generator, a start pulse selector, a magnetic lenses supply and control, an ion pulse scope and integrator, neutron count pulses indicators and integrators, a vacuum meter, a sample temperature indicator, and a test generator (part a).

In the data acquisition room there are situated:

- time analysers (2 pcs of the Accuspec Fast Multiscaler PC cards),
- multiparameter recorder (ADC16 PC card),
- amplitude/time analyser,
- digital and analog optoisolation systems,
- set of integral counters,
- neutron count pulses discriminators and integrators,
- start pulses delay units,
- automatic measurement control unit.

The main electronic systems and devices listed above are discussed in the paper in the following pages.

2.1. High voltage supplies of the linear accelerator and remote control with optical fibres

As shown in Fig.4 there are four high voltage supply units 125 kV, 50 kV, 5 kV and 3 kV. All of them are GLASSMAN series WK, ER and WX, respectively, with 0-10 V input and output remote controls. For all the high voltage supply units remote controllers using optical fibres as communication media and HV insulation have been developed and made. Typical structure of the controller for transmission of analog signals is shown in Fig.5. A simplified version is used for transmission of digital extraction pulse as well as remote HV supplies start signal. An optical fibre is used for light transmission from ion source to the control room.

A high voltage optoisolation using long (about 20 m) optical fibres serves mainly as HV isolation between the electronic devices situated in the accelerator head (on a high potential) and an associated control systems situated in the control room. Here three kinds of data and control transmission can be distinguished:

- direct transmission of light (direct transmission of the ion source glow from the accelerator head to the control room),
- transmission of digital signals (with TTL input/output signals directly connected to the proper optotransmitters),
- transmission of analog control and data signals where information before digital optotransmission is voltage/frequency (U/F) coded and after optotransmission frequency/voltage decoded (F/U).

2.2. Fast electronic switch of the extraction pulse

A high voltage fast electronic switch connected to HV extraction supply and driven by TTL extraction pulse provides a HV pulse to the extraction electrode of the ion source. The switch has been constructed of two BEHLKE HV MOS devices in totem-pole configuration. A special anticoincidence circuit eliminates excessive current pulses during switching. The amplitude of output pulse can be varied from 0 V to 5 kV with switching time about 0.2 µs. Circuit of the switch is shown in Fig.6.

2.3. High frequency power generator

An 60 MHz, 300 W self-excitation power generator on two electronic valves type T01 with coil surrounding the ion source serves as ionising device. The generator is supplied by 0-5 kV supply unit. The generator circuit diagram is shown in Fig.7.

2.4. Deflection system of the residual beam

In order to avoid any fast neutron background produced by the residual ion beam beyond the extraction pulse a set of two deflecting electrodes is placed nearby the outlet of the ion source. One of the electrodes is connected to -90 V dc supply steadily deflecting the residual beam. The other electrode is supplied by compensating -90 V pulse during the extraction pulse, so the ion beam can reach the tritium target. Schematic diagram of the residual beam deflection system is shown in Fig.8.

2.5. D_2O electrolyser and palladium valve heater control

Gas deuterium is obtained by the electrolysis of the heavy water, D_2O. The palladium valve is used to dose gas deuterium to the ion source. The palladium valve temperature is changed by remote control of the palladium valve heater supply voltage (0-10 V). The remote control of the heater voltage is realised *via* a standard optofibre analog link. The D_2O electrolyser is supplied by 12 V DC supply unit with the manual adjustment.

2.6. Measurement of vacuum level.

A two-step vacuum pumping system is use to keep the proper level of vacuum in the accelerator tube. The system consists of the rotary and the turbo-molecular pumps. The vacuum level has to be continuously under control for safety work of the accelerator.

Two channel vacuum meter type Micro-Pascal (ALCATEL MANUAL, 1993) with two vacuum sensors: type pirani PI3C and penning CF2P for low and high vacuum respectively connected to accelerator tube is used for vacuum measurement.

Analog output (0-8V) from the vacuum meter, situated in the experimental hall is connected to the analog meter in the control room and to the multiparameter recording system in the data acquisition room where it is digitally displayed and analogue recorded.

2.7. Ion current detector and preamplifier

A 1 kΩ resistor is used for an insulation of the ion beam target metal plate from the earthed ion-guide tube. The ion pulse current produces on this resistor a voltage pulse which is then linearly amplified by a fast preamplifier with a constant amplification factor. This pulse is delivered to the control room for a visual inspection and further modification. The simplified circuit is shown in Fig.9.

2.8. Master control generator

The master control generator is used to adjust the repetition and the duration of the neutron burst. The generator is based on 1 MHz quartz oscillator and 3 programmable counters: for repetition period, background gate duration, and ion pulse duration (extraction). It contains also two additional programmable counters for delay and width of test pulse. Repetition period of the extraction pulse is manually programmable from 0.1 ms to 99 ms. Duration of the pulse is manually programmable from 1-999 μs. Background gate duration is set internally on 170 μs. The basic structure and the time diagram is shown in Fig.10.

2.9. Start pulse selector

A start pulse is necessary to fix the reference time moment for an analysis of the neutron time-distribution related to the neutron burst. It is important parameter for an activation of time analysers. The start pulse selector produces the following six start pulses:

1. Start pulse at the beginning of extraction pulse.

2. Start pulse at the end of extraction pulse.
3. Start pulse at the beginning of ion pulse (on the ^3H target).
4. Start pulse at the end of ion pulse (on the ^3H target).
5. Coincidence of 1 and 3 start pulses (coincidence of fronts).
6. Coincidence of 2 and 4 start pulses (coincidence of rears).

The most frequently start pulse no 5 is used. It has an high immunity for disturbances and prevents „empty" analyses cycles. The basic structure and the time diagram are shown in Fig.11.

The logical scheme of the generation and the application of the start pulse is shown in Fig.12. The delay units shown in the diagram have been designed and built by the authors on the same principle as the master control generator.

2.10. Test pulse generator

The test generator produces several test pulses strictly synchronised with the extraction pulse of the master generator:

1. Test pulse for the ion current preamplifier. This pulse is the „extraction" pulse and simulates the ion current pulse.
2. Test pulses Tp3 and Tp4 for the A, B, and C, neutron detector preamplifiers. The pulses of both polarities simulate a shape and an amplitude of neutron pulses. Time of their occurrence is chosen within the analysed time window.
3. Test pulses for the monitor preamplifier (Tp1 and Tp2). The pulses of both polarities are neutron-like shaped and are derived from the edges of the extraction pulse. The Tp2 pulse is automatically situated on a maximum of a slow neutron burst and is also foreseen for an on-line dynamic dead-time losses correction system.

Simplified hardware and time diagram of the test generator is shown in Fig.13.

2.11. Electronic devices for neutron detection and registration

The thermal neutrons are detected by two kinds of detectors. There are four detectors in use. Two of them are especially made bell and cylindrical-shaped ^3He detectors. They are used to detect thermal neutrons escaping from the measurement system. The others two are standard BF_3 long detectors. One of them is surrounded by paraffin and placed several meters from the target and serves as a neutron monitor. The other one serves for general purpose diagnostics.

All of the detectors use similar detector electronics, but some of them co-operate with more sophisticated digital electronic devices. They use :

- charge-sensitive preamplifiers type 1005,
- high voltage supply type WN41,
- amplifiers with conditioning type 1101,
- quadruple discriminators type QD-IFJ,
- linear ratemeters type 1301,
- integral counters type 678-IFJ,
- cyclic background counters type BC-IFJ*,
- digital optoisolation type DO-IFJ*,
- analog optoisolation type AO-IFJ*,
- time analysers (FMS PC card).

The devices marked by IFJ* are designed and built in the Laboratory by the authors. The network of detectors electronics is shown in Fig.14.

2.12. Set of integral counters

A set of integral counters type 678-IFJ is used for integral count of valid parameters during experiment. Some of them are used for final correction of dead-time count losses while others serve as a final prove of measurement correctness. More detail arrangement of integral counters and their functions is shown in Fig. 15.

2.13. Cyclic background counters

Background is counted before the beginning of the each fast neutron pulse during background gate pulse (about 170 μs). There are two adjustable background counters for detector A and B respectively. Each counter has an digital/analog converter with output connected to the multiparameter recorder. Background pulses are summed for a period equal of 10^5 cycles of master generator. After this period background counter is reset. If during this period the background exceeds the admissible level the measurement apparatus is switched to the stand-by status (see paragraph 2.14). Simplified block diagram of the background counters is shown in Fig.16.

2.14. Automatic measurement control

The basic system of the automatic measurement control has been designed and built by BURDA *et. al* (1982). Here the general description of the system is repeated to better understanding of the dependencies between the all instrumentation system presented in the paper and the automatic control unit.

The main purpose of the control unit operation is to deliver proper start pulses to the time analyser when the following conditions are fulfilled:

- average intensity of measured pulses is contained in a given interval of intensity,
- start pulses delivered by the start pulse former are correct in shape and frequency, which means that the ion source, the pulsed extraction voltage generator and the HV supply of the accelerator work correctly,
- vacuum pumps work correctly and there is no trouble with their cooling system,
- required constant temperature of the measured system is kept.

Then the control unit, trough the start pulse, starts the run of the multichannel time analyser.

The control unit ends the whole measurement, if any of programmable counters produces a stop signal. The status display indicates the status of the data collection system: READY, ON, PAUSE or STOP. In addition, an interruption - the PAUSE or STOP status - starts an acoustic alarm. A red LED on the front plate of the control unit indicates the reason of the interruption.

The structure of the control unit is given in Fig.17. A control logic is the main module of the unit. Input modules like a window discriminator, a retriggerable univibrator, a programmable counter unit and an emergency signalization unit provide required signals to the control logic and to a pause time detector.

2.15. Middle voltage optoisolation

The middle voltage isolation system serves mainly as noise immune and hardware protection system and uses IC optoisolators. It disconnects galvanically computer based electronic hardware from the rest of electronic systems. This protects computers and computer network from possible disturbances and damage.

The linear accelerator itself and neighbouring cyclotron sporadically generate fast transients and RF signals which transmitted via air and space distributed earthing system can generate quite large voltages which can affect transmitted data and even cause hardware damage. Here two kinds of optoisolation are used:

- Optoisolation of digital (TTL) signals.
- Optoisolation of analog signals (using analog amplifiers with built-in optoisolation). Digital and analog middle voltage optoisolation is shown schematically in Figs. 18 and 19.

2.16. Multichannel time analysers

The final data acquisition is performed by the two Canberra Accuspec FMS PC Fast Multichannel Scaling Boards and standard IBM/PC (FMS MANUAL, 1990). The FMS cards are connected to the rest of electronic system *via* digital optoisolation. Simplified block diagram of the FMS based multichannel time analysers is shown in Fig.2.

The main parameters of FMS are:

- dwell time: from 2 μs to 278 hours
- dead time: less than 10 ns
- input rate: 100 MHz
- number of channels: 8192 and 16384

counts per channel: 2^{31}.

The used FMS boards have one disadvantage. The shortest dwell time obtained in continuous mode is 2 μs while desired time for measurements of time-dependent thermal neutron fields should be (sometimes) shorter than 1 μs.

Another amplitude/time analyser type Canberra 35+ is used (Canberra Manual, 1986) for the maintenance of detector electronics and an emergency reserve.

2.17. Multiparameter recorder

All important parameters of the pulsed neutron generator are constantly recorded and displayed by a multiparameter recording system. The system consists of ADC16 PC Board (ADC Manual, 1993) and standard PC. The system is connected to the neutron generator electronic devices *via* an analog optoisolation system. Block diagram of the multiparameter recorder is shown in Fig.20.

