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BEAM POSITION MONITORING IN THE ISR TRANSFER CHANNELS USING PICK-UP ELECTRODES

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1. INTRODUCTION

Electrostatic pick-up monitors are provided at the beginning and the end of the transfer channels in order to watch constantly the beam 1). Each monitor gives information about the horizontal and vertical position of the beam in the vacuum chamber. Stations are available at PS ejection (PU 102, PU 103) in TT1 (PU 449, PU 451) in TT2 (PO 349, PU 351) and are planned in TT3 (PU 784).

The system is similar to the single-turn beam observation system used in the ISR 2). As in the ISR, the system relies essentially upon the use of the control computer for the collection, the correction, the handling and the display of obtained data.

The system resolution for one pulse is ± 0.5 mm with 20 bunches and ± 1 mm with 4 bunches. This can be improved by averaging over several measurements.

2. LAYOUT (see Fig. 1)

The system can be divided into three parts:

- electronic equipment directly associated with each pick-up.
- control electronics
- the ISR data-collection and data-handling system, including the ARGUS control computer.

2.1. Pick-up station

Most of the equipment is identical to that used in the ISR 2). These units have been designed and built by the RF Group. Only the signal processor (ISR 5102) is somewhat different; it is described in Appendix I.

The signals picked-up by the electrodes are transmitted from the tunnel to the auxiliary buildings (Y, A2, A7) through 75Ω coaxial cables. These cables are driven by the head amplifiers (ISR 3012). The signals are received by the end-of-cable amplifiers (ISR 3018). In the "normal" position the total gain of this wide-band chain is 1/4. However, by means of the individual control units (ISR 3059, ISR 3060), the gain can be changed to "high" (5) or to "low" (1/40). The control units also ensure the correct routing of the test signals (see calibrations) and display an alarm signal in case of malfunction of a head amplifier. Individual controls can be operated locally in the auxiliary buildings but are normally driven remotely from the control room. Local control, as well as alarm, saturation, gain and test status are communicated to the control computer by mean of contacts, scanned by the general purpose data collection system 3).

One output of the end-of-cable amplifier is connected to a level discriminator, which checks for saturation. The other output is connected to the signal processor, which delivers a D.C. level proportional to the charge picked up by the electrode. The value obtained is given by:

$$E_{SP} = \bar{e} \times G_V \times G_i \times \tau \simeq 0{,}8\ 10^{-12}\ N$$

$\bar{e}$ = average signal during the pulse at the electrode = $0.955.10^{-13}$ N ref. 2)

N = number of protons per pulse
G_V = video gain = 1/4
G_i = integration gain = $1{,}6 \times 10^{7}$ ref 2)
τ = integration period = 2,1 μsec

For instance, with an intense beam of 2×10^{12} protons per pulse at the centre of the vacuum chamber, each channel will produce a 1,6 V signal at its output.

This signal will be available 10 msec after the arrival of the trigger pulse. The purpose of this pulse is to trigger the gate around the beam pulse and to control the transfer of the integrated signal to the sample-and-hold circuit.

2.2. Control system

The system is remotely controlled, either manually or by computer, from the control room.

The Pick-up control unit (ISR 5108) in the SRC gives manual control of up to 10 different stations. Each station can be switched on or off individually, gain can be set, test conditions determined. Copies of the 'alarm' and 'saturation' signals, available from the auxiliary buildings, are displayed. The gate width can be switched from 'wide' (20 bunches) to 'narrow' (4 bunches) and vice-versa. Normally the system is in the 'manual control' mode, but as soon as a corresponding programme is activated control is switched over (ISR 5187) automatically to the computer. Gain and the 'on-off' switches are not computer controlled, but gate width and test conditions are. A detailed description of the interface with the computer is given in appendix II. The signals produced in the control room are received in the auxiliary buildings by the control interface (ISR 5103) and distributed to the individual control units, to the test generator and to the offset circuitry.

2.2.1. Test mode

As soon as one station is switched to test mode the generator (ISR 5154) corresponding to the auxiliary building is triggered by the ISR standard timing system 4), 3.3 msec before injection. Pulses of 40 volts are delivered into the 50 Ω cable going to the tunnel and a timing pulse is given to the timing distribution unit. The test pulses are applied to the test inputs of the head amplifiers according to the position of the switches in the control unit (ISR 3059). The delay between test and timing pulse is adjustable, as well as the width of the test pulse. A detailed description of the test generator is given in appendix III.

2.2.2. Offset check

The 20 msec offset-check pulse, which grounds the input of the signal processor, triggers the timing on its trailing edge and initiates the reading of the offset level before the relays open again. The computer will scan the offset voltages a few msecs later.

2.2.3. Timing

For position measurements the timing is triggered by the fast pulse also used to trigger the kicker magnet; this pulse is delayed to obtain the exact time relation. A description of the timing distribution unit is given in Appendix IV. The zero check circuitry, the level discriminators for saturation detection and the timing distribution amplifier are housed in a special crate (ISR 5107).

Most of these units were designed produced and installed by the Beam Transfer Section of the ISR Controls Group.

