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# ELECTRONIC INSTRUMENTS FOR RADIATION DETECTORS AND CONTROL SYSTEMS

by

R. BENOIT*, E. DE BLUST*, L. ISABELLA**, V. MANDL*, and G. MELANDRONE*

*Euratom
**CEI, Milan

1966

Joint Nuclear Research Center
Ispra Establishment - Italy

Chemistry Department
Nuclear Chemistry

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CONTENTS



## SUMMARY

Electronics instruments developed in the Nuclear Chemistry Laboratory of the Chemistry Department are described. They include low noise amplifiers for solid state detectors and gridded ionization chambers, fast electronics, power systems for the construction of lithium drifted semiconductors detectors and automatic controls for activation analysis and radiochemical separations.

## 1. INTRODUCTION

The aim of this paper is to describe briefly the electronic instruments which have been developed in the Nuclear Chemistry Laboratory during the last years. These instruments have been designed and built in connection with the research activities of the laboratory and are subdivided into the following branches:

Low noise amplifiers for semiconductor detectors and gridded ionization chambers.

Fast electronics for time measurements with photomultipliers and semiconductor detectors.

Power supplies and control systems for the construction of lithium drifted semiconductor detectors.

Automatic control for activation analysis and radiochemical separations.

The main electrical characteristics of each instrument developed are indicated and for some of these the circuit diagram is given. Their performance in physical measurements are specified and other possible fields of application are mentioned.

All the instruments described have been tested for long periods of operation and have shown good reliability.

## 2. LOW NOISE AMPLIFIERS FOR SEMICONDUCTOR DETECTORS AND GRIDDED IONIZATION CHAMBERS.

by R.Benoit and G.Melandrone

Semiconductor detectors and gridded ionization chambers are characterized by extremely good intrinsic energy resolution. Our effort was focused on developing electronic instruments which could take full advantage of these characteristics. For this purpose low noise charge and voltage sensitive preamplifiers, high gain linear ampli-

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fiers, and pile-up detectors were developed.

## 2.1 Low noise charge sensitive preamplifiers for semiconductor detectors.

Three types of charge sensitive preamplifiers for different types of semiconductor detectors have been built. They are:

a) preamplifiers for high capacitance and high leakage current detectors such as surface barrier types

b) general purpose preamplifiers for medium capacitance and medium leakage current, (small surface barrier and silicon lithium drifted detectors)

c) preamplifiers for low capacitance and low leakage current detectors, (germanium lithium drifted).

The main electrical characteristics of these three types of preamplifiers are given in Table 1.

TABLE 1

LOW NOISE PREAMPLIFIERS

| Preamplifier type | Input tube | Sensitivity in mV/MeV in Ge | Output rise time in nsec | Noise in KeV at f.w.h.m. at zero ext. capacitance | Power supply |
|---|---|---|---|---|---|
| a | E810 F | 11,7 | 30 | 3,5 | +270Vdc 20mA 6,3V ac |
| b | E810 F | 25 | 30 | 2,5 | +270Vdc 20mA 6,3V ac |
| c | EC1000 | 63,5 | 45 | 1,4 | +270Vdc 20mA 6,3V ac |

The schematic diagrams of the type a and b preamplifiers are shown in Fig. 1. The first tube has been selected and its operating conditions adjusted for low grid current and high transconductance so that a maximum signal to noise ratio is obtained with the type of detector desired. A semiautomatic curve tracer system has also been developed

for this purpose, and the tubes were aged for a period of 100 hours before being selected. The block diagram of this curve tracer system, with a typical plot of an EC 1000 tube, is shown in Fig. 2. The grid voltages, Vg, and the grid currents, Ig, for different plate voltages, Vp, are recorded on an X-Y plotter; first with the switch SW1 in pos. 1 and than in pos. 2. The grid current is proportional to the difference between plots 1 and 2, as shown by the dashed line.
A type c preamplifier circuit is shown in Fig. 3. In this circuit a cascode input configuration with bootstrap has been used in order to increase the signal to noise ratio and the dynamic input capacitance.
The performance of the type b and c preamplifiers is reported in Figs. 4 and 5. These show the resolution in KeV at FWHM (Full Width Half Maximum) for a germanium detector (W = 2.8 eV/electron-hole pair) vs. the shaping time constants. One RC differentation and one RC integration of equal time constant are considered and the curves are plotted using the external capacity as a parameter. This measurement was performed by injecting a known quantity of charge at the preamplifier input and using the root mean square voltmeter method described by Gillespie(1) and Fairstein(2). In the upper parts of the Figures are shown the energy resolution vs. the total input capacitance measured at the optimal time shaping constant.

The typical performance of these preamplifiers is shown in Fig. 6 . In the upper part is reported an $\bar{e}$ spectrum of $Cd^{109}$ performed with a b type preamplifier and a Silicon Lithium Drifted Detector cooled to -90°C. In the lower part is plotted an $\bar{e}$ spectrum of $Cs^{137}$ performed with a c type preamplifier and the same detector as above cooled to -175°C.

## 2.2 Voltage sensitive preamplifiers for gridded ionization chambers.

Different types of preamplifiers with a cascode input, followed by a bootstrapped cathode follower, in order to increase the open loop gain, have been designed and tested. The following tubes have been used at the input: E180F, E83F, 404A, E88CC.

These have been selected for their high transconductance to grid current ratio.

Typical characteristics of the triode connected E83F and of the E88CC are shown in figs. 7 and 8 . The operating points are selected at a grid bias corresponding to the maximum of the grid current curve, (where electronic current is negligible). The ratios of transconductance vs. grid current for the two tubes these conditions are the following:

| Vp in volts | gm in A/V/Ig in A | |
|---|---|---|
| | E83F | E88CC |
| 50 | | $3,6 \times 10^9$ |
| 60 | | $1,96 \times 10^9$ |
| 70 | $0,544 \times 10^9$ | $1,17 \times 10^9$ |
| 80 | $0,736 \times 10^9$ | $1,03 \times 10^9$ |
| 90 | $0,738 \times 10^9$ | |

The theoretical signal to noise ratio can than be calculated (taking into account the input capacitance of the tube), and the tube itself can be selected.

The best results were obtained with the preamplifier shown in fig. 9 using an E88CC at the input. This tube was placed inside the ionization chamber in order to reduce the stray capacitances.

A typical alpha spectrum obtained with this preamplifier, using the best E88CC selected among twenty tested tubes and with RC pulse shaping, constants of $\tau$ = RC int = RC diff = 2us, is shown in Fig. 10.

Fig. 11 shows the FWHM vs. shaping time constants f ($\tau$) of this preamplifier obtained by injecting a known charge from a pulse generator. The external capacitance was 10 pF.

## 2.3 High gain linear amplifiers.

High gain amplifiers composed of a voltage sensitive input loop with independently variable RC integrating and differentiating time constants, and one main and one biased post amplifier have been built. Two internal independent voltage supplies; one for biasing the semiconductor detectors and the other for operating an external preamplifier, are also provided.

The gain is stabilized by internal feedback, and the principal characteristics of the amplifier and its different parts are reported in Table 2. These amplifiers are a modified version of the ORTEC Model 201 low noise amplifier in which a set of variable RC time constants and an input amplifying loop were added.

### 2.4 Pile-up detection circuit.

A pile-up detection circuit which rejects two or more superimposed on closely spaced events in a time range from 5 to 500 usec was developed and is described in reference (3). The circuit also provides the possibility of cancelling two or more pulses superimposed on their front edges and is used in connection with linear amplifiers described in Sec. 2.3. The schematic diagram is illustrated in Fig. 12.

## 3. FAST ELECTRONICS FOR TIME MEASUREMENTS WITH PHOTOMULTIPLIERS AND SEMICONDUCTOR DETECTORS.

by L.Isabella * and V.Mandl

A fast counting system in the time domain of nanoseconds has been developed. The input cricuits were designed to work either with fast photomultipliers such as types 56AVP and XP 1020 (manufactured by Phillips) or with semiconductor detectors. The parts were assembled in shielded modular plug-in units and are operated from a common power-supply of -20, -10 and +10 Volts.
Transistors and Germanium tunnel diodes were used, and the input and output impedance were kept at 50 ohm. Most signals have negative polarity, 0.5 V output amplitude, across a 50 ohm load. Coaxial 50 ohm transformers have also been built and are used to invert the signal polarities, when required.

The instruments which have been developed, and their main characteristics, are listed in Table 3. This equipment, up to now, has been used for time resolution measurements on fast photomultipliers (principally XP 1020) and for alpha-gamma and alpha-electron coincidences. The results obtained in the field of time resolution measurements with photomultipliers are reported in references(10) and (11). The half-life determination of the 73.6 KeV level of $Np^{239}$, performed by the delayed coicncidence technique, is described in reference(4). In this measurement a photomultiplier has been used for detecting the gammas and a surface barrier semiconductor detector for the alphas.

* CEI, Milano

TABLE 2 HIGH GAIN LINEAR AMPLIFIER

| Part | Input polarity | Voltage gain | Rise time | Time constants | Output polarity | Dynamic range | Integral linearity |
|---|---|---|---|---|---|---|---|
| Input loop (voltage sensitive) | positive or negative | 50 or 300 | 0.1-0.15 usec | 0.22, 0.33, 0.47, 0.56, 0.68, 0.82, 1.2, 1.4, 1.6usec | output is internally connected to the main ampl. | 0 -15V | $\pm$0.2% of 95% of the full range output |
| Main amplifier | positive | 25, 50, 100 or 200 | 0.3usec | no | positive | 0-100V | $\pm$0.25% of the maximum output |
| Post amplifier (0-100V threshold) | positive | 2, 4, 8 or 16 | | no | positive | 0-100V | $\pm$0.5% of 80% of the full range output |

Alpha-electron and alpha-gamma coincidence measurements of $Bi^{212}$ with Lithium Drifted Semiconductors detectors are still in progress. Refering to Table 3 both types of amplifiers were developed for semiconductor detectors since the gain of recent P.M.'s is sufficiently high so that no further amplification is necessary.

The discriminator, in its most recent version, uses a Ge 1N3716 tunnel diode with a peak current of 4.7 mA, and has a time walk of about 2 nsec for input signal amplitudes from 100 to 500 mV. XP 1020 P.M. output pulses were used for this measurement and the test conditions are illustrated in Fig. 25. A hydrogen discharge lamp(4) was used to generate short light pulses, of about 1.5 nsec f.w.h.m., and a system of "polaroid" lenses was used to vary the light intensity over a central area of 1" diameter on the photocathode. This collimation was used to simulate the experimental conditions of the PM with a 1"x1" scintillator crystal and to avoid transit time jitter from the center to the border of the photocathode. The PM output controls the STOP input of the Time to Pulse Converter (TPC) which is started on each flash of the hydrogen lamp. These START signals are picked off by means of a capacitive antenna which is sensitive to the current through the lamp. The output of the TPC is analyzed with a 256 channel pulse height analyzer.

Two different types of TPC have been developed. The first one is a START-STOP type, i.e. two inputs with distinct characteristics are used and the signal at the START input must always precede the one at the STOP input. This converter also has a gate which can control the START signal, and is triggered with an external pulse which normally comes from a coincidence.