3. UNDER DEVELOPMENT

Upgrading process of the pulsed neutron generator is constantly carried on and several new devices are currently under development.

3.1. Thermostatic system for the experimental set-up

New thermostatic system is destined for control and stabilisation of the sample temperature in the range of 5 °C ÷ 80 °C (± 0.2 °C). The hot/cold air flow in semi-hermetic circuit (with cooler, heater and fan) controlled by microprocessor (PID with autotuning) will stabilise sample temperature. Except of an thermostatic camera for currently measured sample, an additional camera is foreseen for seasoning next sample.

The new sample thermostatic system will enhance the existing one where only constant temperature equal 20 °C(± 0.4 °C) of the sample can be stabilised. Schematically the new sample thermostatic system is shown in Fig.21.

3.2. Target displacement system

Target displacement system is destined for remote programmed control of target position, while the ionic beam position remains unchanged. The ionic beam diameter is approximately 5 mm and the active target diameter is about 25 mm. The existing system allows to around ±5 mm beam displacement using an asymmetric quadruple magnet coil system. A further displacement of target to the consecutive position is possible only manually after a dehermetisation of the vacuum of the accelerator tube. More over even the small ±5 mm shift of beam position is highly undesirable because high geometric symmetry between fast neutron source and sample arrangement is essential for precise measurement.

The new system will allow to use the whole target surface without a dehermetisation. The system consists of inclining ball-bearing, flexible joint of ionic guide comprising the target and of two programmable (satellite-antenna like) moving shaft remote controlled systems. (For vertical and horizontal displacements of the target with 1 mm steps over the ± 20 mm range). The project of the new target displacement system is shown schematically in Fig.22.

3.3. Dynamic correction of count losses

The high precision measurements of the die-away curve performed at the pulsed neutron generator need an accurate correction of the counts registered by the multichannel time-analyser due to existence of the dead-time count losses. A method used in the interpretation of measurements (DROZDOWICZ *et.al,* 1993) is very accurate but assumes a constant and stable thermal neutron flux during the experiment. Any deviation from this condition causes an additional error in a final correction of the collected data. A relatively simple electronic system for a „dynamic on-line correction of count loses'' is now under development. The system „measures" count loses for each individual neutron cycle, so the final data correction is much more immune for fast and slow changes of the neutron source intensity during the experiment.

4. FINAL REMARKS

The electronic instrumentation system for the pulsed neutron generator has been modernised in the last few years. The paper reports the present status of the of the system. Some devices have been bought (*e.g.* HV power supplies, FMS analysers) but many new devices have been designed and made in the Laboratory. This is because the accelerator techniques require very specialised and unique electronic solutions. A part of electronic devices which successfully worked in the past had to be changed for the new ones which are built in modern techniques. The new electronic solutions have been employed. All the reconstruction and modernisation give a possibility to reach a better final accuracy of experiments carried on at the pulsed neutron generator. The main apparatus problem which is very important but difficult to solve is to find the suitable fast multiscaler not involving a change to a nanosecond technique.

The properties of the pulsed neutron generator and the instrumentation system give a possibility to make experiments with time-dependent neutron fields in the range of microseconds. This corresponds to the thermal neutron lifetime in many media. The system is inadequate for measurements of neutron slowing-down processes which require much shorter neutron bursts and much faster time analyses.

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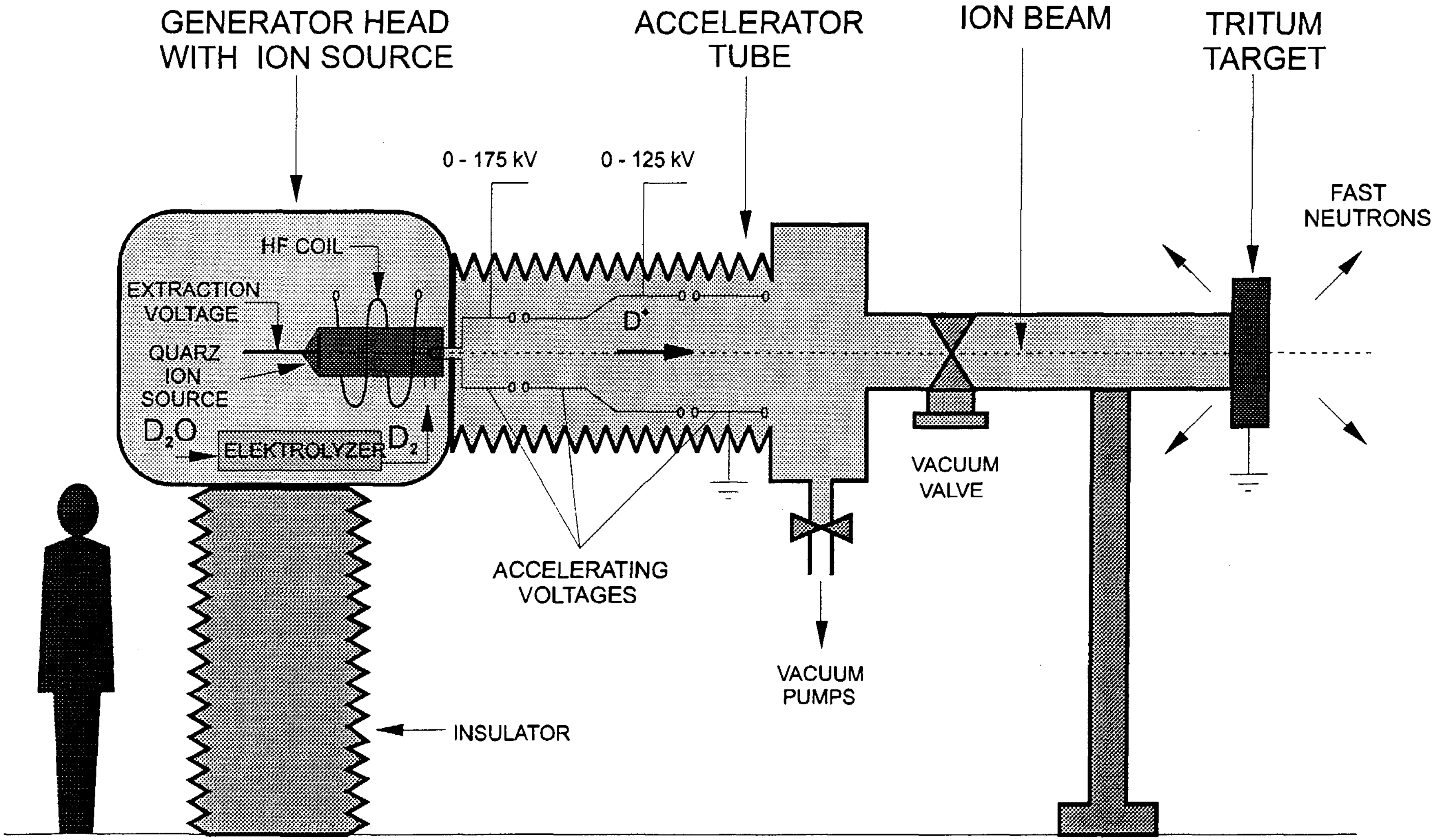

Fig.1.PULSED NEUTRON GENERATOR

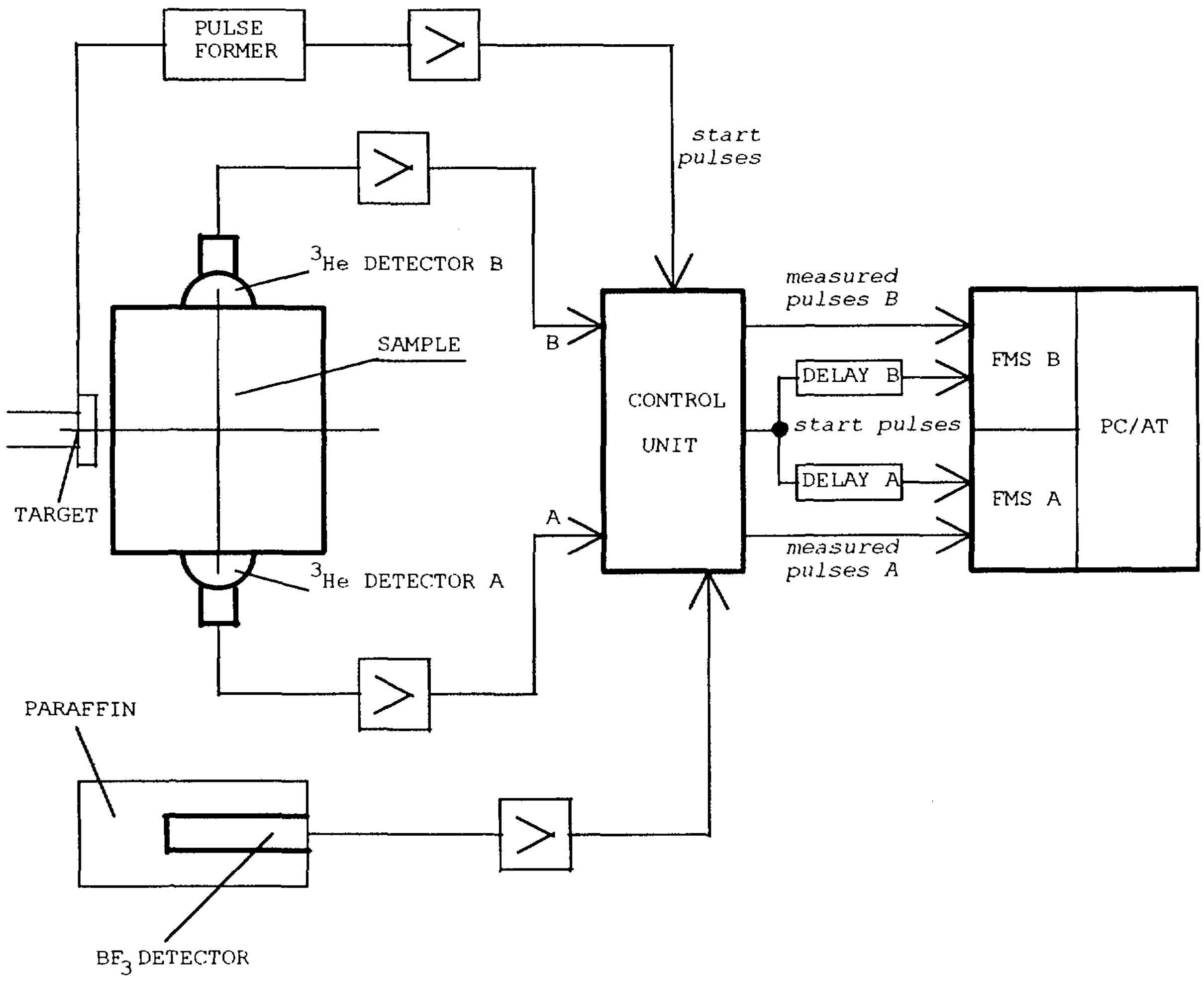

Fig.2.Block diagram of the instrumentation system for the registration of the thermal neutron time decay curve.