2.3. Data-collection and data-handling

Analog and digital data are available from each monitor

- 4 voltages describing the position of the beam
- open or closed contacts giving the status of the monitor (gain, test, alarm, a.s.o)

The voltages are scanned in pairs (vertical or horizontal) by the standard analog scanner . The selection can be done manually (ISR 7051), in which case the values are displayed in the control room on two voltmeters (ISR 7064A), or by computer. Because of the computations needed to determine the beam position from these voltages, the manual mode is however not very useful.

The selected voltages are converted into pulse trains by two analog to digital converters (ISR 7068), transmitted to the control room and converted by the computer interface (ISR 7065) into two digital words.

On the other hand the contact scanner will inform the computer continuously (up-dated every 120 msec) about the status of each pick-up In the auxiliary building the digital data are collected in the digital scanner interface (ISR 5118) and scanned (ISR 7046).

(No scanners are available in building Y. Signals are transmitted through multipair cables to A2).

3. COMPUTATIONS AND CALIBRATIONS

For each measurement (horizontal or vertical beam position) two numbers A and B are delivered to the computer, each proportional to the distance between the centre of charge of the beam and one sideplane of the monitor.

The values A and B are corrected for the offset (Ao and Bo) introduced by the signal processor. Offsets are recorded automatically by the computer during offset-check measurements. Obviously the sum of the two corrected numbers (A-Ao) and (B-Bo) should be constant for a given beam current.

The beam deviation from the centre of the monitor is caluculated in mm:

$$X = \frac{(A - Ao)-\eta(B - Bo)}{(A + Ao)+\eta(B - Bo)} \quad K$$

The factor η takes into account the imbalance between the two amplification chains. η is measured by applying equal test pulses (BALANCE) at the 4 test inputs of the head amplifiers.

$$\eta = \frac{(A_{Test} - Ao)}{(B_{Test} - Bo)}$$

In principle the K factor should be equal to the physical dimensions of the monitor, i.e. 84 and 42 mm resp. However, due to non-linearities close to the electrodes, the real sensitivity of the monitor was measured by J. Borer as being 87,5 mm and 43,5 mm. Moreover, because of the parasitic coupling between electrodes, the conversion factor K must include a correction that varies from monitor to monitor. K is measured (SCALING) by applying the test signal only to one out of each pair of electrodes.

$$K_{Horizontal} = \frac{(Atest - Ao) + \eta\,(Bparasitic - Bo)}{(Atest - Ao) - \eta\,(Bparasitic - Bo)} \quad 87{,}5$$

$$K_{Vertical} = \frac{(Ctest - Co) + \eta\,(Dparasitic - Do)}{(Ctest - Co) - \eta\,(Dparasitic - Do)} \quad 43{,}5$$

typically: $K_{Horizontal} = 98.0$ mm $K_{Vertical} = 53.2$ mm.

These calibrations however assume that the capacitive divider composed of the electrode capacity (100 pF) and the small test capacitor (1 pF) is equal for both channels. If we assume an imbalance of the two dividers ($\omega = 1$ for a perfect balance) the η factor will be spoiled and different K values are obtained depending if the test pulse is applied to one or the other electrode (K_1 and K_2). During the calibration procedure both K_1 (SCALING 1 - 3) and K_2 (SCALING 2 - 4) are measured and ω is calculated.

$$\omega = \frac{(K_2 - 1)(K_1 + 1)}{(K_2 + 1)(K_1 - 1)}$$

ω should remain between 0.98 and 1.02 for a good pick-up station.

4. OPERATING INFORMATION

Before each run the system should be calibrated. This can be done during injection if necessary.

Program BTPC will measure, store and print-out to the operator the offset levels, η, K and ω for both planes of each specified pick-up monitor. Each measurement is averaged over 25 readings and extreme values are discarded. Moreover the offset voltages of the signal processors will be updated automatically every hour during a run.

Beam positions can be obtained by using the beam transfer monitoring program: BTMO. It will provide horizontal and vertical beam position values in mm (positive if left or up, negative if right or down). If several pulses are measured by the same program the average value and the σ of the distribution will be calculated automatically. Of course the data provided by the beam transfer pick-up monitors could also be used in more complex programs, such as beam watching or beam steering.

For more details of the program, consult the Argus Program descriptions.

Important: Luminescent screens or S.E.M. grids left in the beam line cause scattering and interfere with the measurements of nearby pick-up monitors.

5. PERFORMANCE AND TESTS

Originally the system was developed to watch a full pulse of 20 bunches and a 3 μsec gating time was provided.

The electronic noise measured in situ for one signal processor is typically: $\sigma = 2$ mV. The total noise (without beam) is typically: $\sigma = 3$ mV. Internal and external noise sources contribute about equal amounts.

From this, it is possible to predict the position resolution, knowing that for 20 bunches (1.5 10^{12} protons/pulse) each signal processor will give 1.2 V output:

$$\sigma_H = \frac{3\sqrt{2}}{2.400} .98 \simeq 0,2 \text{ mm}$$

$$\sigma_V = \frac{3\sqrt{2}}{2.400} .54 \simeq 0,1 \text{ mm}$$

With 4 bunches (3.10^{11} protons/pulse) each signal processor gives 240 mV output. Thus

$$\sigma_H = \frac{3\sqrt{2}}{480} .98 \simeq 0,9 \text{ mm}$$

$$\sigma_V = \frac{3\sqrt{2}}{480} .54 \simeq 0,5 \text{ mm}$$

In Table I are listed the results of the tests carried out during runs 23, 32, 38, 42 and 43. It can be seen that with 4 bunches:

$$\sigma_H \simeq 0.95 \text{ mm}$$

$$\sigma_V \simeq 0.55 \text{ mm}$$

which fit well with the predicted values. With 20 bunches however (only one set of measurements)

$$\sigma_H \simeq 0,34 \text{ mm}$$

$$\sigma_V \simeq 0,12 \text{ mm}$$

the results, at least for the horizontal position are worse than predicted. This may be due to the intrinsic beam position instability.