The second converter is of the pulse overlap type and the two inputs are symmetrical. In this circuit the coincidence is obtained from the same signals which enter the converter and a simpler circuit configuration is achieved with about the same performances as in the first type concerning the measured time internal, overall linearity, and stability.

Other instruments do not require special comment.

TABLE 3 FAST ELECTRONIC CIRCUITS

| Type and model | Main characteristics | Remarks |
|---|---|---|
| Voltage divider for 56AVP P.M. | Bleeder current 3 mA, fast output from anode and slow output from dynode N°12 | see Fig. 13 |
| Voltage divider for XP1020 P.M. | Bleeder current of 2 mA for the first 10 dynodes and 10 mA for the last three. Coaxial anode output (50 ohms) and slow output from dynode N° 10. | see Fig. 14 |
| Model 1 Preamplifier | positive or negative input polarity, 10 ohm input impedance, voltage gain of about 70, output rise time 2 nsec, output polarity inverted with respect to the input, max. out. 0.7 Volts. | see Fig. 15 and reference (4). |
| Model 10 Preamplifier | input polarity negative, 50 ohm input impedance, voltage gain of 10, output rise time 1 nsec, output polarity negative, max. output 1 Volt. | modified version of the preamp. described in reference (5), see Fig. 16 |
| Fast discriminator D1 | Minimum input threshold 1 mA across 50 ohms, signal length 2 nsec at f.w.h.m. Output rise time 3 nsec, duration 100 nsec standard, with possibility of inserting external delay lines for shorter lengths. Recovery time 150 nsec. | see Fig.17 and reference (4). |
| Double coincidence and Fan-out | Coincidence: resolving time 15 nsec, output signal 2V amplitude, 200 nsec length. Fan-out: two identical circuits with two independent outputs; each output is about the same as the input. | see Fig.18, two symmetrical output channels, not indicated in the figure, are provided for each input. |

TABLE 3 Continued

| Type and model | Main characteristics | Remarks |
|---|---|---|
| Double pulse stretcher S1 | Accepts and delivers positive and negative signals, minimum input signal duration 1 nsec at f.w.h.m. gives 2 nsec output. Two identical circuits on same plug unit. | based on the circuit described in reference 6 see Fig. 19. |
| Double linear Gate G1 | Gate normally closed, accepts negative input signals in 20-500 mV range; pedestal 1 mV Control signal positive 0.5V amplitude, must bracket and precede the input by 10 nsec. | based on the circuit described in reference 7, see Fig. 20 |
| Time to pulse height converter C1 | Start-Stop type, input negative, output either polarity. Time range: 50 nsec standard with possibility of obtaining longer ranges. Time resolution: 20 psec short period, 50 psec long period. Acceptance of the input signal can be controlled by an internal gate. Internal reset is provided.<br>Output can be stretched. | see Fig.21 and reference (4). |
| Time to pulse height converter C10 | Overlap type - output positive.<br>Time range: 100 nsec when operated from D1 type discriminators.<br>Time resolution: 30 psec short period; 100 psec long period. | see Fig. 22 |
| Fast pile-up detector | Accepts signals from D1 discriminators and produces an output for each pair of input signals separated by 15 nsec to 1.5 nsec. Two identical units are built in the same plug and internally connected to an OR circuit. | modified version of the circuit described in reference (8), see Fig.23. |
| High input impedance cathode follower | Tube EC 1000 is used, output rise time 1 nsec, output impedance 70 ohms. | circuit described in reference 9; see Fig. 24. |

## 4. POWER SUPPLIES AND CONTROL SYSTEMS FOR THE CONSTRUCTION OF LITHIUM DRIFTED SEMICONDUCTOR DETECTORS.

by E.De Blust

Three different power supplies for construction of silicon and germanium lithium drifted semiconductor detectors have been built. Two of these have a dc output and the third is pulsed. The outstanding characteristics are the following:

type A maximum dc output 500V 15W

type B maximum dc output 1000V 250W

type C maximum pulsed output 600V 90W
frequency range from 1 to 1000 cycles/sec.

The type A power supply has been developed in collaboration with the Research Reactor Service of the Reactor Physics Department and is described in reference (12). The block diagram of the part which has been built in this laboratory is shown in Fig. 26. The control voltage of the series control element is obtained by monitoring the current and the voltage across the semiconductor diode. These two variables are measured with logarithme sensitive circuits and the power delivered to the diode, during the drifting process, is obtained by summing the two logarithms. The instrument is based on a similar type described in reference (13). The type B power supply has been developed for construction of large and thick lithium drifted detectors. The block diagram of the circuit is reported in Fig.27. The output power is controlled by varying the conduction angle of two Silicon Controlled Rectifiers (S.C.R.) which are placed in the primary winding of the transformer. These S.C.R. are triggered from a blocking oscillator with a repetition frequency of 10 Kc/sec. The blocking oscillator is driven from a generator which delivers output pulses from 0 to 9 msec width, syncronized from 220 Va.c. The pulse width control is performed manually through an adjustable current feedback from the power output. This feedback acts as a security control during the drifting process and prevents any increase by more than 5% of the rated value of the output current.
The type C pulsed power supply has been built following the schematic of reference (14), and its block diagramm is reported in Fig. 28. The capacitor C is charged through an S.C.R. and a series inductance to an energy of 0.09 joule, and discharges into the semiconductor diode immersed in a boiling liquid. The output power is limited by a current interlock which controls the firing frequency of the S.C.R.

A separate circuit with control system is used for the immersion heater.

The semiconductor detectors constructed with these power supplier and their performance are described in references (15) and (16).

## 5. AUTOMATIC CONTROLS FOR THE ACTIVATION ANALYSIS AND RADIOCHEMICAL SEPARATIONS.

by G.Melandrone

In this field the following equipement has been built:

a) a programmer for activation analysis by means of a 14 MeV neutron generator

b) sample changers

c) automatic equipment for radiochemical separations

The programmer has been developed and is used in connection with a 14 MeV neutron generator manufactured by IMICAM (Milano) and installed in this laboratory. It allows remote on-off control of the neutron flux, controls its focusing and gives the possibility of programming and recording all data of interest over a set of operations.

The block diagram of the equipment is reported in Fig. 29. The program unit is triggered by the sample being irradiated, which switches an the neutron flux on arrival at the front of the generator and switches it off after withdrawal.

The sequence control counts and registers the following:

a) the integrated neutron flux

b) the transit time of the sample from the generator to the gamma counter, and

c) the sample activity at preset times (this operation is continuously repeated so that half life measurements can be performed)

The gas inlet control operates the pin-valve of the deuterium bottle thus allowing better control of the plasma. The focusing meter control the amount of defocussed deuterons, and keeps them to a minimum thus improving the neutron yield and ameliorating the neutron geometry.

A detailed description of this control system is given in reference (17). It was developed for routine analysis of oxygen in terphenils.

The sample changer and its control system are shown in the block diagram of Fig. 30. It may be operated either manually or from an external control unit which has been built and is connected to the pulse height analyzer and to a timer.

The automatic equipment for radiochemical separation can perform different chemical reactions.Itis composed of modular units which can be assembled and interconected in different ways, depending on the chemical separation desired. The equipment developed is composed of two types of modular units: 1) the pump with its program unit; 2) the fraction collector and series-parallel deviator.

The pump, which consists of a 30 ml glass syringe, is operated by a synchronons motor which drives the piston, and is controled by a unit assembled on a printed circuit card placed on the upper part of the pumping unit itself.

The fraction collector is composed of a chromatographic column and a fraction collector. A three-way glass stopcock, driven by a micromator, can direct the column effluent to the collecting bottle or to another chromatographic column according to the program selected on the printed circuit card of the pumping unit.

The different ways of operation and the results obtained are described in reference (18).

More sophysticated automatic equipment has recently been developed in collaboration with the S.R.R. (Research Reactors Service) and consists of one programming and one operating unit. The program unit supplier a 24 Vdc voltage for operating up to sixteen various elements such as pumps, valves, heaters, fans, etc., at different preset time intervals and sequences. The program patter is engraved on a printed circuit card. A complete chemical process is contained on such a card.

The operating unit contains the pumps and valves which are used to start, regulate and stop the various reagents along the analytical line, and to control the line itself. The pump is of a peristalic type and is operated by a stepping motor driven by a 24 V variable frequency generator contained in the program unit. The speed of the pump can be varied in five steps between 0.2 and 4 ml/min by changing the control frequency on the programming card.

A detailed description of the equipment and its applications is given in reference (19).

## 6. ACKNOWLEDGEMENTS

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## 7 - CAPTIONS OF THE FIGURES

Fig. 1 Schematic diagram of the charge sensitive preamplifier type a and b.

Fig. 2 Block diagram of the semiautomatic curve tracer system and a typical plot of a EC1000 tube.

Fig. 3 Schematic diagram of the charge sensitive preamplifier type c.

Fig. 4 Resolution at f.w.h.m. vs. shaping time constant for type b preamplifier.

Fig. 5 Resolution at f.w.h.m. vs. shaping time constants for type c preamplifier.

Fig. 6 Typical performance of the charge sensitive preamplifiers upper part: $Cd^{109}$ $e^-$ spectra performed with type b preamplifier lower part $Cs^{137}$ $e^-$ spectra performed with type c preamplifier.

Fig. 7 Typical Ip vs. Vg and Ig vs. Vg characteristic of E83F tube (triode connected).

Fig. 8 Typical Ip vs. Vg and Ig vs. Vg characteristic of E88CC tube.

Fig. 9 Schematic diagram of a voltage sensitive preamplifier for gridded ionization chambers.

Fig.10 Alpha spectra of $Th^{230}$, voltage sensitive preamplifier of Fig.9 was used for this measurement.

Fig.11 FWHM vs. equal integrating and differetiantiating time constants.

Fig.12 Schematic diagram of the pile-up detector.

Fig.13 Voltage divider for 56AVP photomultiplier.

Fig.14 Voltage divider for XP 1020 photomultiplier.

Fig.15 Model 1 Preamplifier.

Fig.16 Model 10 Preamplifier.

Fig.17 Fast discriminator D1.

Fig.18 Double coincidence and fan-out.

Fig.19 Double pulse stretcher.

Fig.20 Linear Gate.

Fig.21 Time to pulse height converter C1.

Fig.22 Time to pulse height converter C10.

Fig. 23 Fast pile-up detector.

Fig. 24 High input impedance cathode follower.

Fig. 25 Experimental arrangement for testing the discriminator slewing characteristics.

Fig. 26 Block diagram of the type A constant dc power supply for construction of the lithium drifted semiconductor detectors.

Fig. 27 Block diagram of the type B constant dc power supply for construction of lithium drifted semiconductor detectors.

Fig. 28 Block diagram of the type C pulsed power supply for construction of lithium drifted semiconductor detectors.

Fig. 29 Block diagramm of the programmer for activation analysis by means of the IMICAM neutron generator.

Fig. 30 Block diagram of the sample changer and control system.