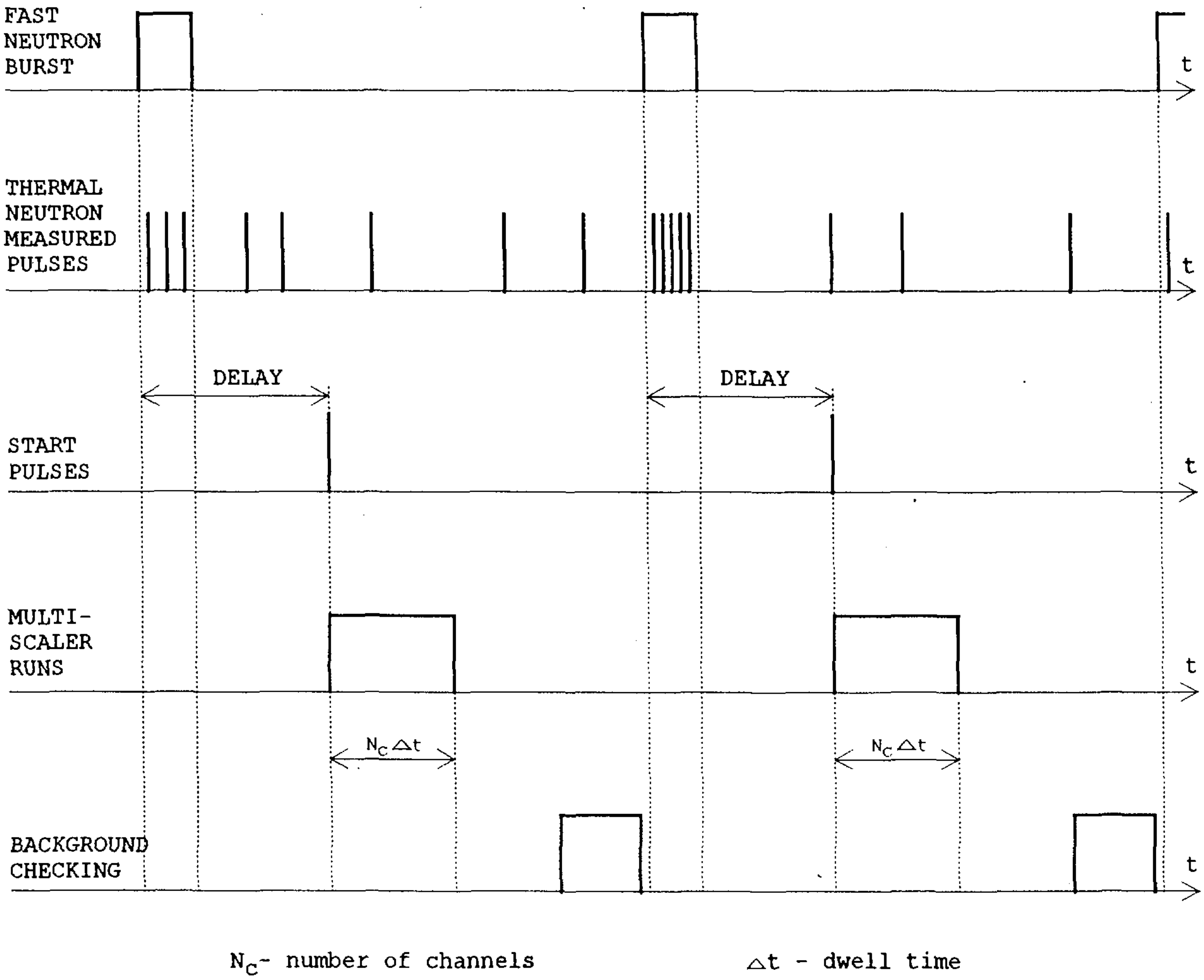

Fig.3.Timing diagram of the pulsed neutron measurement.

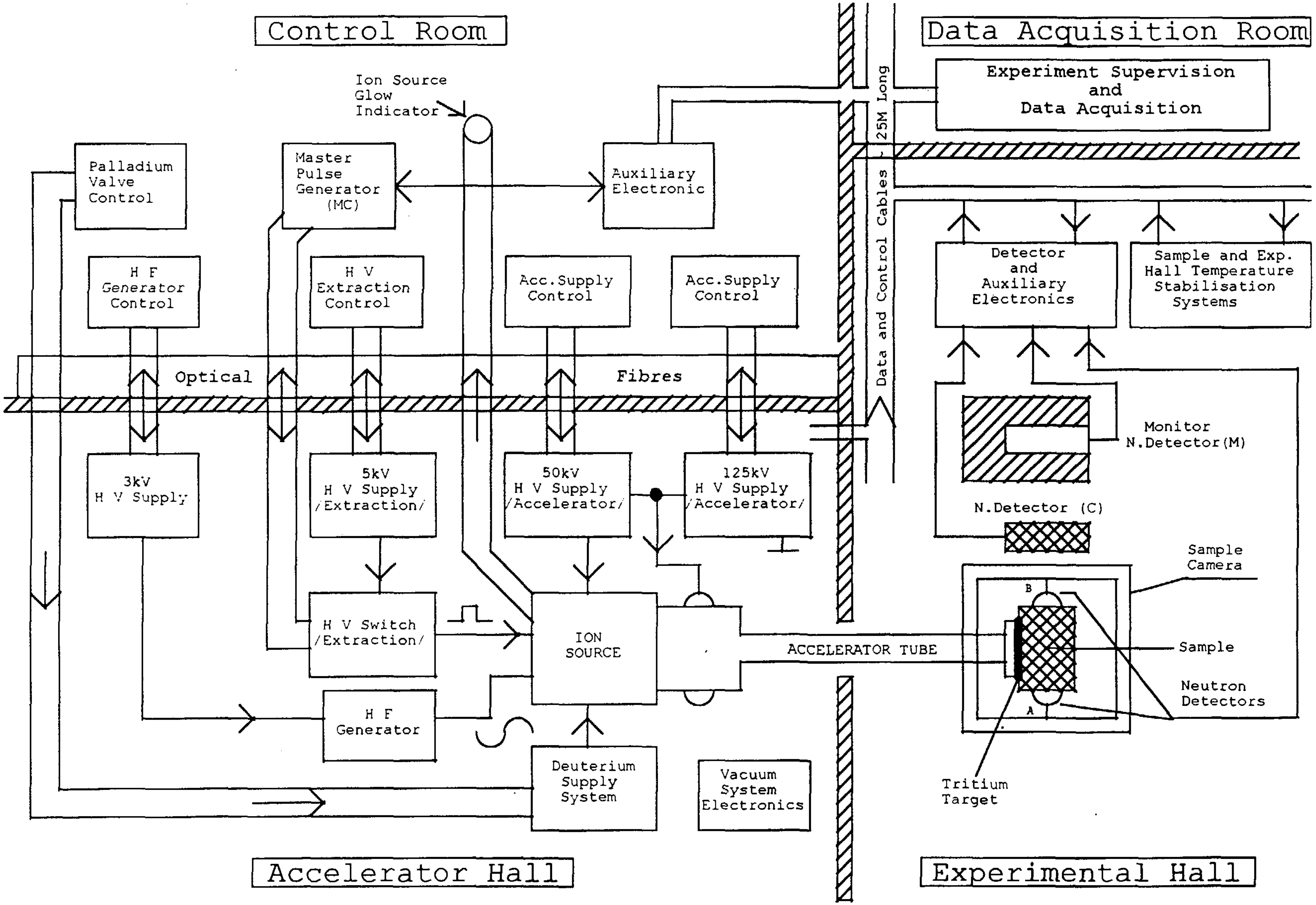

Fig.4.Main electronic nodes and their situating.

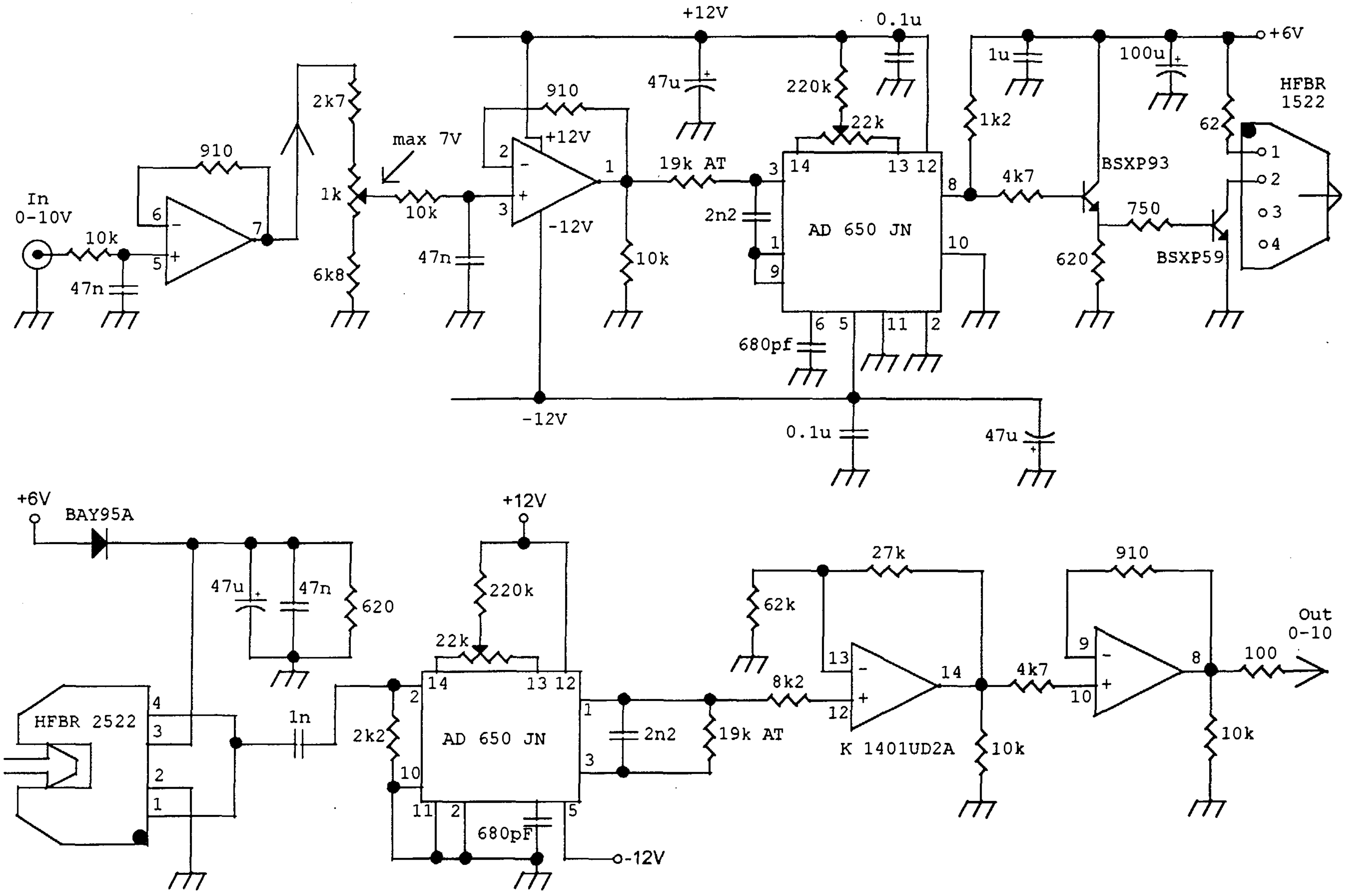

Fig.5.High voltage optoisolation system (analog version).