During many ISR tests, only 4 bunches are injected into the ISR. Therefore a narrow (1 μsec) gatewidth was provided. From Table I it can be seen that the resolution was improved with 4 bunches:

$$\sigma_H \simeq 0.45 \text{ mm}$$

$$\sigma_V \simeq 0.30 \text{ mm}$$

and with 2 bunches (only one set of measurements)

$$\sigma_H \simeq 0.85 \text{ mm}$$
$$\sigma_V \simeq 0.40 \text{ mm}$$

From these tests, as well as from the theoretical predictions, one may conclude that in 95% of all cases (2σ limit) horizontal position measurement will be accurate to within ± 0.5 mm for a 20 bunch beam, and within ± 1 mm with 4 bunches (using the narrow gate width). The vertical resolution is two times better.

ACKNOWLEDGMENTS

This project has been carried out under the responsibility of D. Neet and required the contribution of several persons of different groups in the ISR.

The pick-ups and associated circuitry have been designed by J. Borer, calibrated by D. Cocq and installed by S. Turner.

Most of the control equipment has been designed and installed by A. Barlow.

K. Kohler has ensured the data-collection and R. Keyser developed the programs.

Many measurements have been carried out by P. Brummer.

The collaboration of M. Vignes (Regie) in the development of this system was greatly appreciated.

REFERENCES

1) D.A.G. Neet, Computer Control for the Beam Transfer System of the ISR, ISR-CO/69-72.

2) J. Borer and R. Scholl, the ISR Beam Position Monitor System, ISR-CO/RF/69-55.

3) P. Wolstenholme, Input and Output Systems for the ISR Control Computer, ISR-CO/69-24.

4) I. Barnett, the Proposed ISR Timing System, ISR-CO/68-56.

No.	Run	Bunches	Monitor	Width	Number of measurements	HORIZONTAL position mm	HORIZONTAL σ	HORIZONTAL ω	VERTICAL position	VERTICAL σ	VERTICAL ω	SEM GRIDS Horizontal mm	SEM GRIDS Vertical mm
1	23	4	102	narrow	20	+0.4	0.32		-5.5	0.25			
2	23	4	103	narrow	20	-10.2	0.45		-1.9	0.20			
3	32	2	102	narrow	19	+0.3	0.80	1.007	-0.9	0.40	0.980	+1	-1
4	32	2	103	narrow	19	+0.7	0.9	1.007	-2.2	0.40	1.004	+1	-1
5	32	4	102	narrow	35	+0.7	0.39	1.007	-1.4	0.32	0.980		
6	32	4	103	narrow	35	+0.6	0.50	1.007	-2.2	0.21	1.004		
7	32	4	102	narrow	100	+0.6	0.40	1.007	-1.5	0.41	0.980		
8	32	4	103	narrow	100	+0.6	0.56	1.007	-2.1	0.19	1.004		
9	32	4	351	narrow	100	+1.1	0.76	1.023	-0.3	0.28	0.993		
10	38	4	102	wide	98	-2.3	0.54	1.001	-1.9	0.34	1.001		
11	38	4	103	wide	98	+0.8	0.99	1.000	-2.6	0.43	0.997		
12	38	4	449	wide	93	+1.5	0.73	1.000	-0.7	0.45	1.002		
13	38	4	349	wide	33	0.0	0.87	0.993	-0.2	0.53	1.005		
14	38	4	351	wide	33	-8.0	1.00	1.020	-2.0	0.74	0.997		
15	42	4	103	wide	100	+2.1	0.76	1.006	-0.7	0.37	1.003		
16	42	4	349	wide	80	+2.8	1.15	0.995	-1.0	0.69	1.006		
17	42	4	351	wide	80	-9.7	0.67	1.022	-1.0	0.57	0.995		
18	42	4	451	wide	20	-4.4	1.8	1.003	-0.5	0.58	1.003		
19	43	20	103	wide	180	+3.2	0.34	1.006	-1.7	0.12	1.003		
20													
21													
22													
23													
24													

[1] If the measurements are displayed vs. time a position change of ≃ 1 mm can be observed (report on run 32)

APPENDIX I

Signal Processor: ISR 5102

As in the ISR single-turn beam observation system, the signal processor is composed of a fast integrator followed by a sample-and-hold circuit. The main difference consist in a switched filter at the input of the integrator. The principle of this filter is given in Fig. 2.