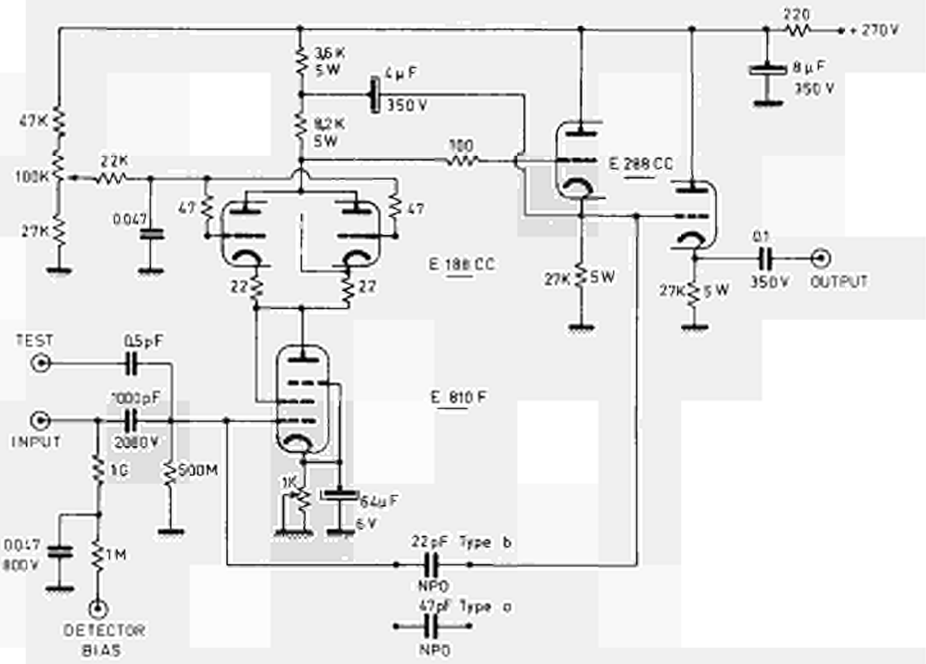
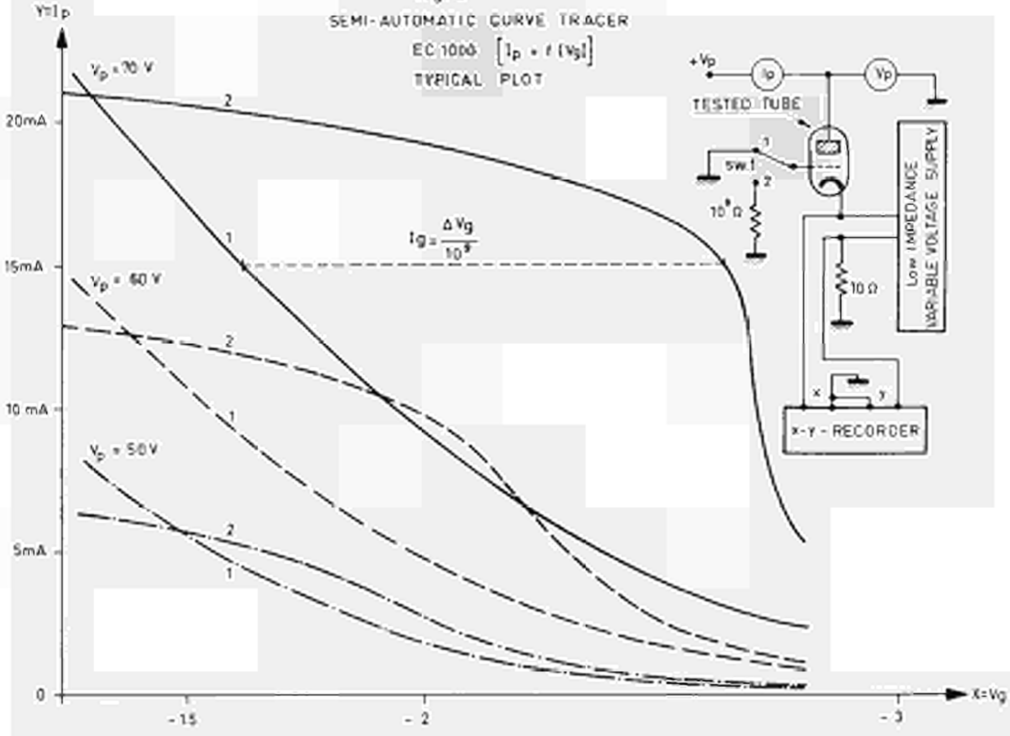