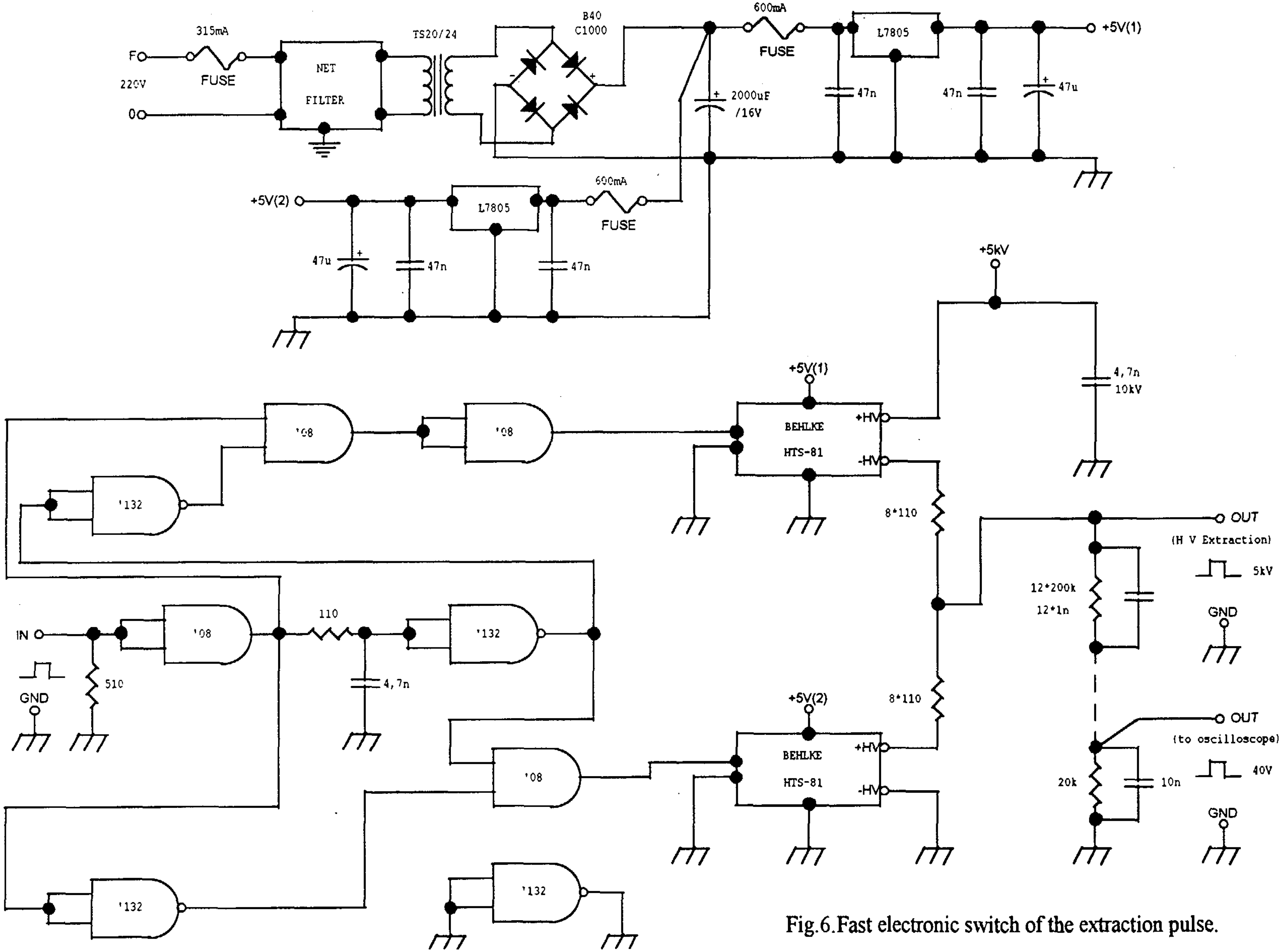

Fig.6.Fast electronic switch of the extraction pulse.

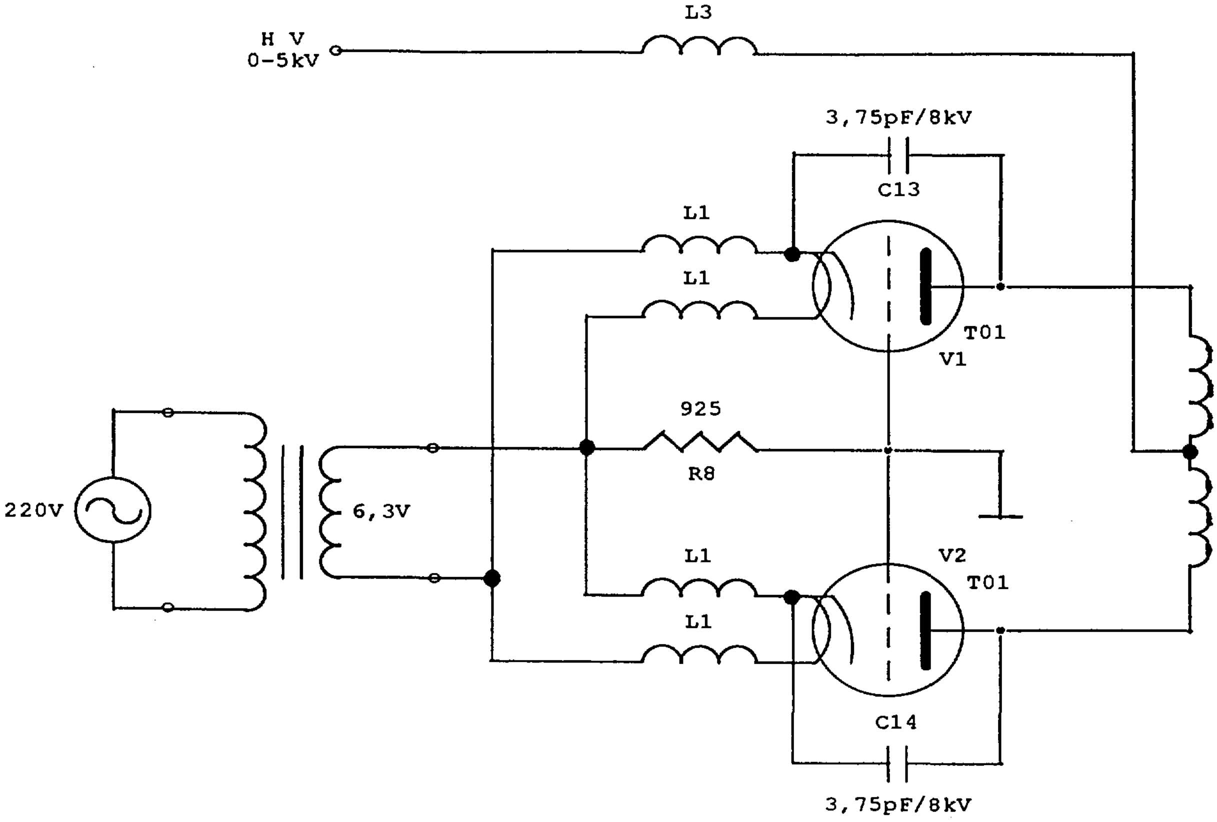

Fig.7.High frequency power generator.

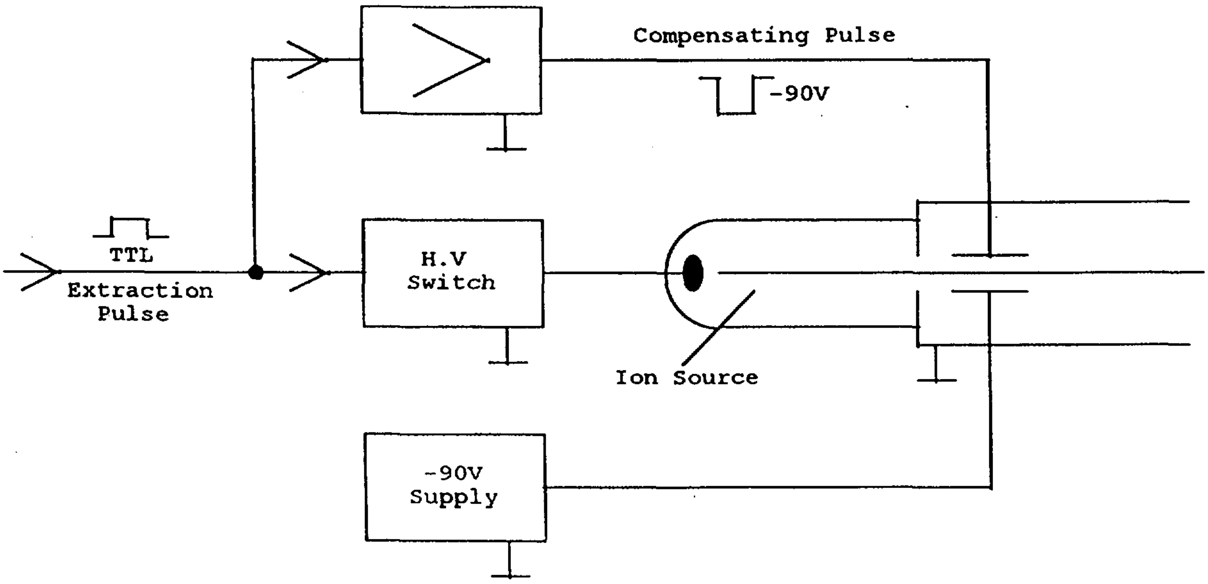

Fig.8.Shematic diagram of the deflection system for the residual beam.

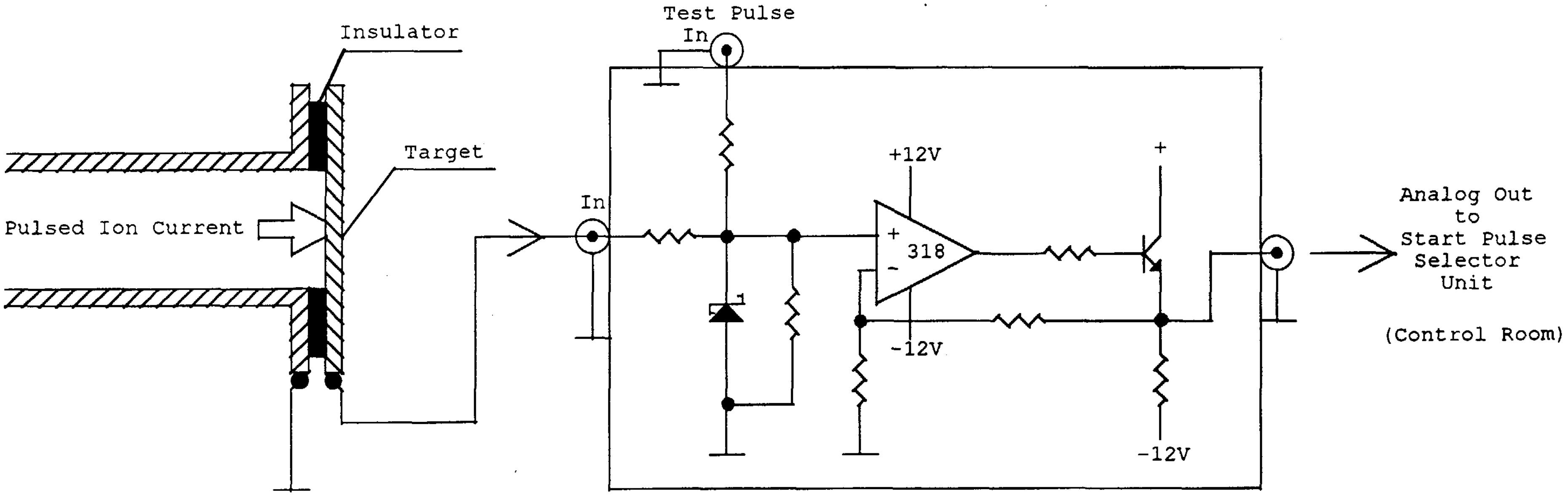

Fig.9.Ion current detector and preamplifier.