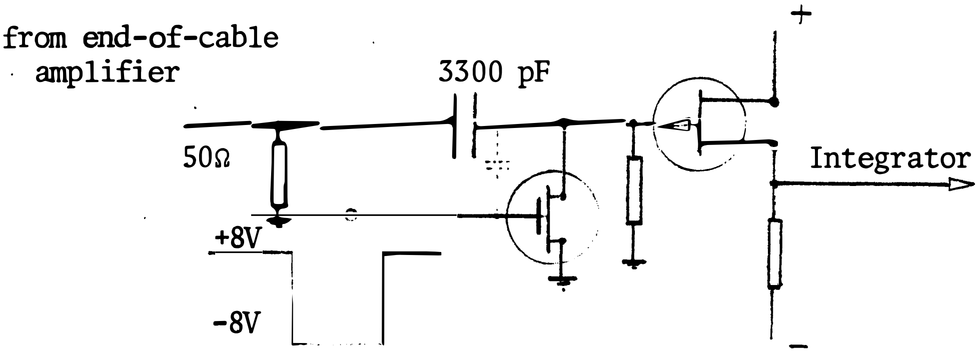

Fig. 2

Normally the input MOSFET is 'on' (R on $\simeq$ 200 Ω) and the coupling network between the signal processor and the end-of-cable amplifier has a short time constant ($\simeq$ 0.5 μsec). Just before the arrival of the beam pulse the MOSFET is turned off and a coupling time constant of 3 msecs is obtained. The sag of the beam pulse envelop (2 μsecs wide) will be less than 0.1%. After the passage of the pulse, the MOSFET is turned 'on' again. The 'on' time is too short (3 μsecs) to allow the building-up of significant low frequency noise.

Reducing the coupling capacitor would enhance the noise rejection. However one is limited by the capacitive divider formed by the MOSFET's GATE-DRAIN capacitor and the coupling capacitor. In the present case 0.1% of the 16V necessary to switch the MOSFET is seen as a pedestal at the integrator input. Decreasing the coupling capcitor would increase the magnitude of this pedestal by the same ratio.

The four signal processors corresponding to one monitor are housed together in one unit. Each signal processor is available as one independent plug-in card (ISR 5102-1). The unit contains also a timing card (ISR 5102-2) shared by the four channels. The complete circuit diagram of the signal processor is given in Figs. 3, 4 and 5.

APPENDIX II

Computer Interface: ISR 7239/11

A very simple interface with the control computer was developed (Fig. 6). When a 'computer control' signal is sent to the 'switch-over' box (ISR 5187) the test conditions and the gate width are directly controlled by the decoded computer output signals. Indicator lights are provided on the 'switch-over' box and on the manual control unit. For offset-check a 20 msec (IC 2) pulse is sent to the signal processors (Fig.1). The same signal is delayed for 40 msecs (IC 3/1) in the interface unit and generates an interrupt signal (IC 3/2). On that signal the computer will scan the offset levels. The interface is housed in a small ISR-8905-3 unit and built using high level logic (MHTL). A red lamp on the front panel lights each time an offset-check pulse is issued.

APPENDIX III

Test Generator: ISR 5154

For test and calibration purposes a constant amount of charge is injected in the test inputs of the monitors during the input gate 'open' time. The pulses are transmitted through a 50Ω coaxial cable from the generator in the auxiliary building to the head amplifiers in the tunnel. Because the cable is terminated on a small capacitor (2 or 4 pF), the generators output impedance should be 50Ω to avoid that reflected signals would disturb the calibration.

The capacitive divider, formed by the 1pF test capacitor and the 100 pF electrode capacitance, is attenuating the signal 40 dB. Therefore, at least 40V pulses are required.

This generator was developed in a hurry and only standard components could be used.

The whole equipment is housed in an ISR-8905-3 crate.

The circuit diagram of the basic generator is given in Fig. 7. It was built using Transistor-Transistor logic (Texas).

For test purposes an internal 1c/sec clock can be used, but normally the device is synchronised with injection (3.3 msec before injection). Both the signal and the trigger pulse can be delayed.

P3: trigger pulse: 0.1 μsec up to 2.5 μsec delay
P2: signal pulse: 0.3 μsec up to 10 μsec delay
The output pulse width is variable

P1: pulse width: 0.1 μsec up to 2.5 μsec wide

APPENDIX III (page 2)

If necessary the signal rate can be divided by two against the trigger rate. The outputs are A.C. or D.C. coupled (AMP jacks with capacitors or jumpers).

The generator is driving two output amplifiers (Fig. 8). An amplifier is mainly composed of a fast current-switch (2N918) driving four collector-followers (2N2905A) through two emitter-followers (2N2222A). In steady-state conditions the output transistors (2N2905A) are almost biased 'off' by the inductive load (5 mH) in the collector of the current-swith. Hence the total dissipation is kept within acceptable limits. The output filter is provided to compensate for losses in the transmission cable.

APPENDIX IV

Timing Distribution Amplifier: ISR 5119/1

This circuit (Fig. 9) is mainly composed of a series of fast current-switches (max. 10) driving individual output lines. Each output can deliver - 0.5 Volts on 50Ω. All these switches are driven in parallel by another one (T23, T24). Three possible trigger signals converge here. The injection timing signal has a buffered 50Ω input and provides a sharp threshold crossing for accurate timing. The test input and the zero-trigger input do not have these provisions. However, the zero-trigger (offset-check), which is a rather slow signal, is filtered and then shaped by a SN72710.