Fig 1 CHARGE SENSITIVE LOW NOISE PRE-AMPLIFIER (E 810 F) TYPE a AND b

Fig. 2
SEMI-AUTOMATIC CURVE TRACER
EC 1000 [$I_p = f(V_g)$]
TYPICAL PLOT



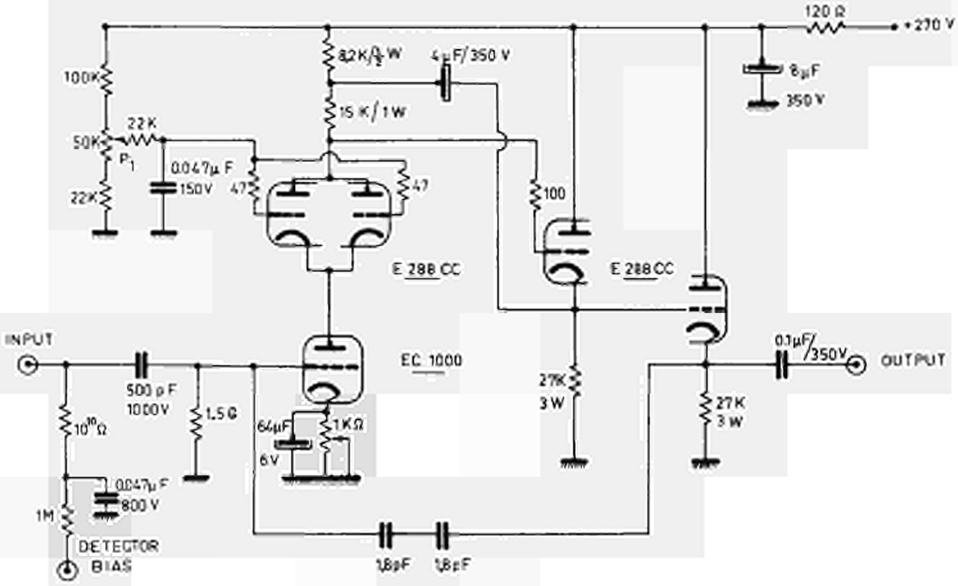



Fig. 3 CHARGE SENSITIVE LOW NOISE PRE-AMPLIFIER (EC1000) TYPE C

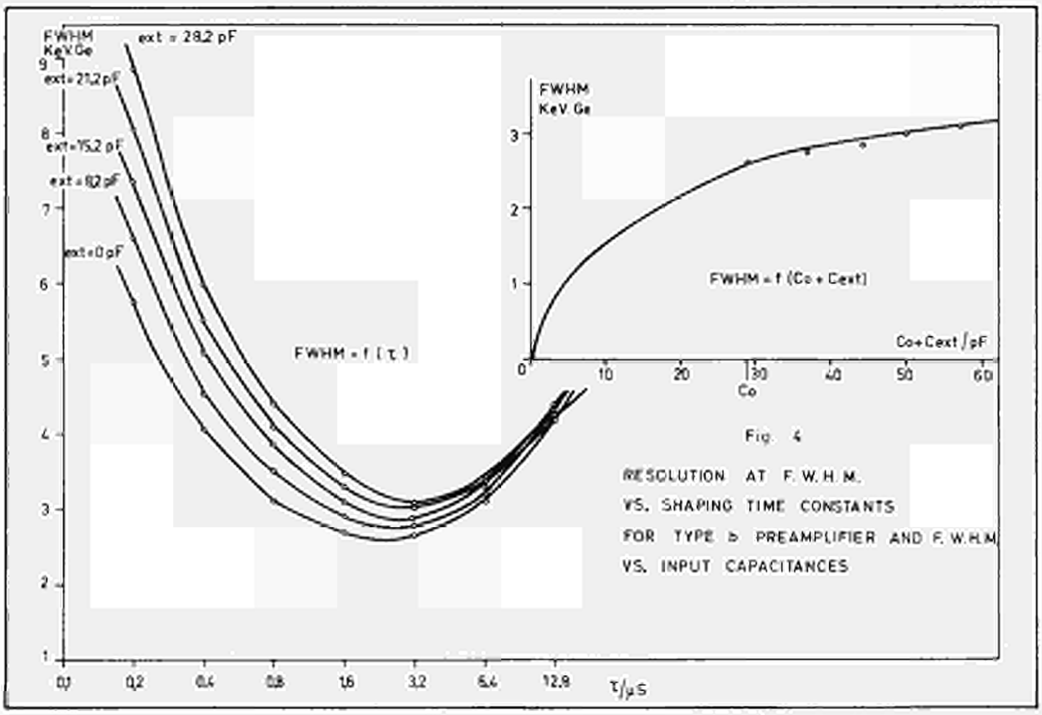



Fig. 4

RESOLUTION AT F. W. H. M.
VS. SHAPING TIME CONSTANTS
FOR TYPE b PREAMPLIFIER AND F. W. H. M.
VS. INPUT CAPACITANCES

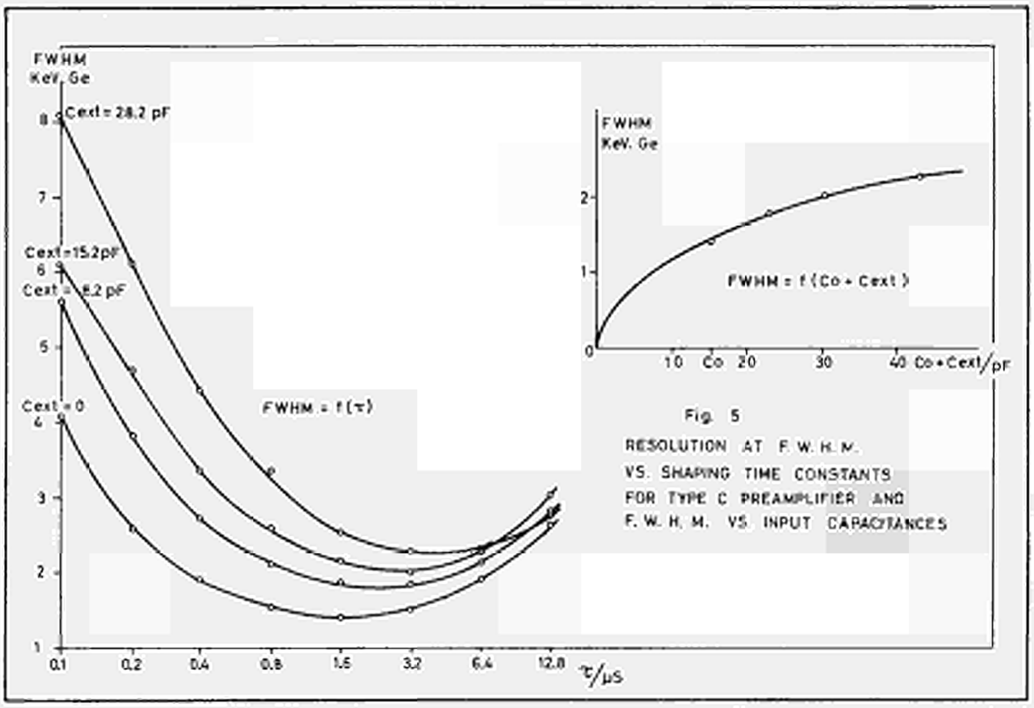



Fig. 5

RESOLUTION AT F. W. H. M.
VS. SHAPING TIME CONSTANTS
FOR TYPE C PREAMPLIFIER AND
F. W. H. M. VS. INPUT CAPACITANCES

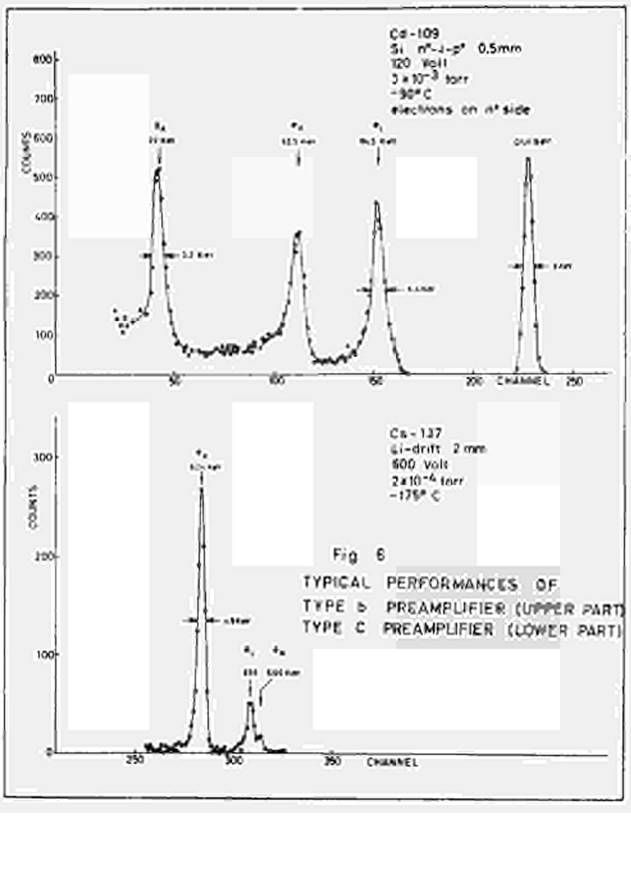



Fig. 6

TYPICAL PERFORMANCES OF
TYPE b. PREAMPLIFIER (UPPER PART)
TYPE C PREAMPLIFIER (LOWER PART)

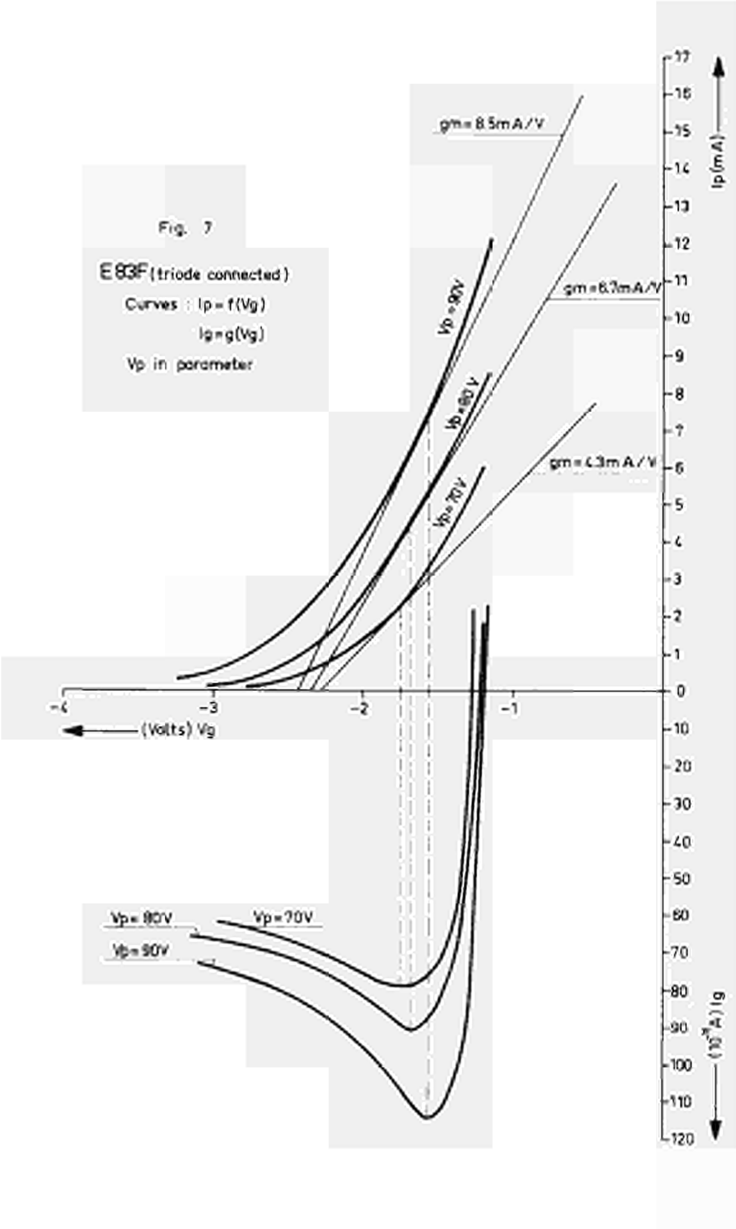


Fig. 7
E83F (triode connected)
Curves : Ip = f(Vg)
Ig = g(Vg)
Vp in parameter
gm = 8.5mA/V
gm = 6.7mA/V
gm = 4.3mA/V
Vp = 90V
Vp = 80V
Vp = 70V
Ip (mA)
(Volts) Vg
$(10^{-9}A)$ Ig

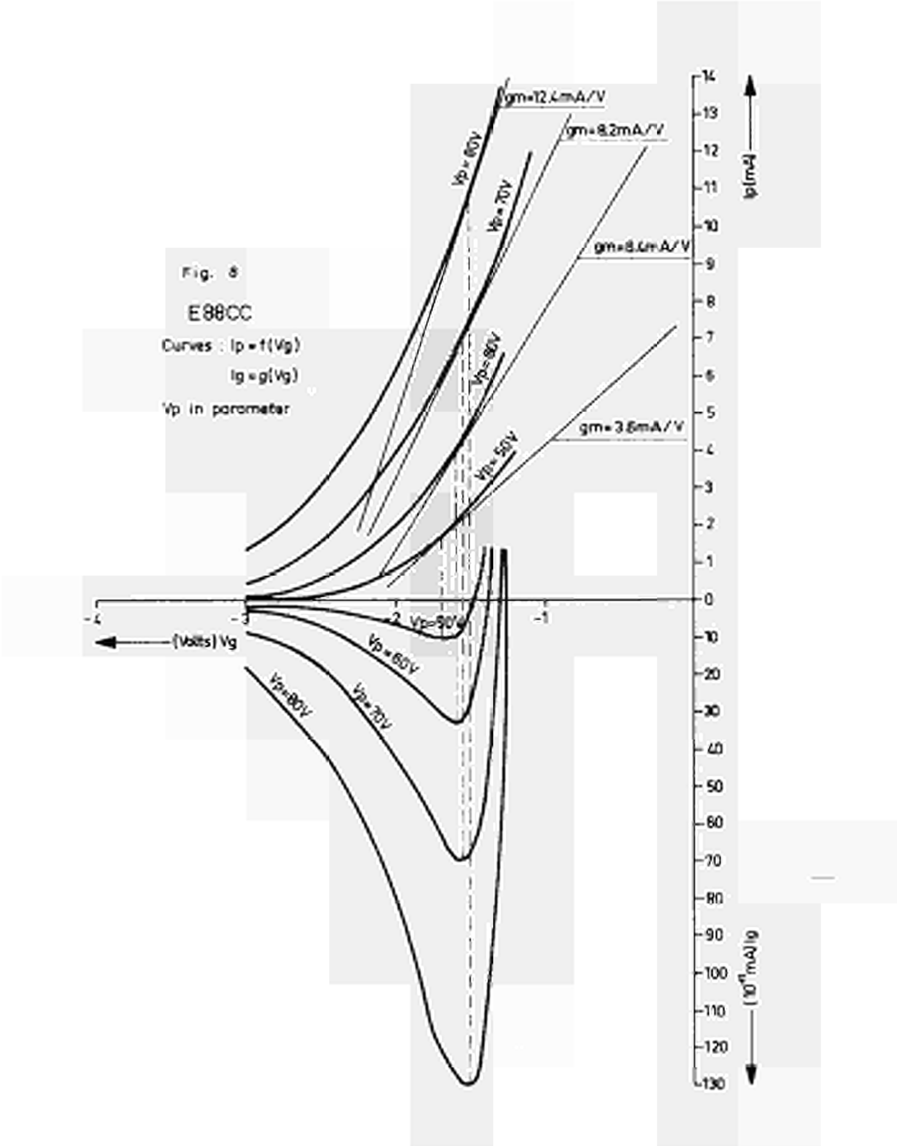
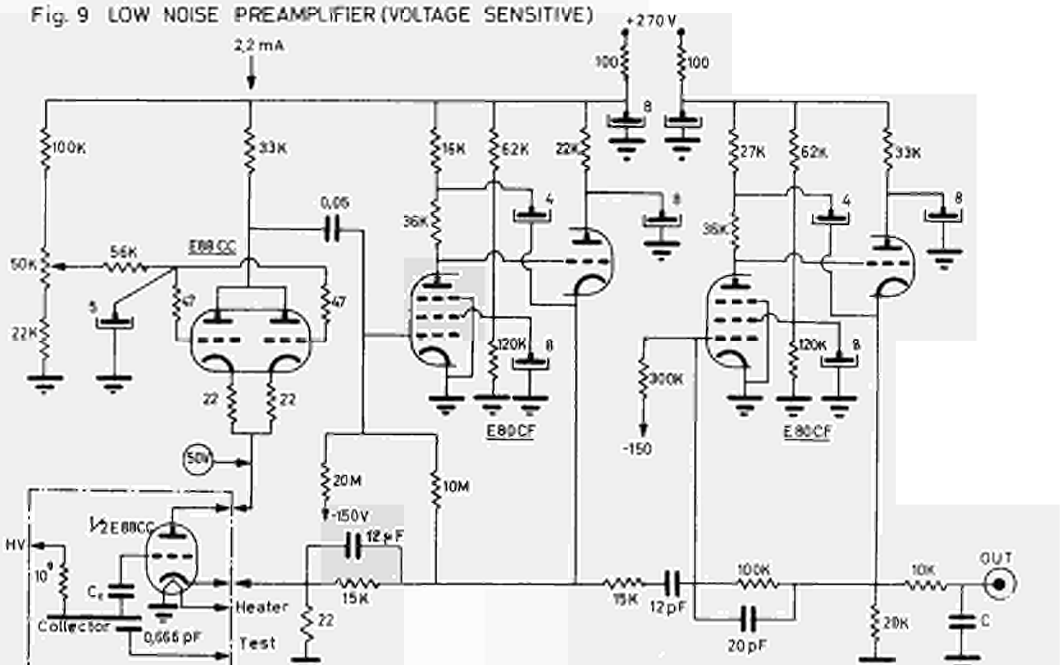