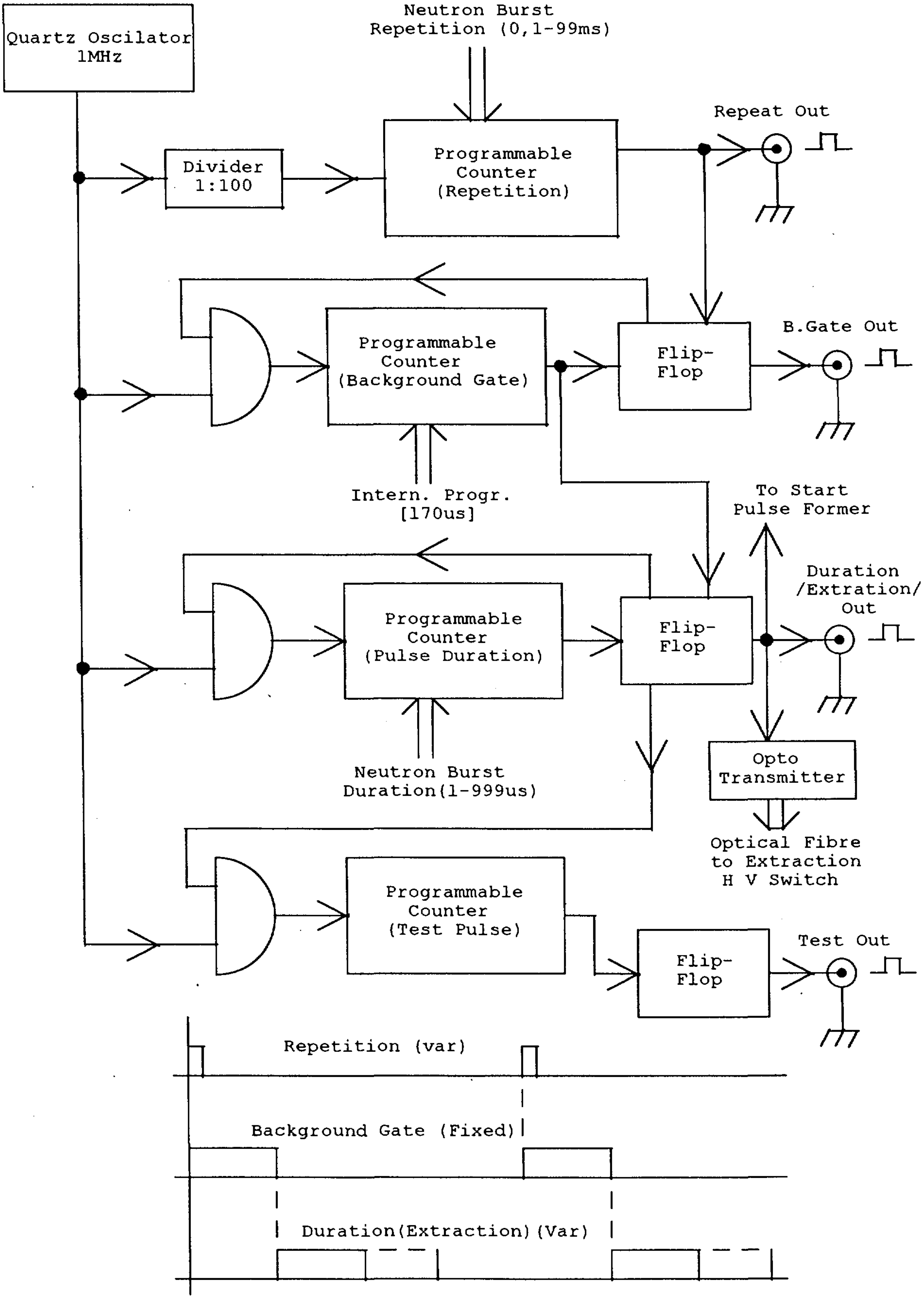

Fig.10.Master control generator.

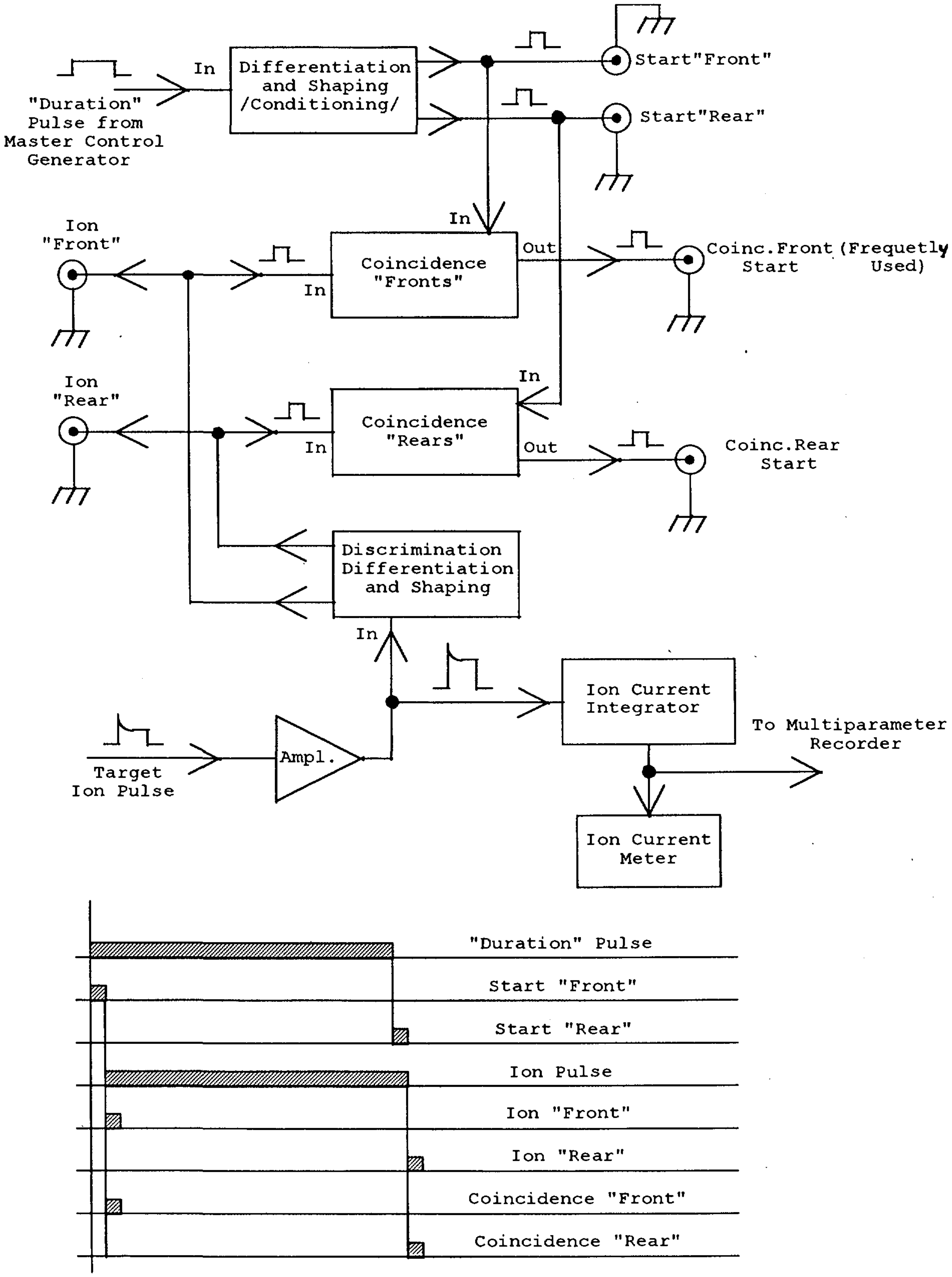

Fig.11.Start pulse selector and time diagram.

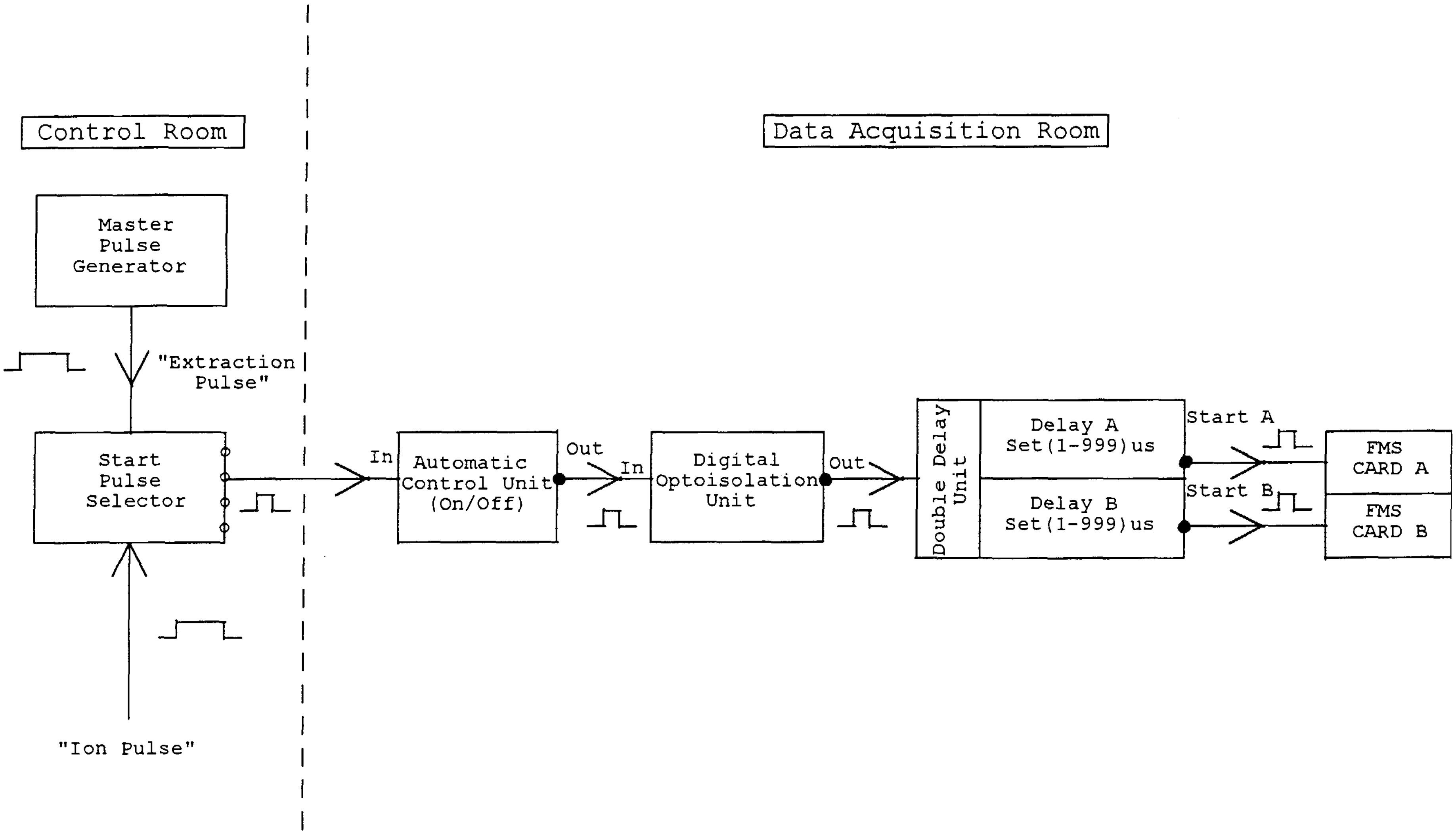

Fig.12.Start pulse pathway.