In the Y-building two injection pulses are available at 1 μsec interval. Only the second should trigger the system. Therefore, the driving current switch (T23, T24) is normally disabled. The first pulse triggers the integrated monostable (SN4121) and provides (with a slight delay) a 2 μsec 'enabled' period allowing the second pulse to trigger the system. Of course, this part of the circuit is only used in the Y-building.

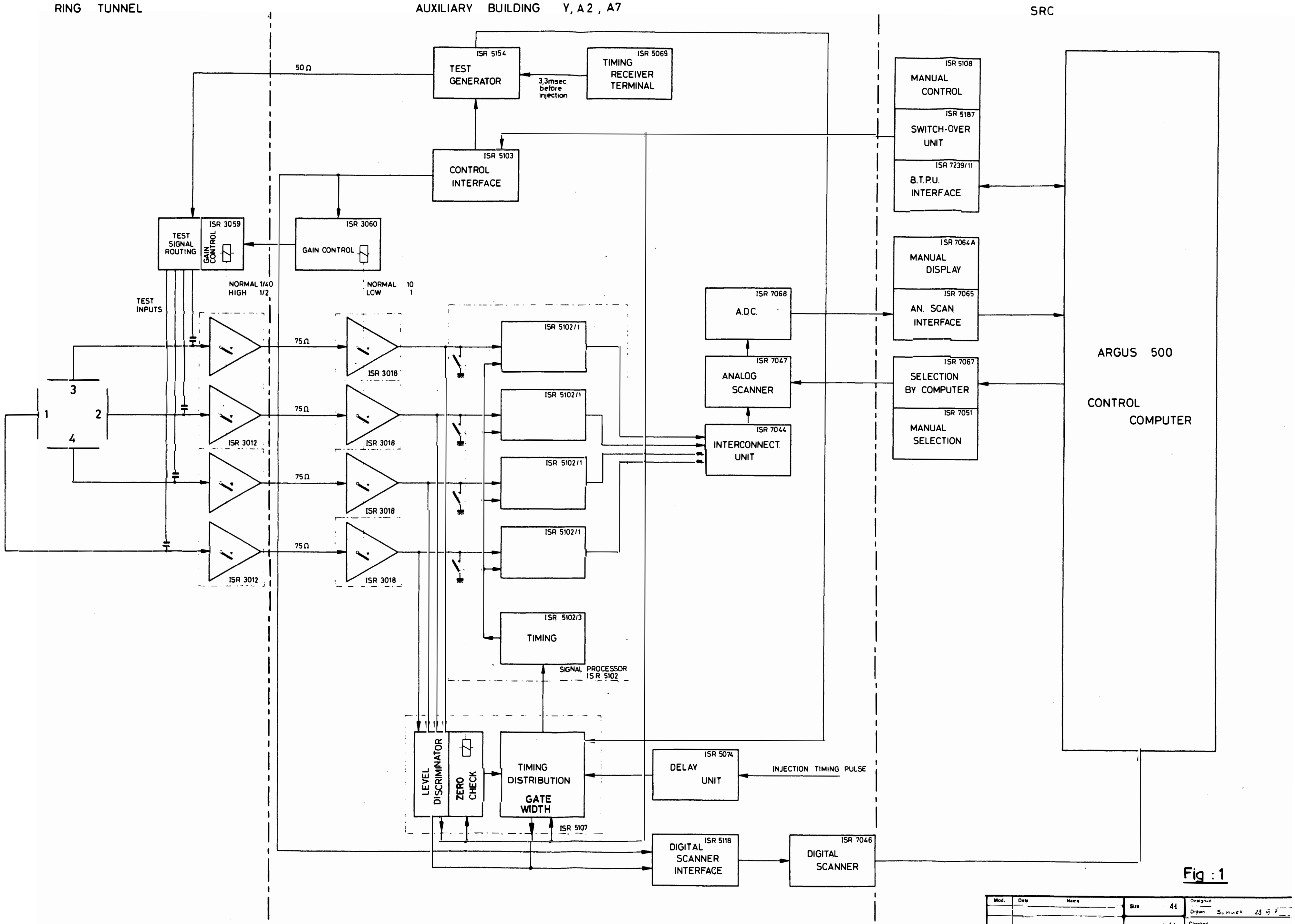

Fig : 1

Mod.	Date	Name	Size	A1	Designed
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			Sheet	1/1	Checked
					App'd