Fig. 8
E88CC
Curves : Ip = f(Vg)
Ig = g(Vg)
Vp in parameter
gm = 12.4mA/V
gm = 8.2mA/V
gm = 6.6mA/V
gm = 3.6mA/V
Vp = 80V
Vp = 70V
Vp = 60V
Vp = 50V
Ip (mA)
(Volts) Vg
$(10^{-9}mA)$ Ig

Fig. 9 LOW NOISE PREAMPLIFIER (VOLTAGE SENSITIVE)




(The capacitances are expressed in $\mu F$)

C= 200 pF - capacitance of the connected cable $C_c$ = 500pF 20000V

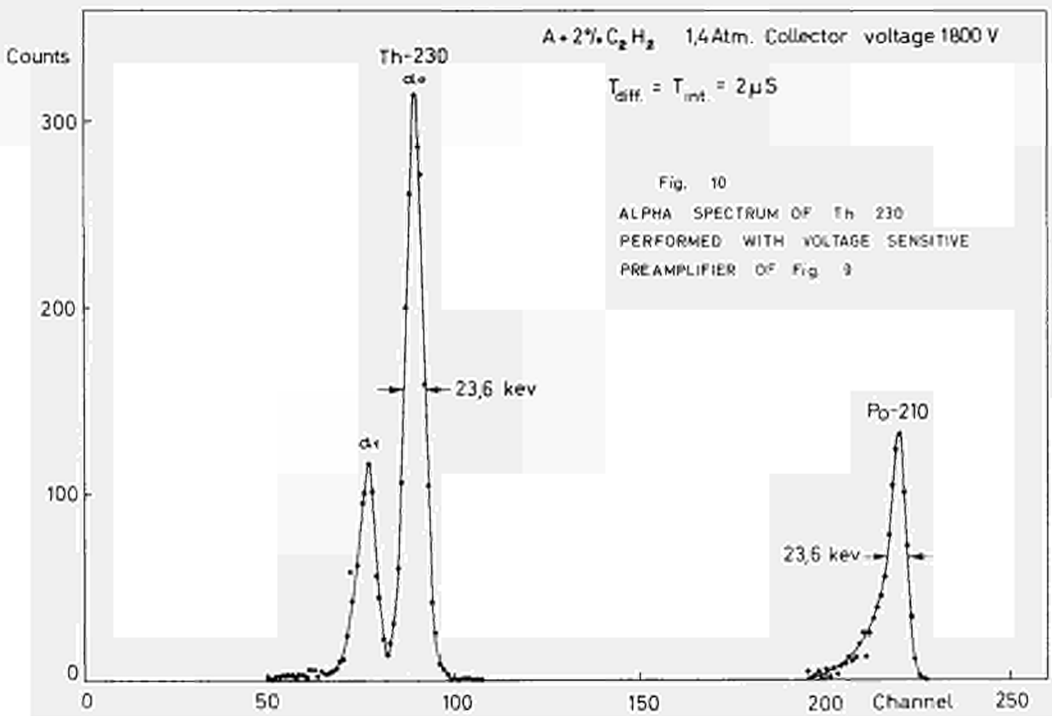



Fig. 10
ALPHA SPECTRUM OF Th 230 PERFORMED WITH VOLTAGE SENSITIVE PREAMPLIFIER OF Fig. 9

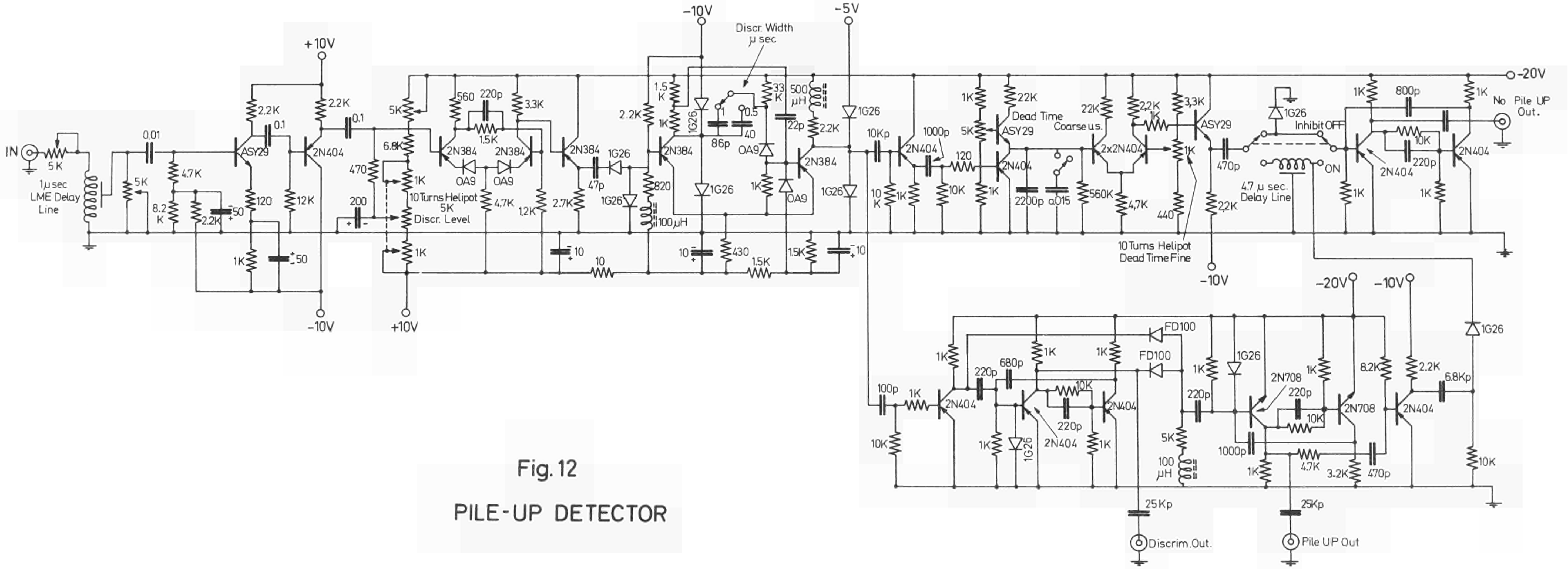


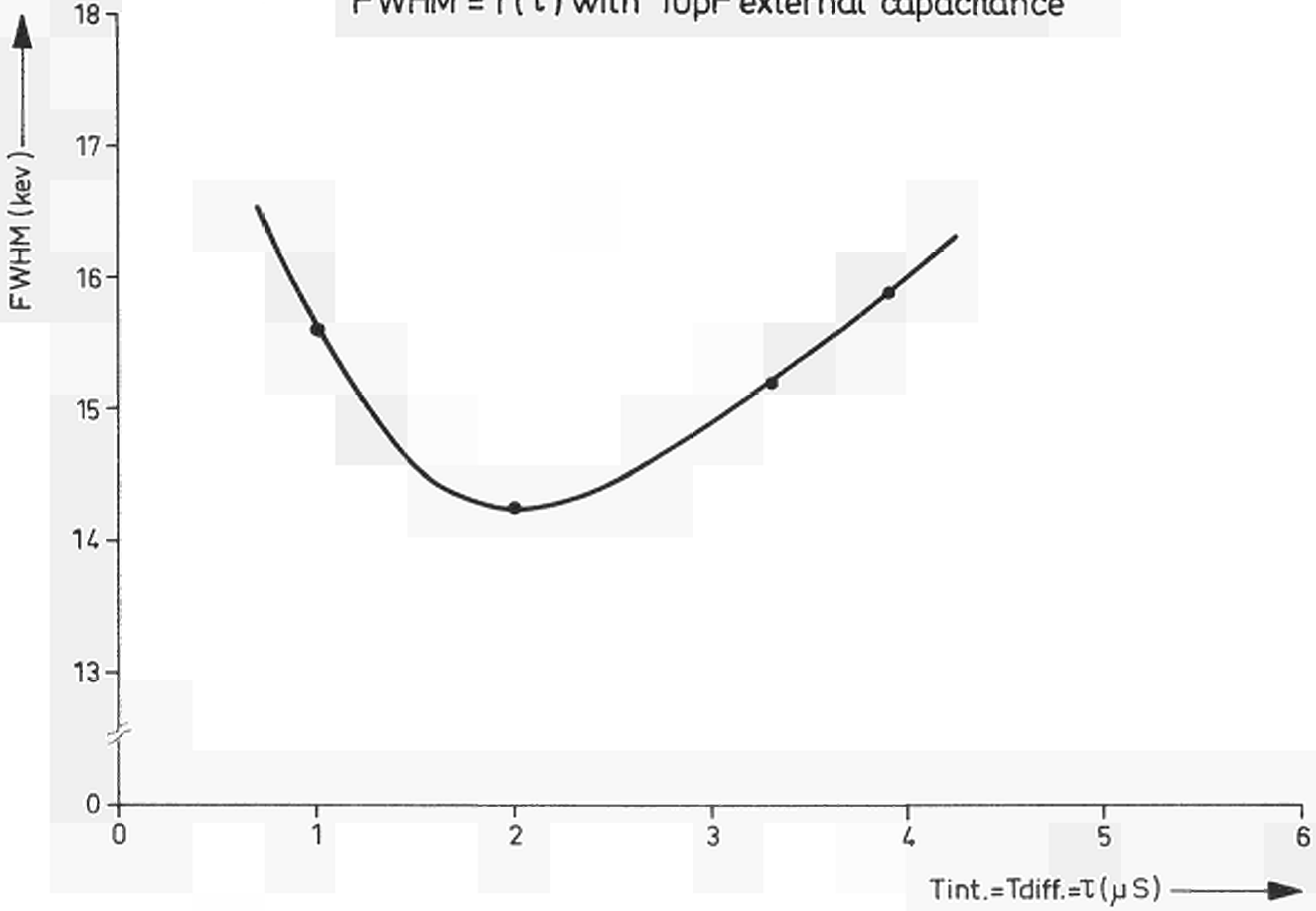

Fig. 12

PILE-UP DETECTOR