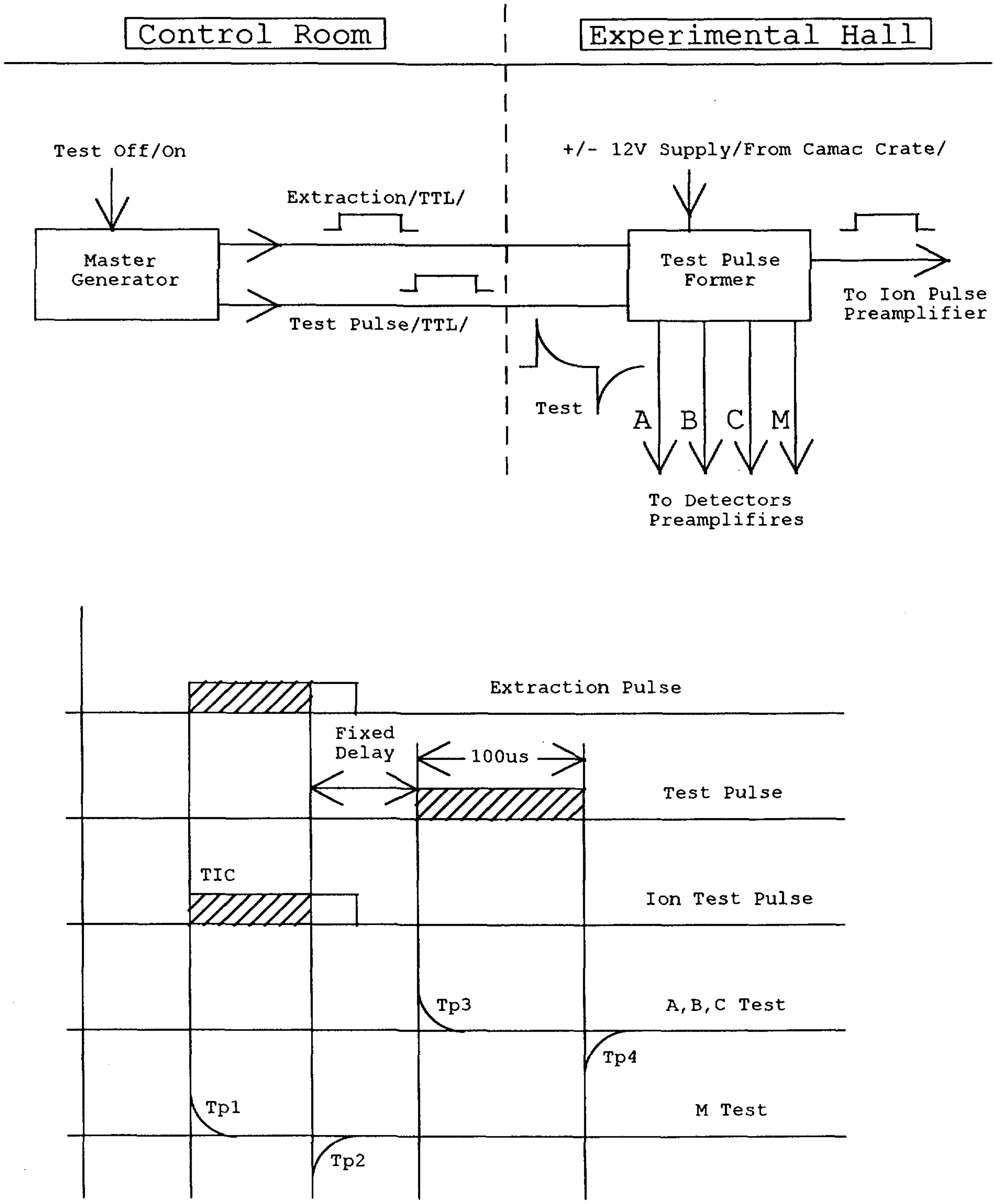

Fig. 13.Test pulses generator and time diagram.

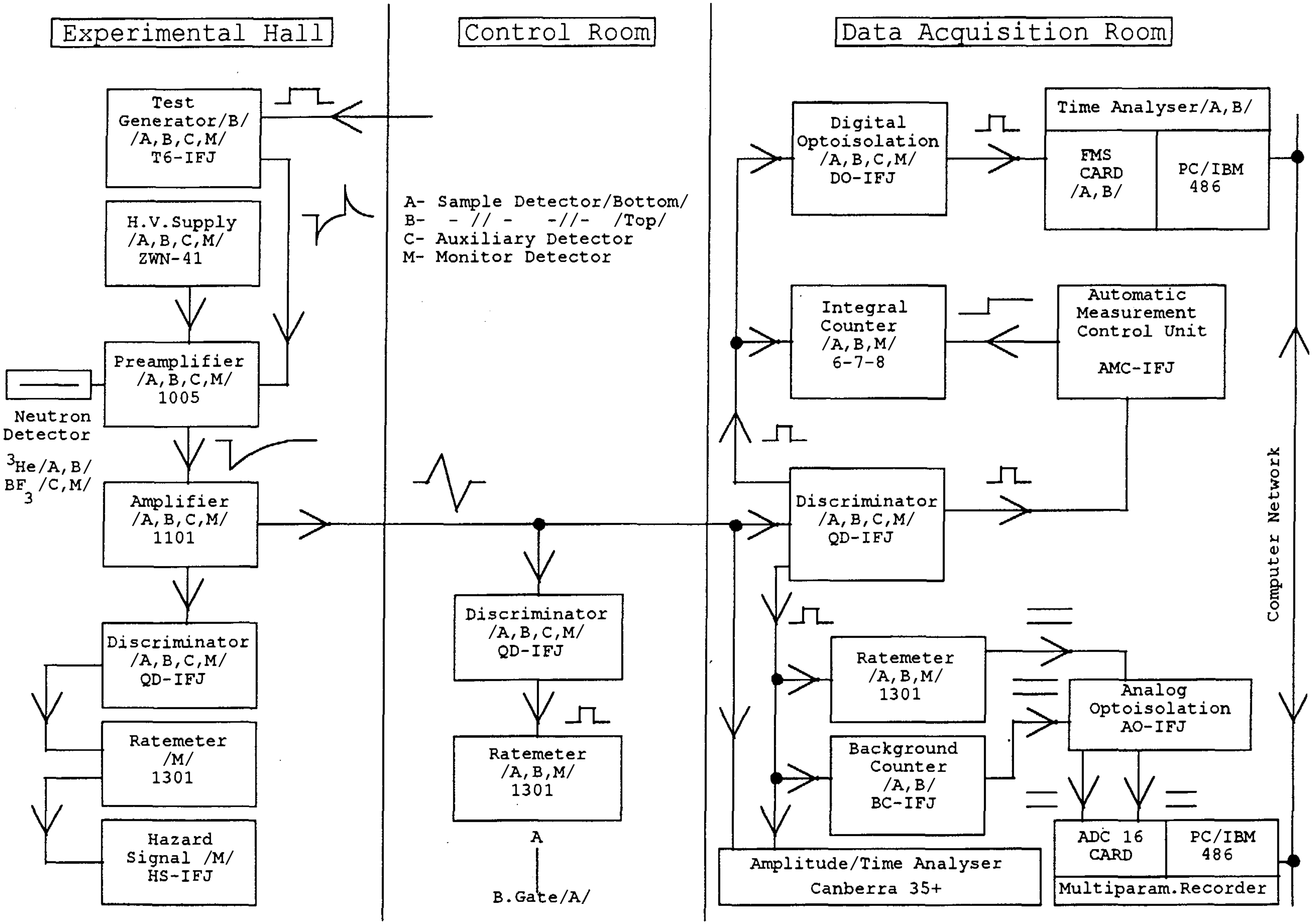

Fig.14.Chain of electronic devices for neutron detectioand registration.

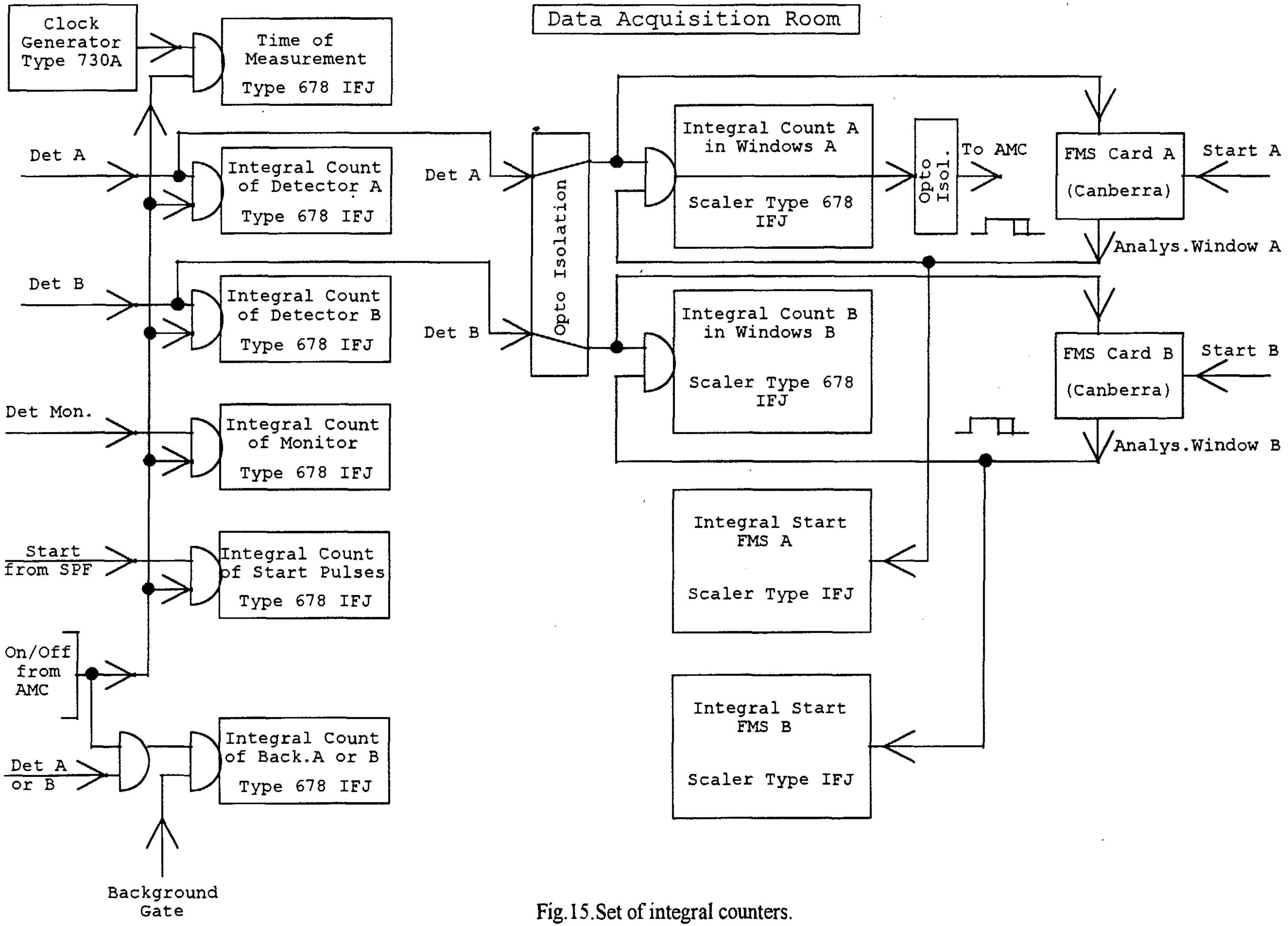

Fig.15.Set of integral counters.