BEAM POSITION MONITORING
IN THE ISR TRANFER USING
P.U. ELECTRODES

CERN ISR 1211 Genève

B. ISR. 1520

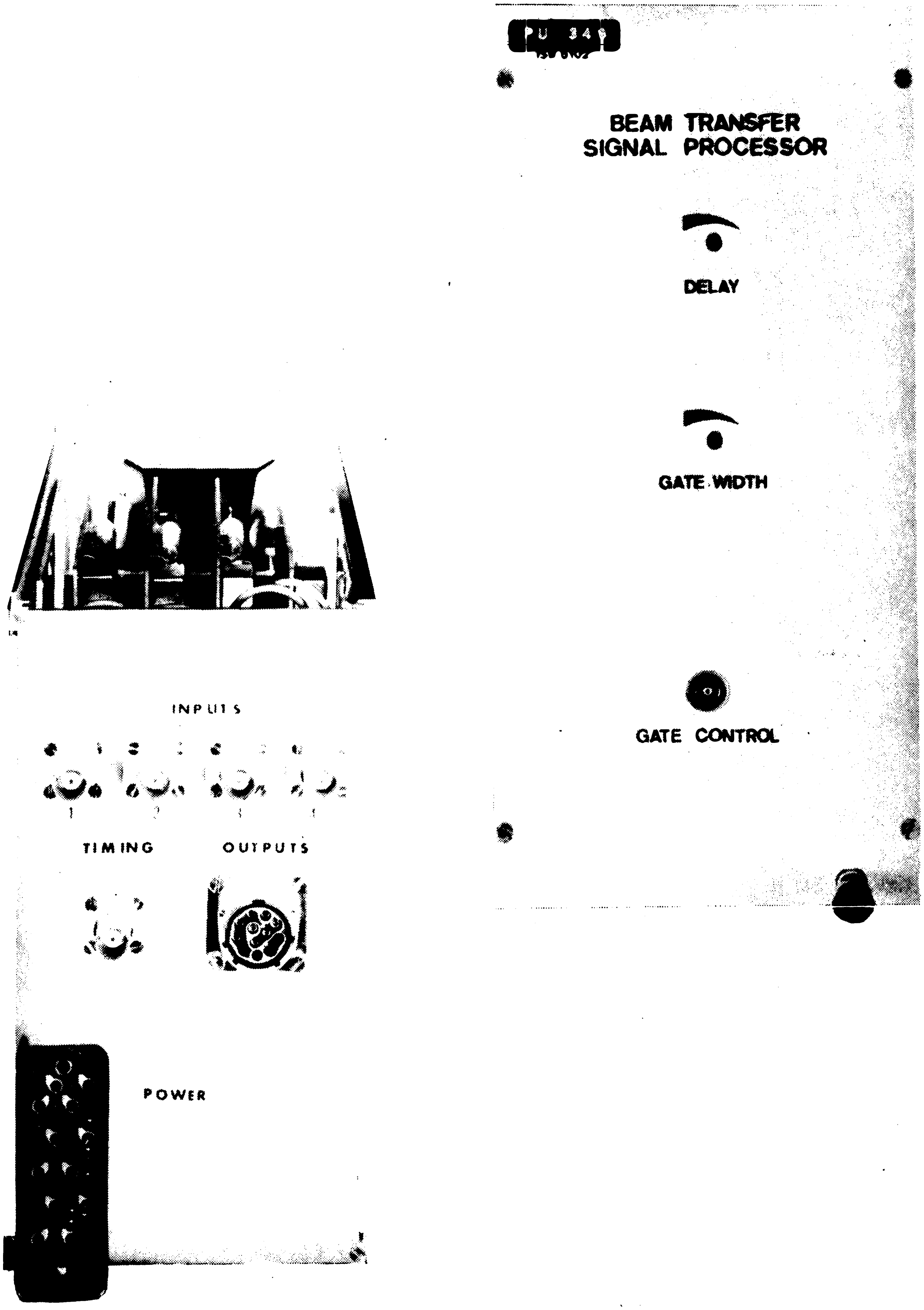
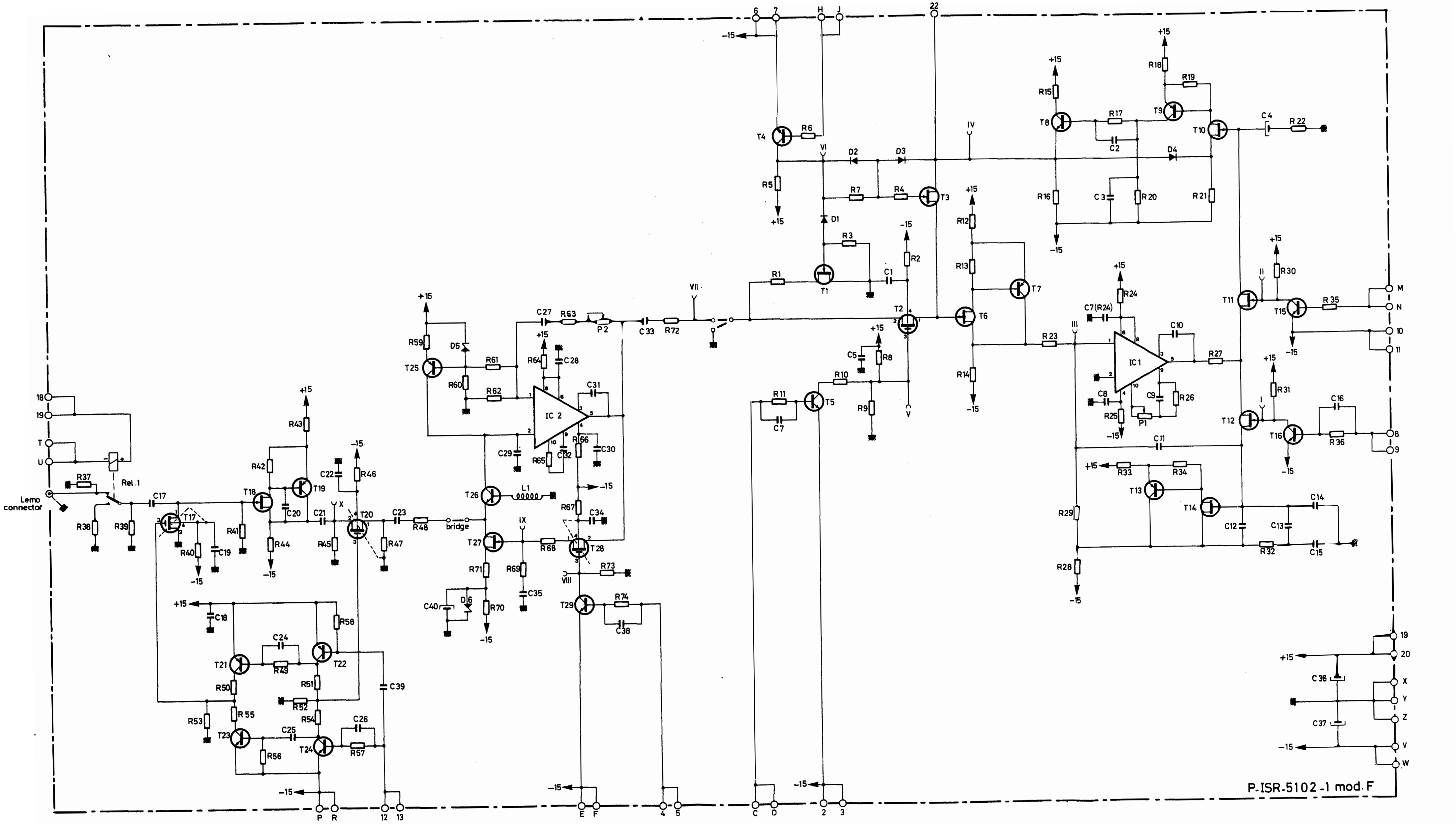