Fig. 11

LOW NOISE PREAMPLIFIER FOR IONIZATION CHAMBER

FWHM = f (τ) with 10pF external capacitance



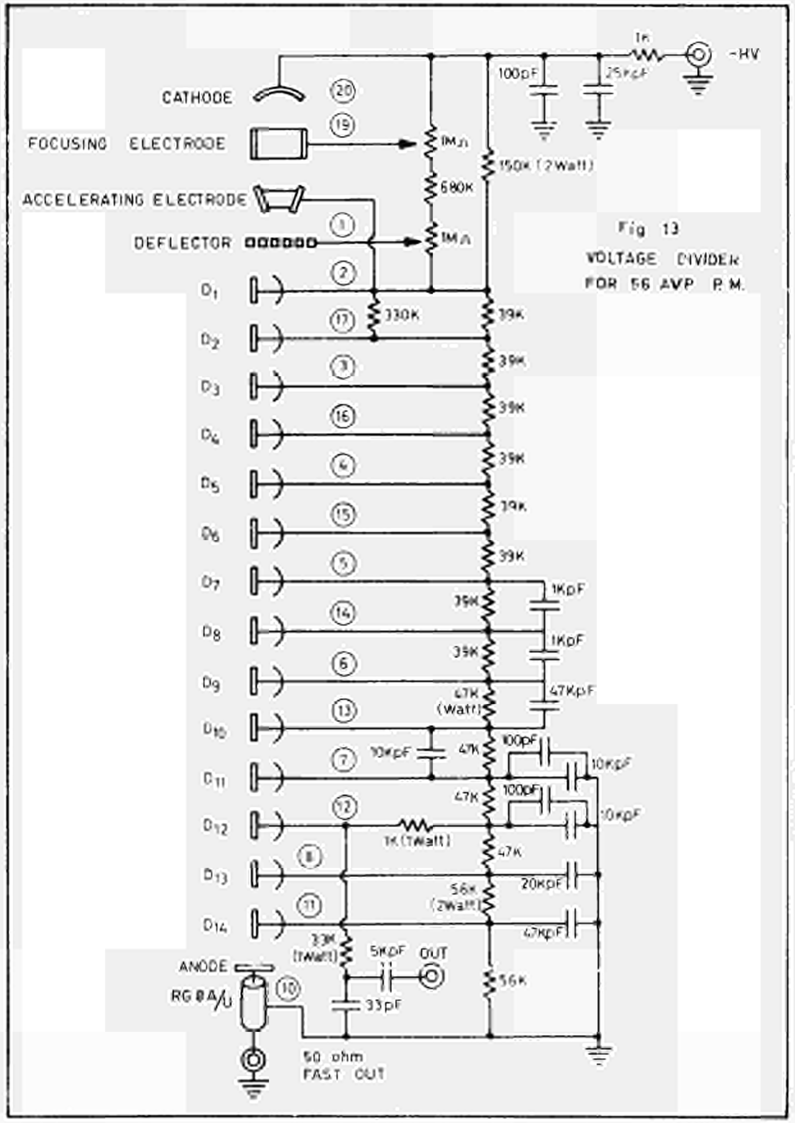



Fig 13

VOLTAGE DIVIDER FOR 56 AVP P.M.

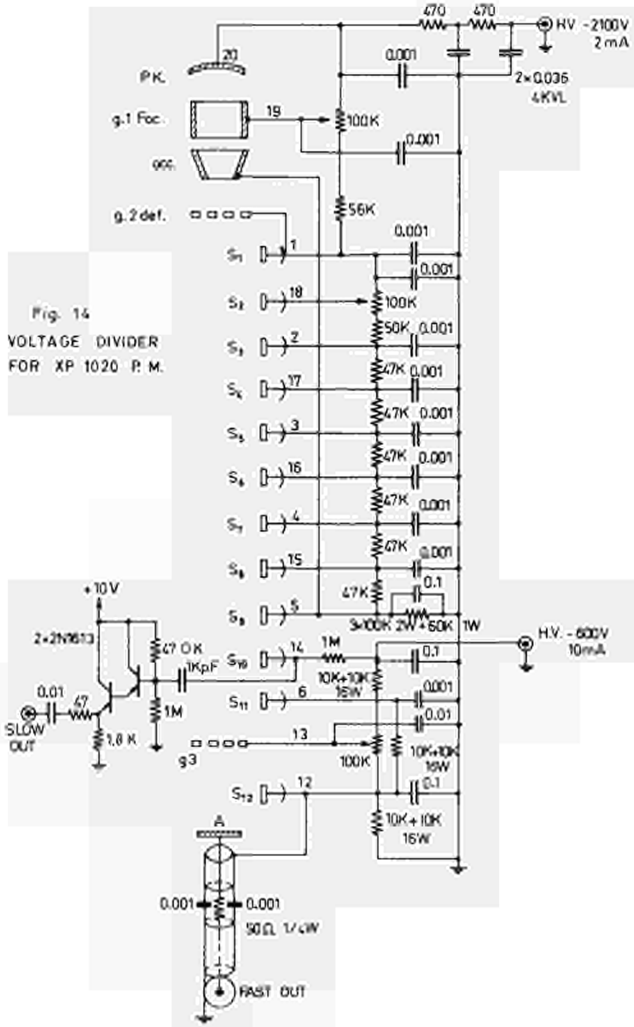
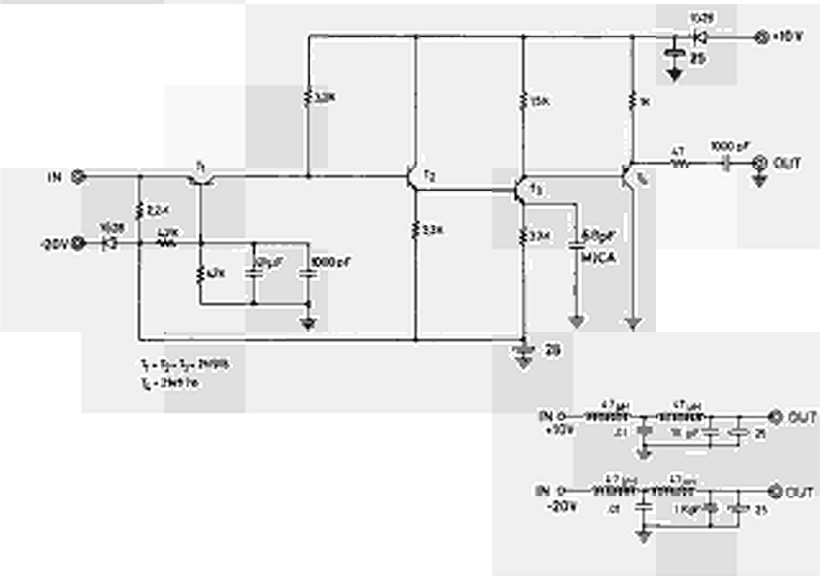



Fig. 14

VOLTAGE DIVIDER FOR XP 1020 P. M.

Fig. 15

MODEL 1 PREAMPLIFIER



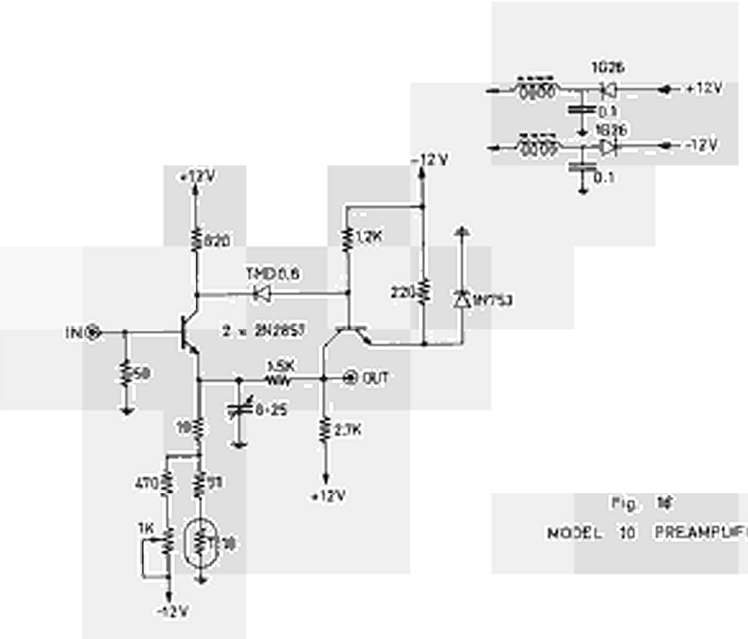
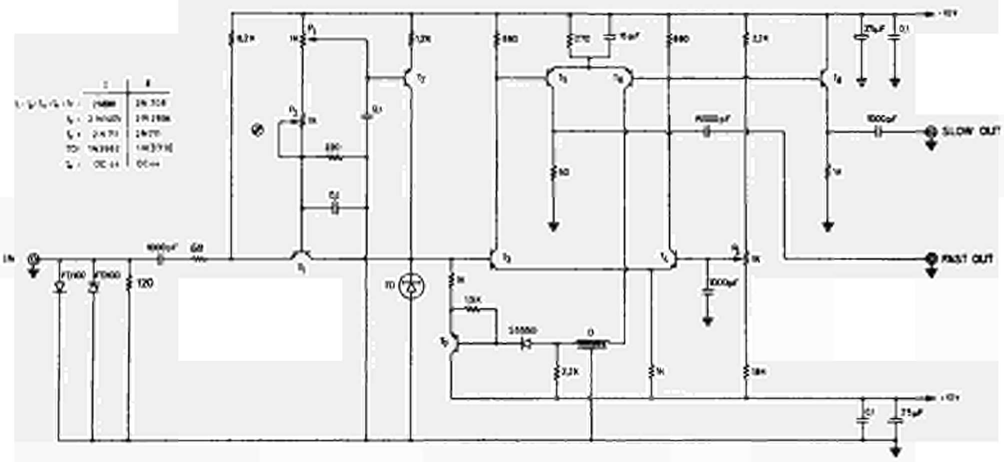




Fig. 16

MODEL 10 PREAMPLIFIER

Fig 17

FAST DISCRIMINATOR D 1



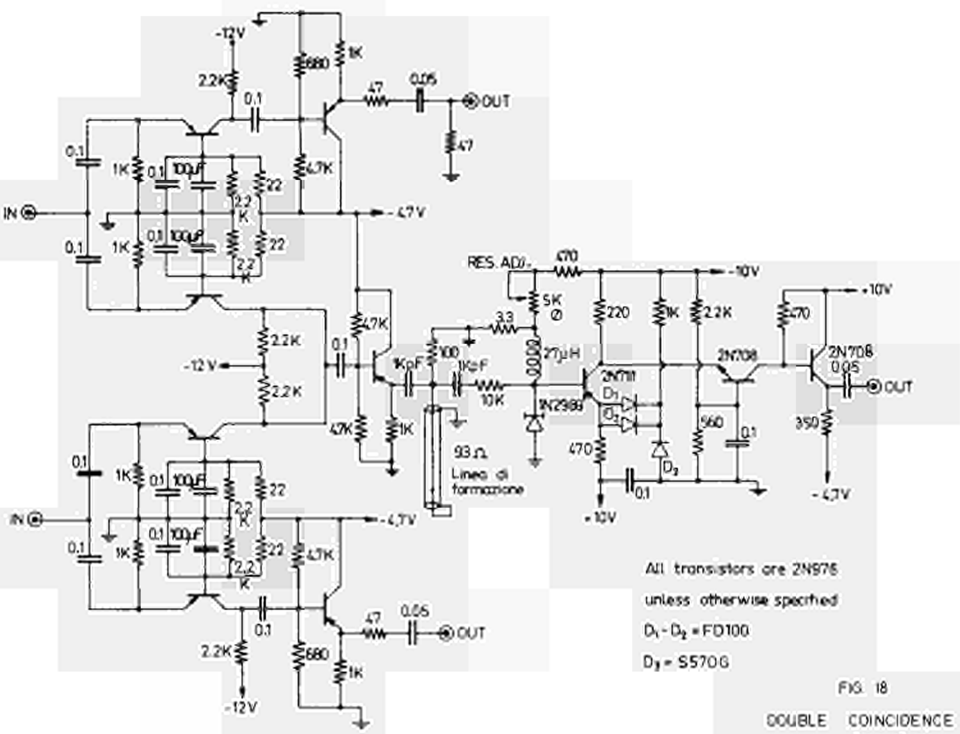
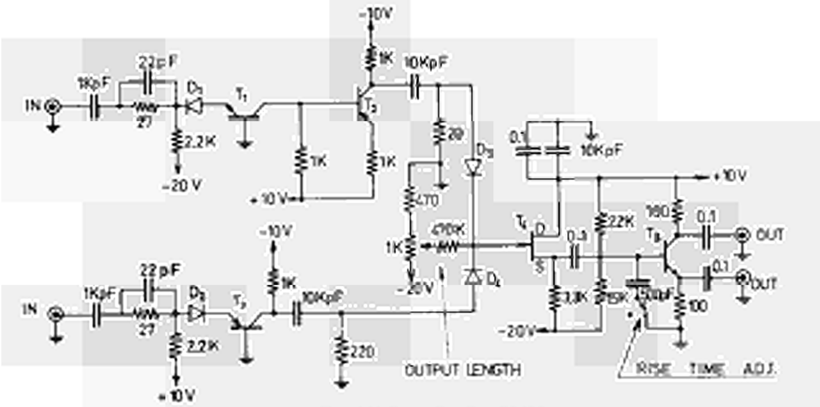