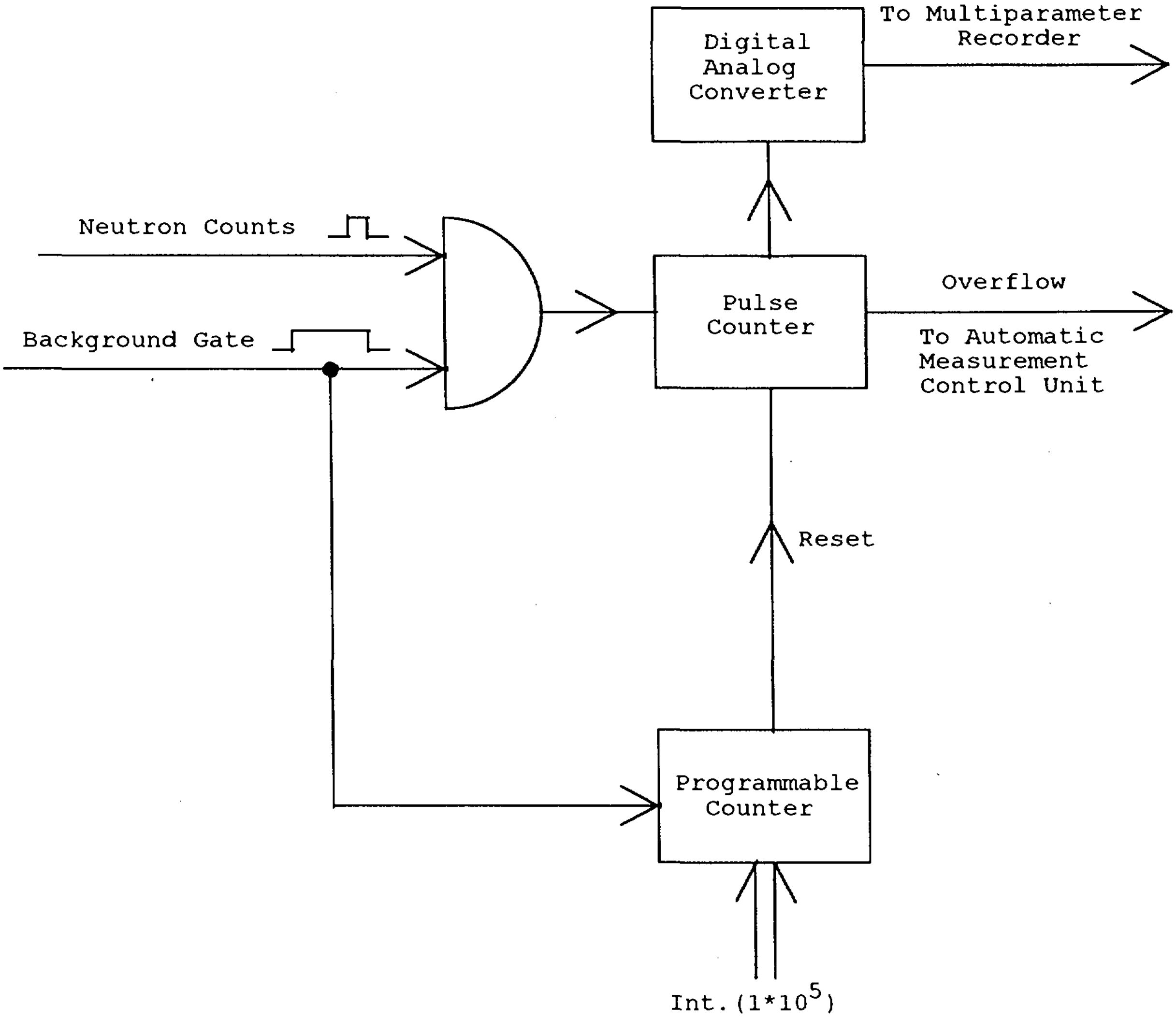

Fig.16.Cyclic background counter (simplifed).

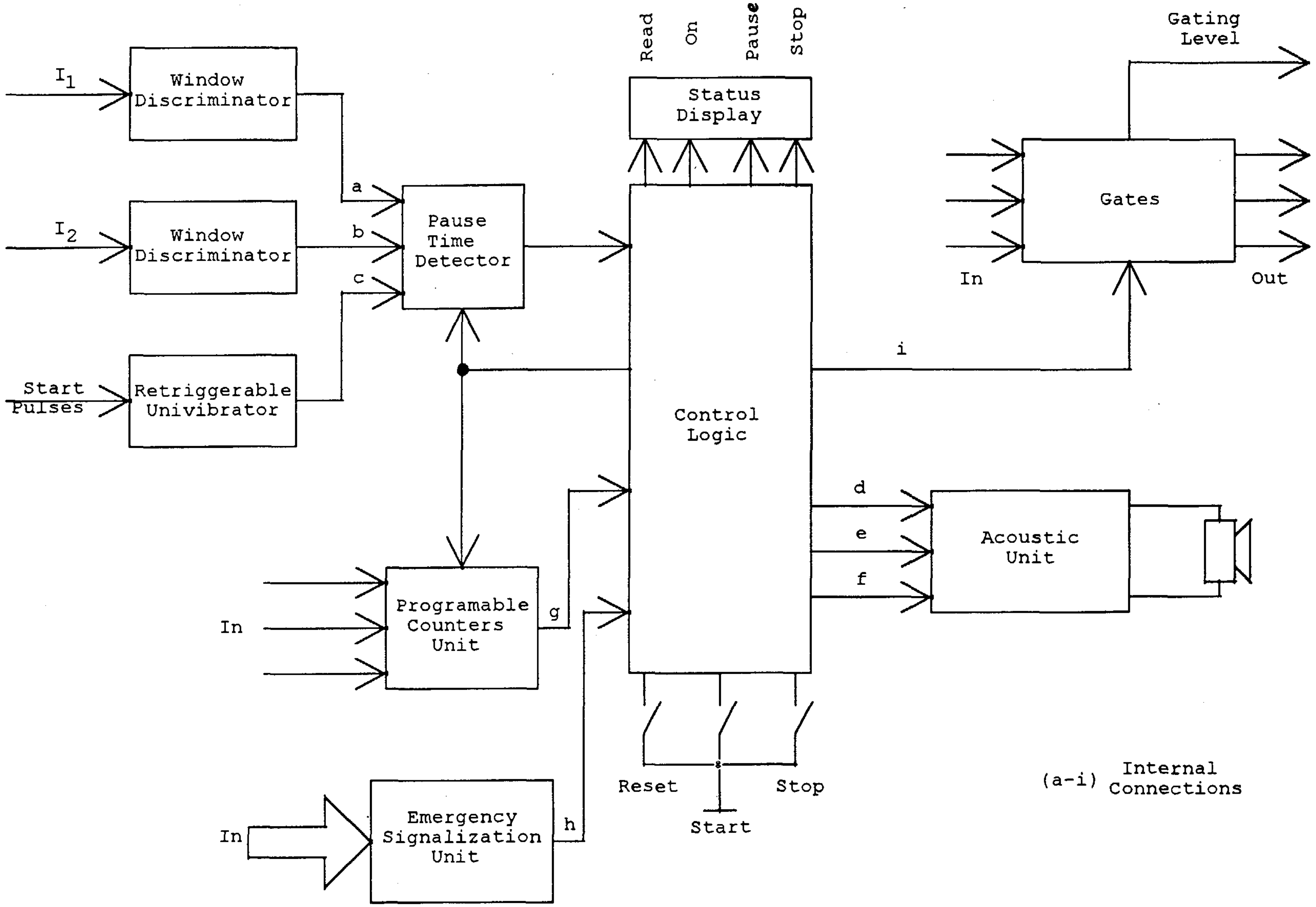

Fig.17.Schematic diagram of the AMC unit.

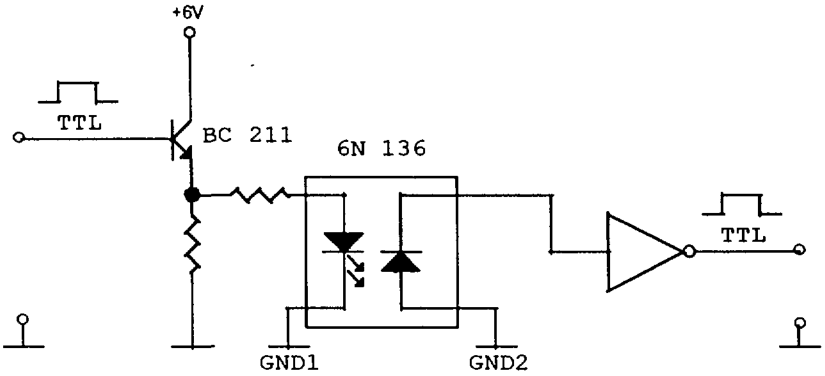

Fig.18.Digital optoisolation (simplifed).

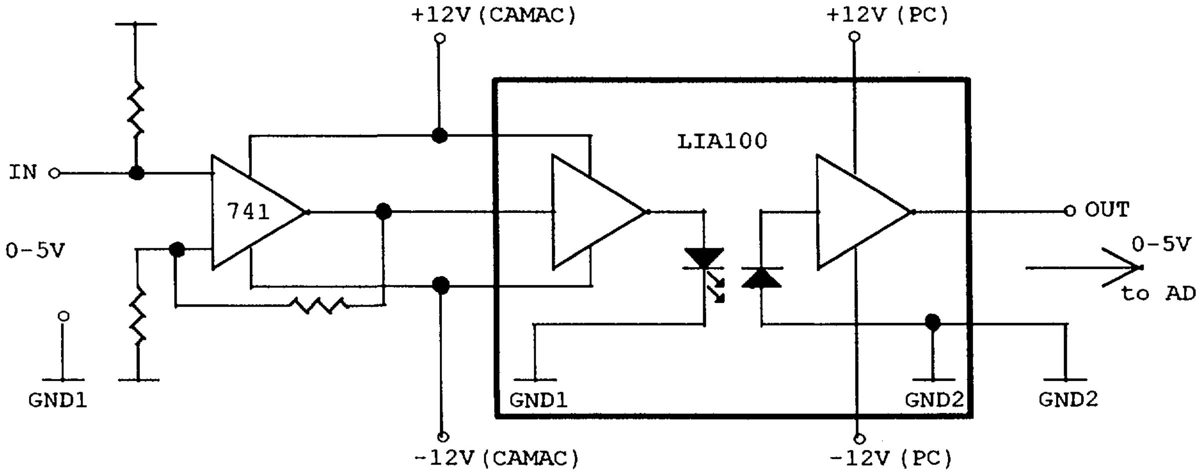

Fig.19.Analog signal optoisolation (simplifed).