PU 349
BEAM TRANSFER
SIGNAL PROCESSOR
DELAY
GATE WIDTH
GATE CONTROL
INPUTS
TIMING
OUTPUTS
POWER

Fig : 3



COMPONENTS LIST : L-ISR-5102-1

P.C. IN N.S. CARD

Fig. : 4

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					App'd
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SIGNAL PROCESSOR					C-ISR-5102-1

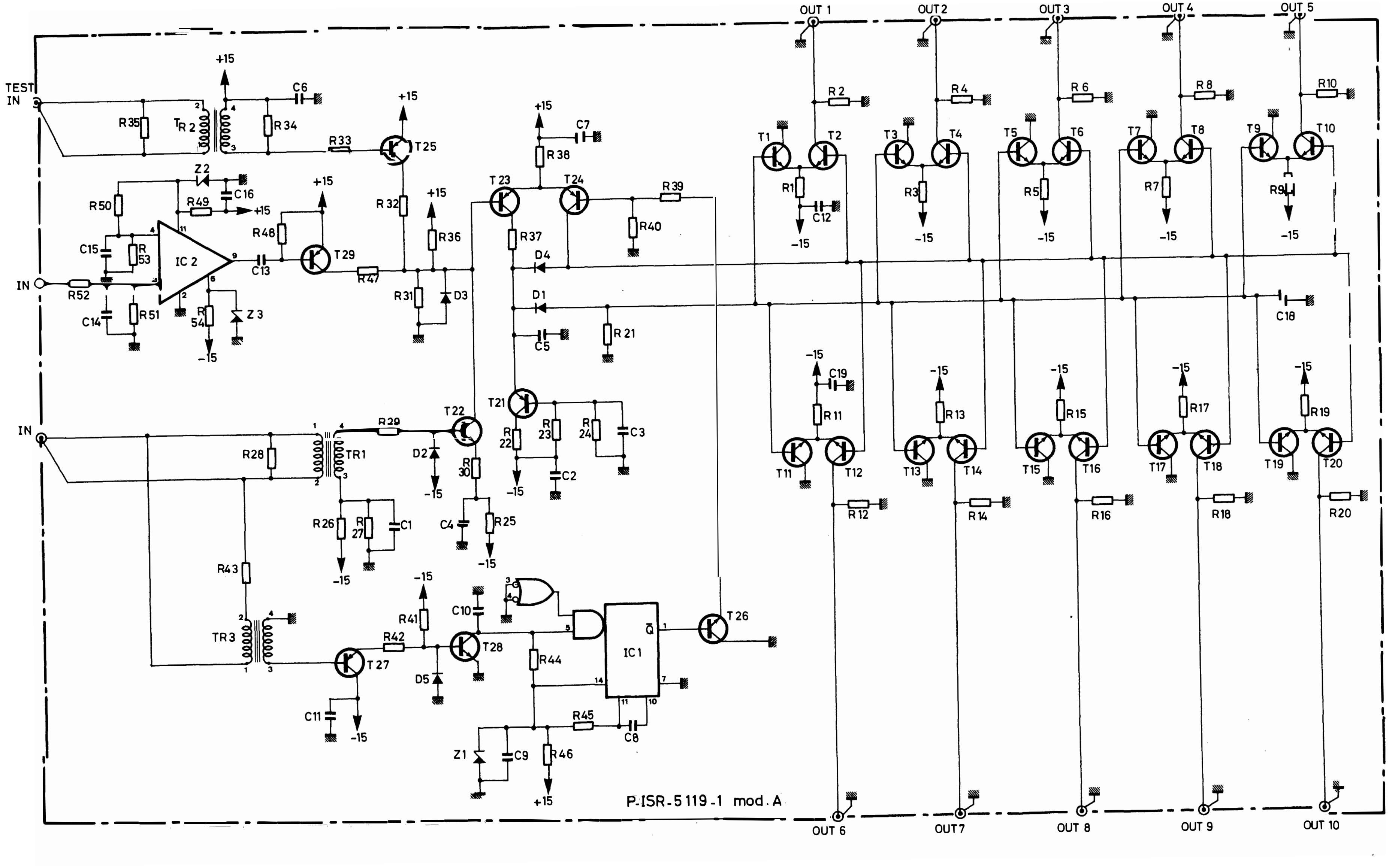

Fig : 5