FIG. 18

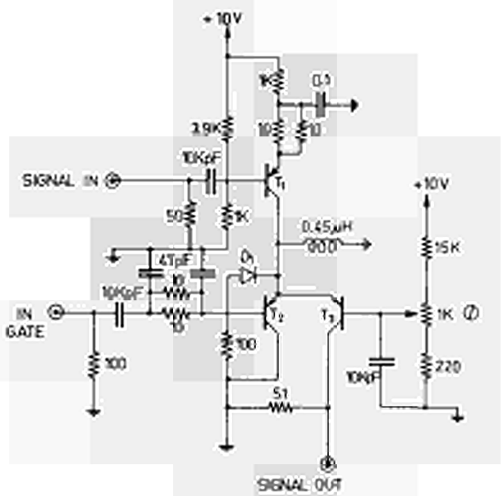
DOUBLE COINCIDENCE AND FAN - OUT




$T_1$ - 2N917
$T_2$-$T_3$-2N976
$T_4$ - TX833
$T_5$ - 2N708

$D_1$ - $D_2$ - FD100
$D_3$ - $D_4$ - S555G

FIG. 19
PULSE STRETCHER




$T_1$-$T_2$-$T_3$ = 2N976
$D_1$ = S555G

FIG. 20
LINEAR GATE

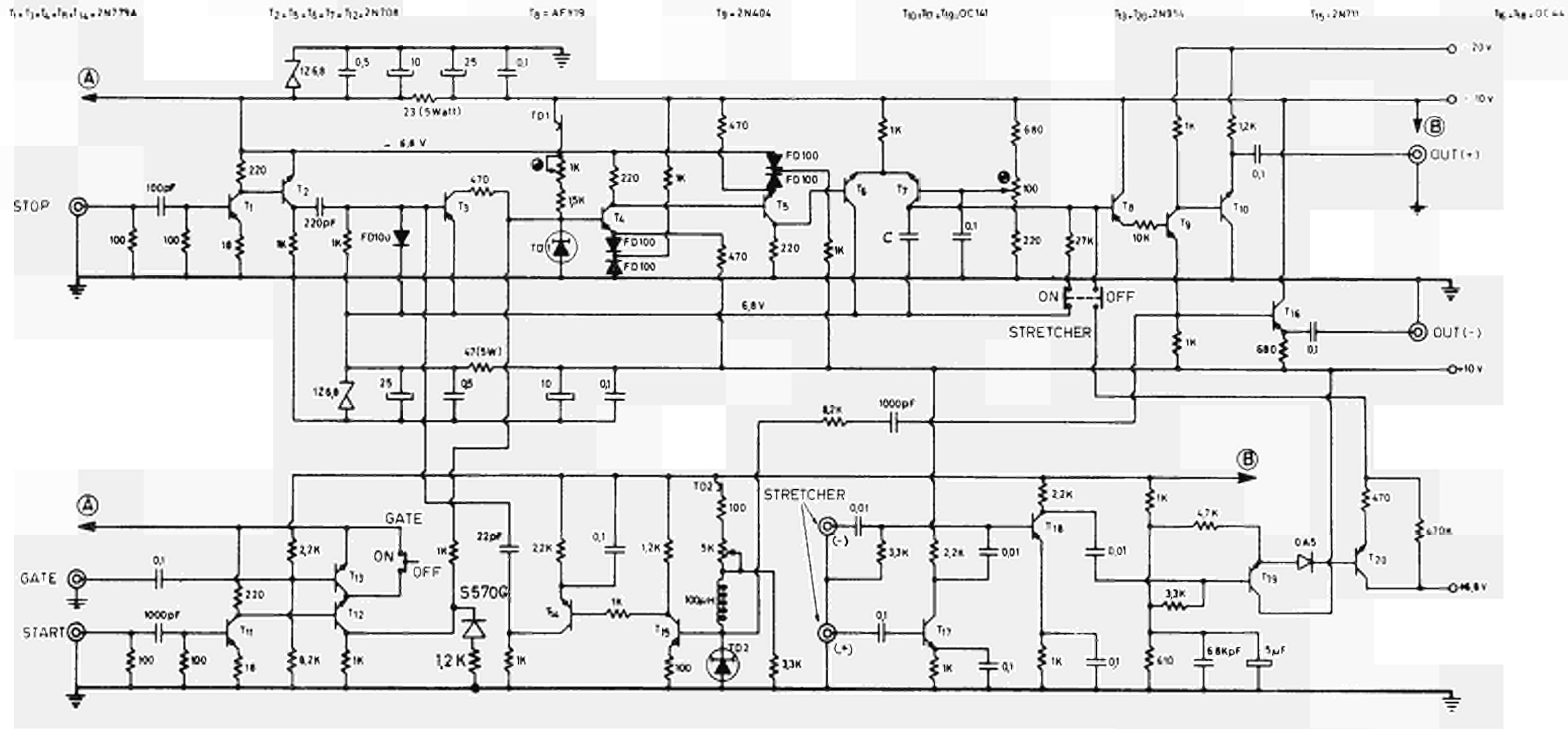
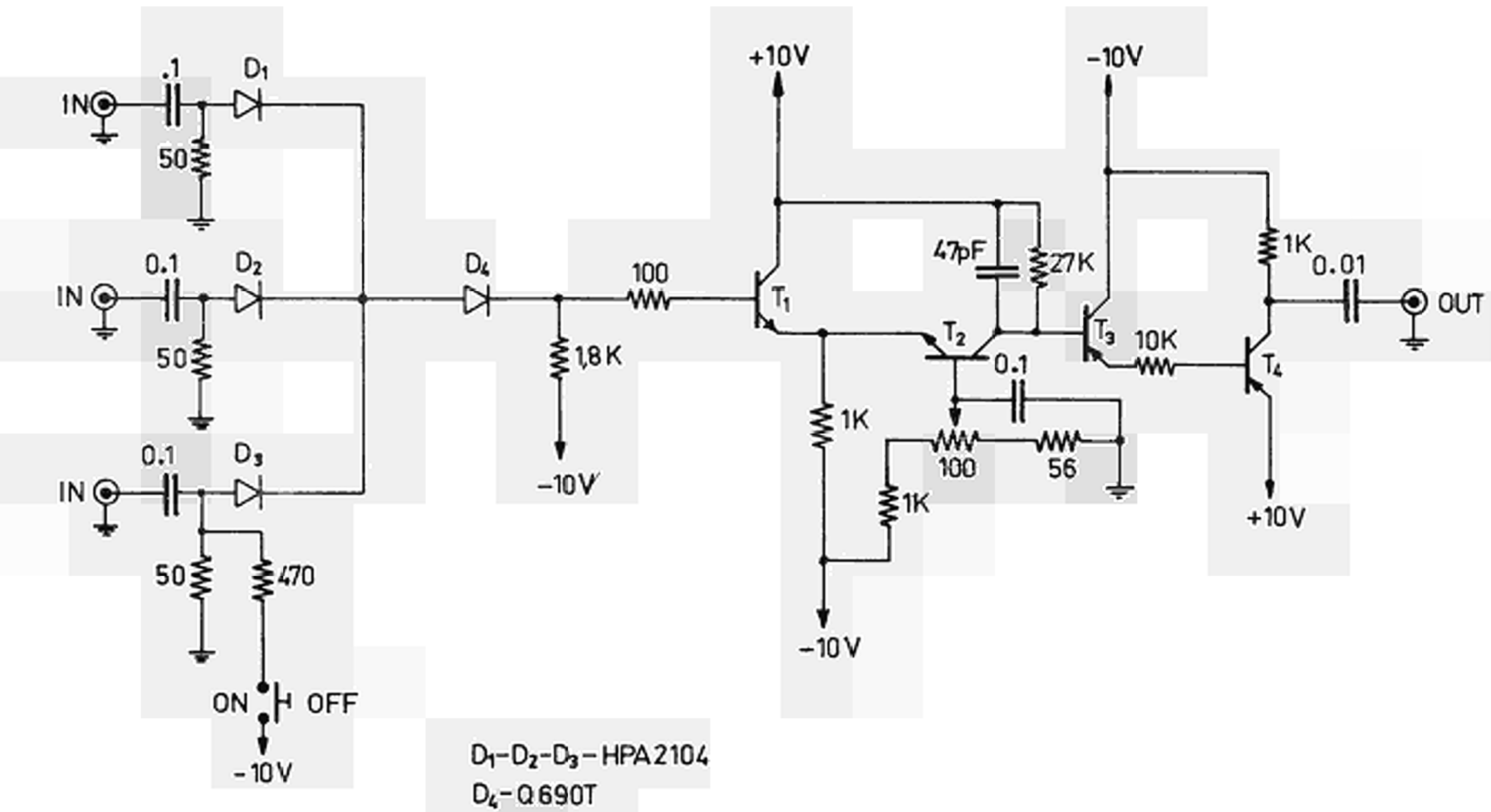