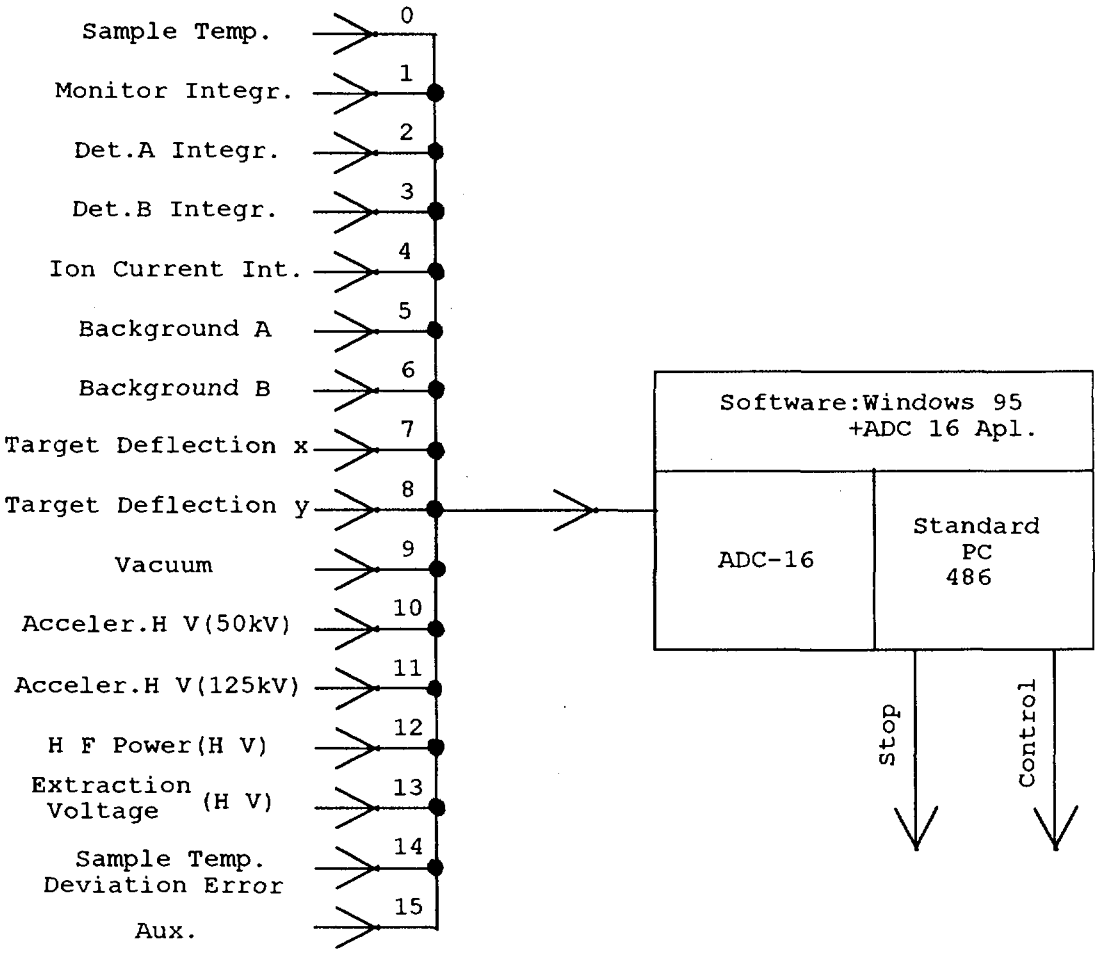

Fig.20.Multiparameter recorder.

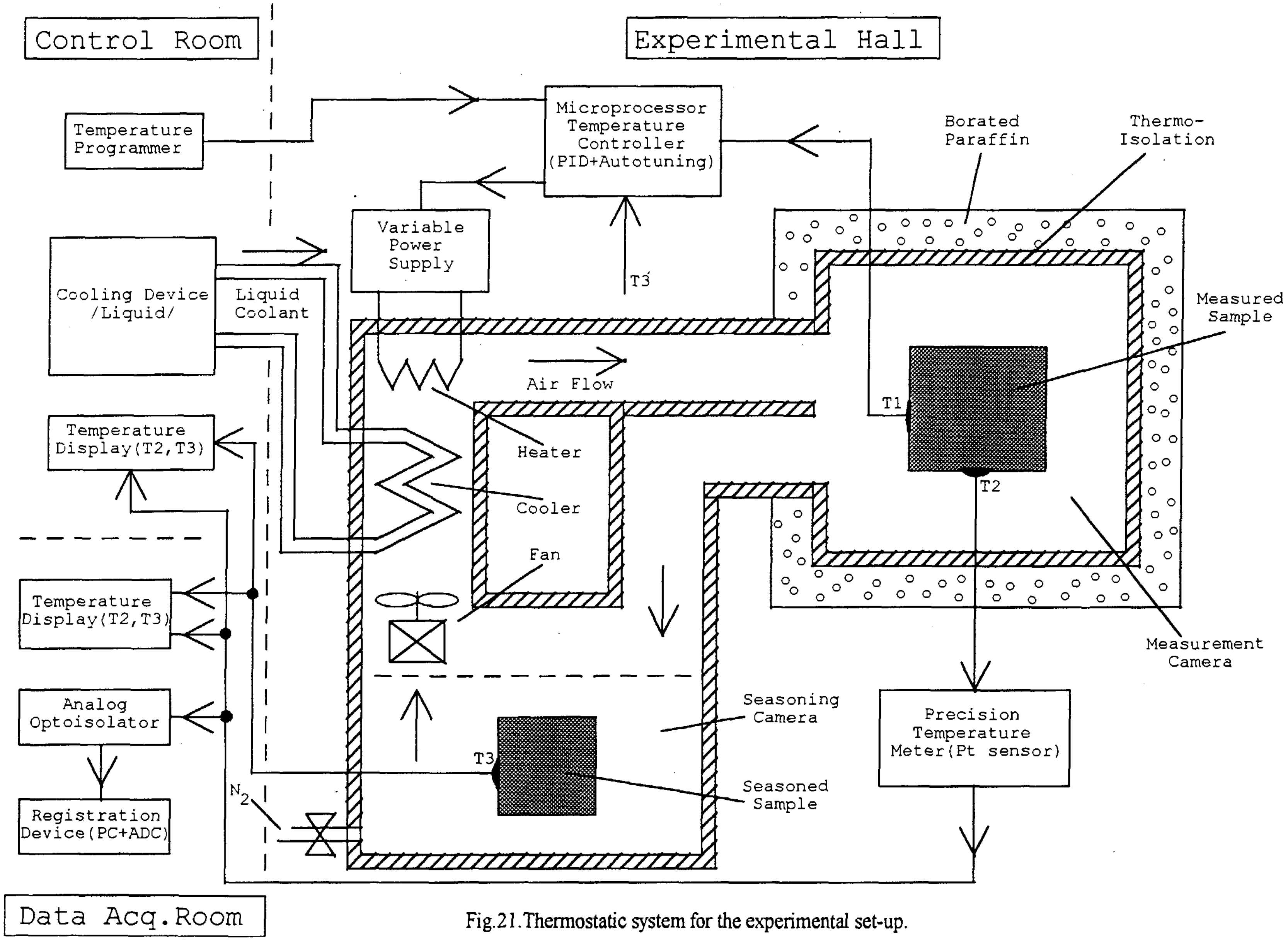

Fig.21.Thermostatic system for the experimental set-up.

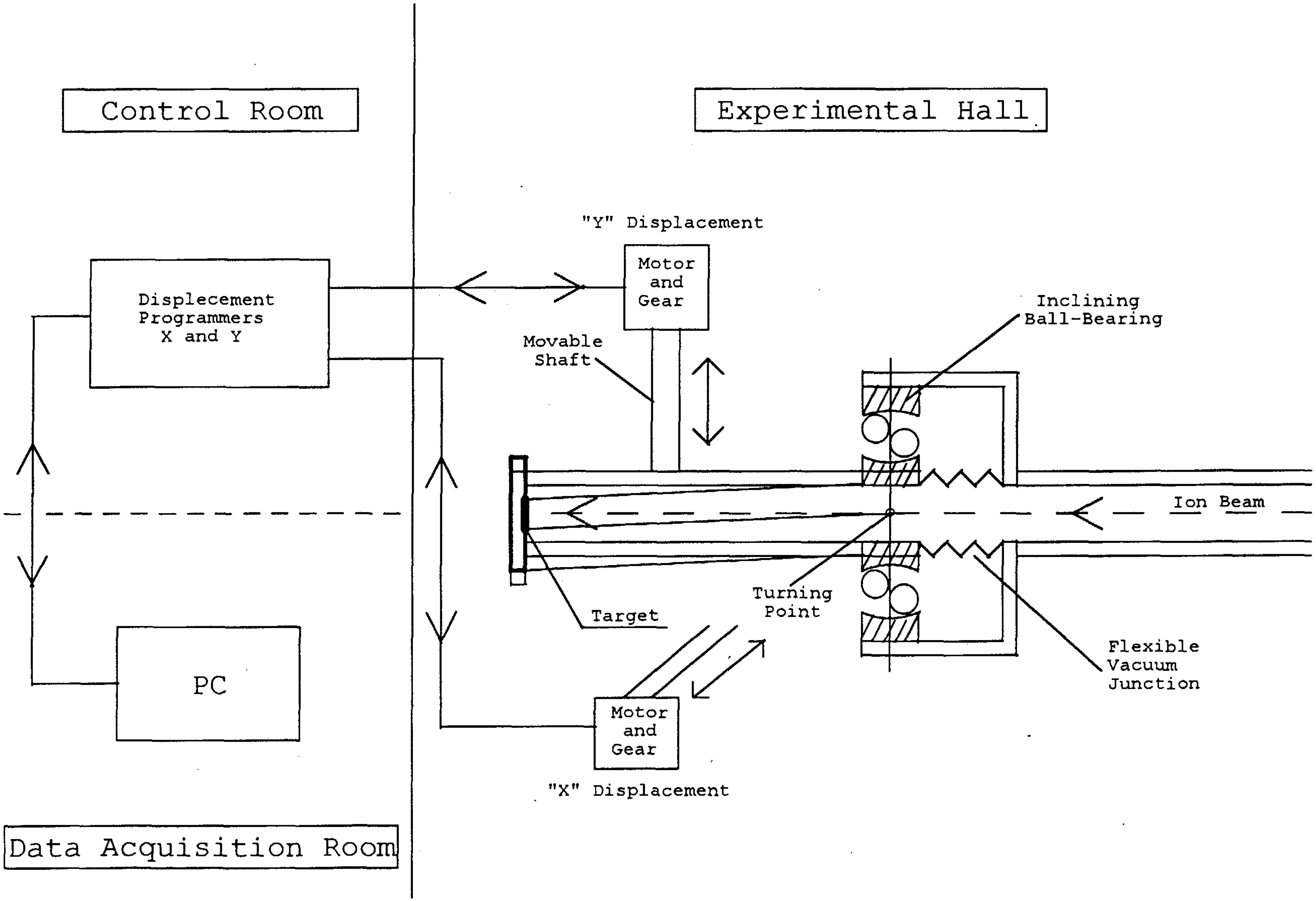

Fig.22.Movable target system.