FIG. 21

TIME TO PULSE HEIGHT CONVERTER C 1




D1-D2-D3-HPA2104
D4-Q690T
T1-T2-2N918
T3-T4-2N2894

FIG. 22

TIME TO PULSE CONVERTER
C. 10

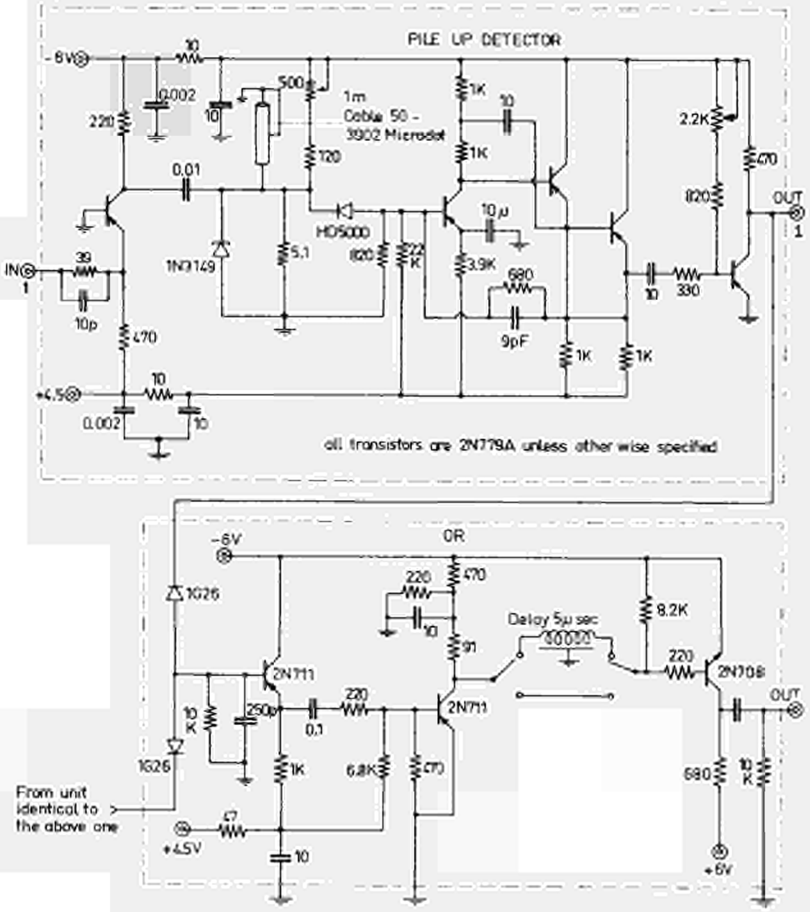



FIG. 23

FAST PILE-UP DETECTOR

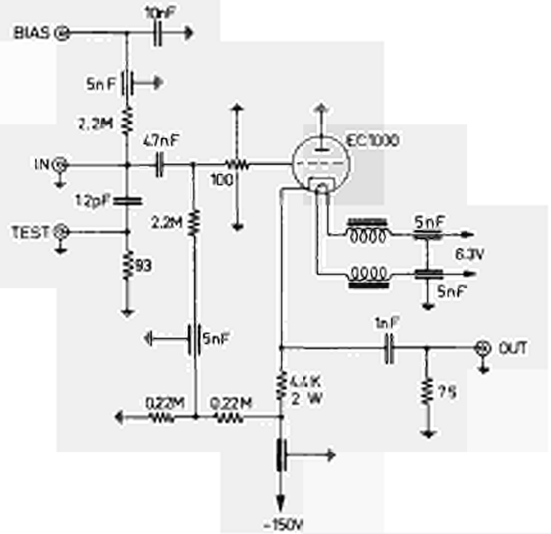



FIG. 24

HIGH INPUT IMPEDANCE CATHODE FOLLOWER

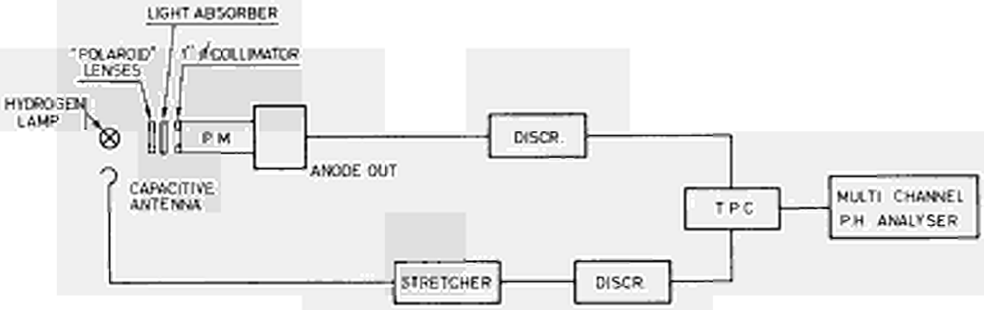



FIG. 25

EXPERIMENTAL ARRANGEMENT FOR TESTING THE DISCRIMINATOR SLEWING CHARACTERISTIC

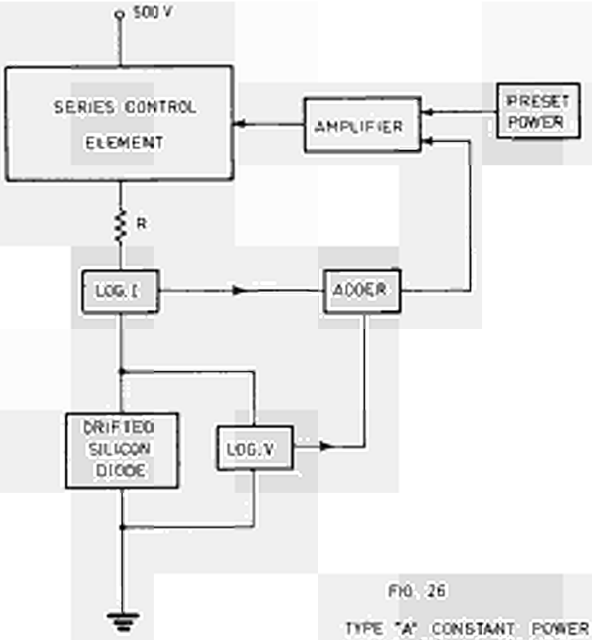



FIG. 26

TYPE "A" CONSTANT POWER SUPPLY FOR CONSTRUCTION OF THE LITHIUM DRIFTED SEMICONDUCTOR DETECTORS

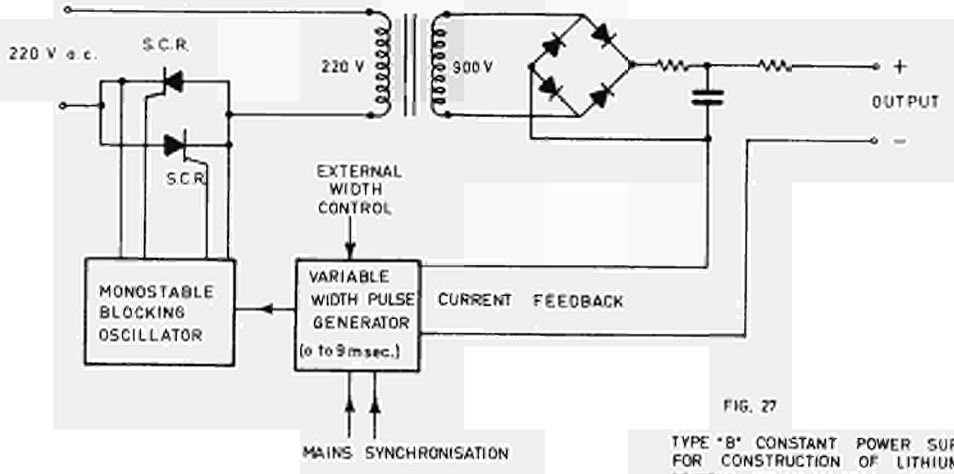



FIG. 27

TYPE "B" CONSTANT POWER SUPPLY FOR CONSTRUCTION OF LITHIUM DRIFTED SEMICONDUCTOR DETECTORS

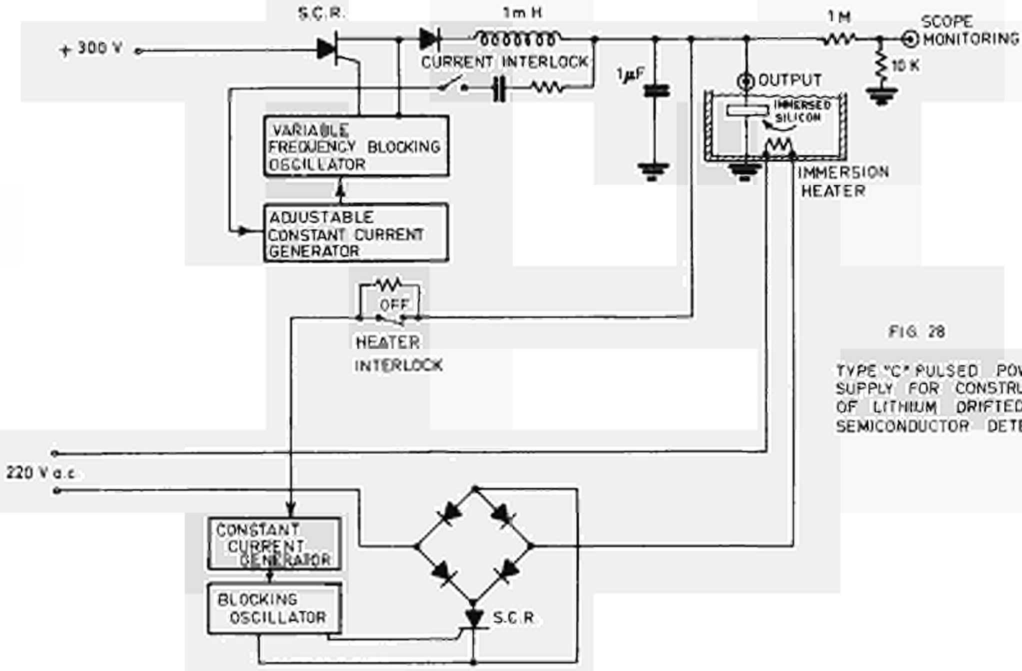



FIG. 28

TYPE "C" PULSED POWER SUPPLY FOR CONSTRUCTION OF LITHIUM DRIFTED SEMICONDUCTOR DETECTORS

FIG. 29

PROGRAMMER FOR ACTIVATION ANALYSIS BY MEANS OF THE IMICAM NEUTRON GENERATOR

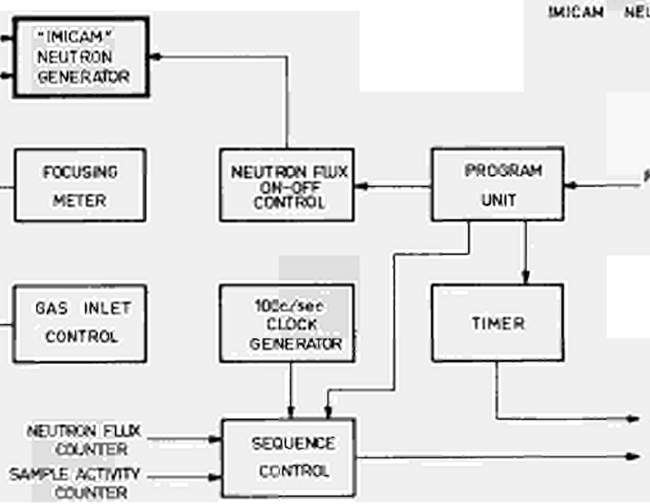
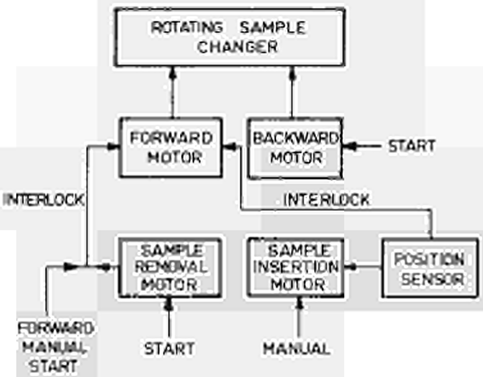



FIG. 30

SAMPLE CHANGER AND CONTROL SYSTEM



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Alfred Nobel

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