P.C. IN CHASSIS 19"

Mod. | Date | Name
Size A2
Sheet 1/1
Designed H.VERELST
Drawn A.MERCIER 4-8-71
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App'd
CERN/ISR 1211 Genève

TIMING EXPANDER

C-ISR-5119-1

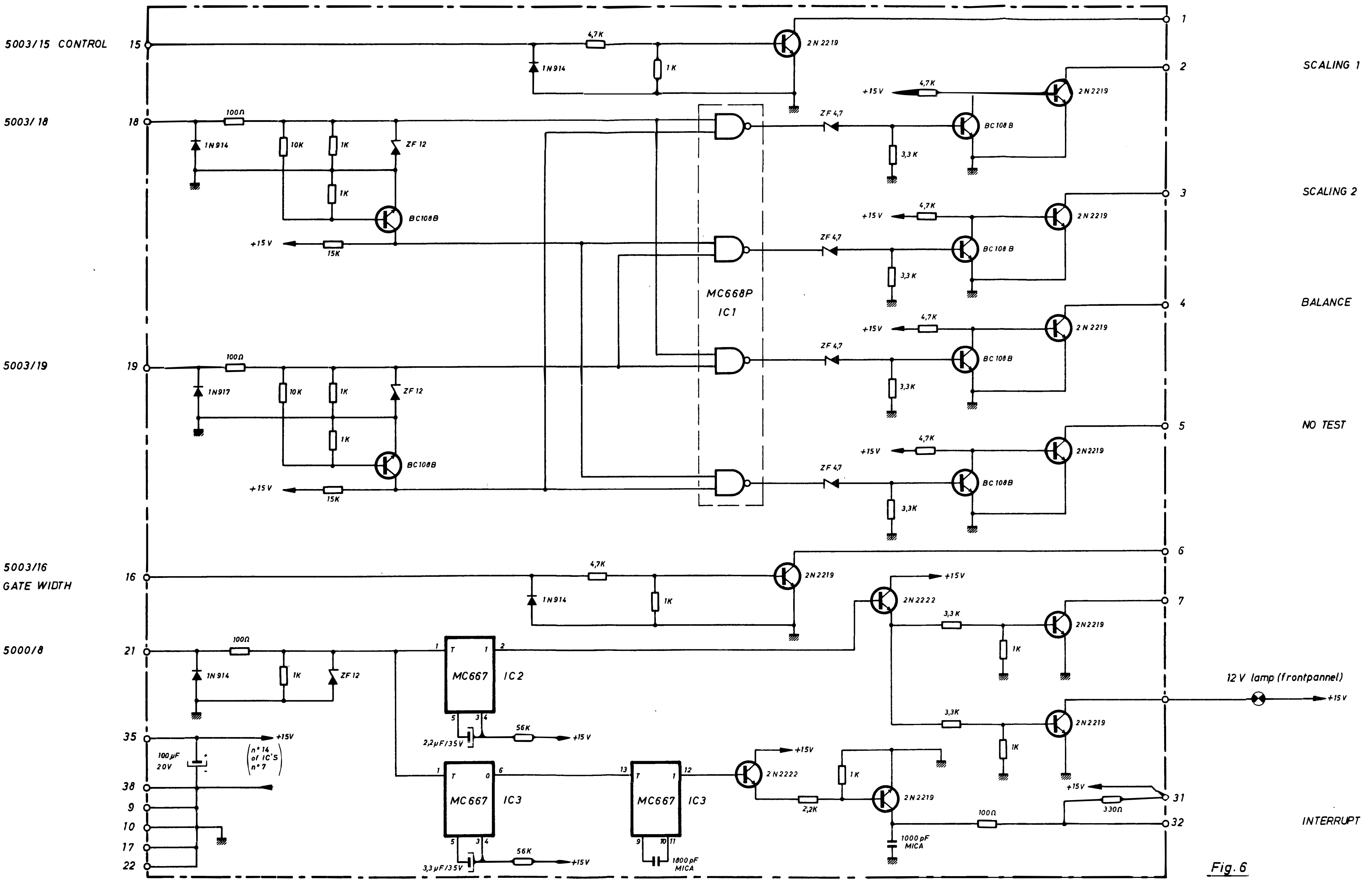

Fig. 6

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					CERN/ISR 1211 Genève

B.T.P.U. INTERFACE

C_ISR_7239/1

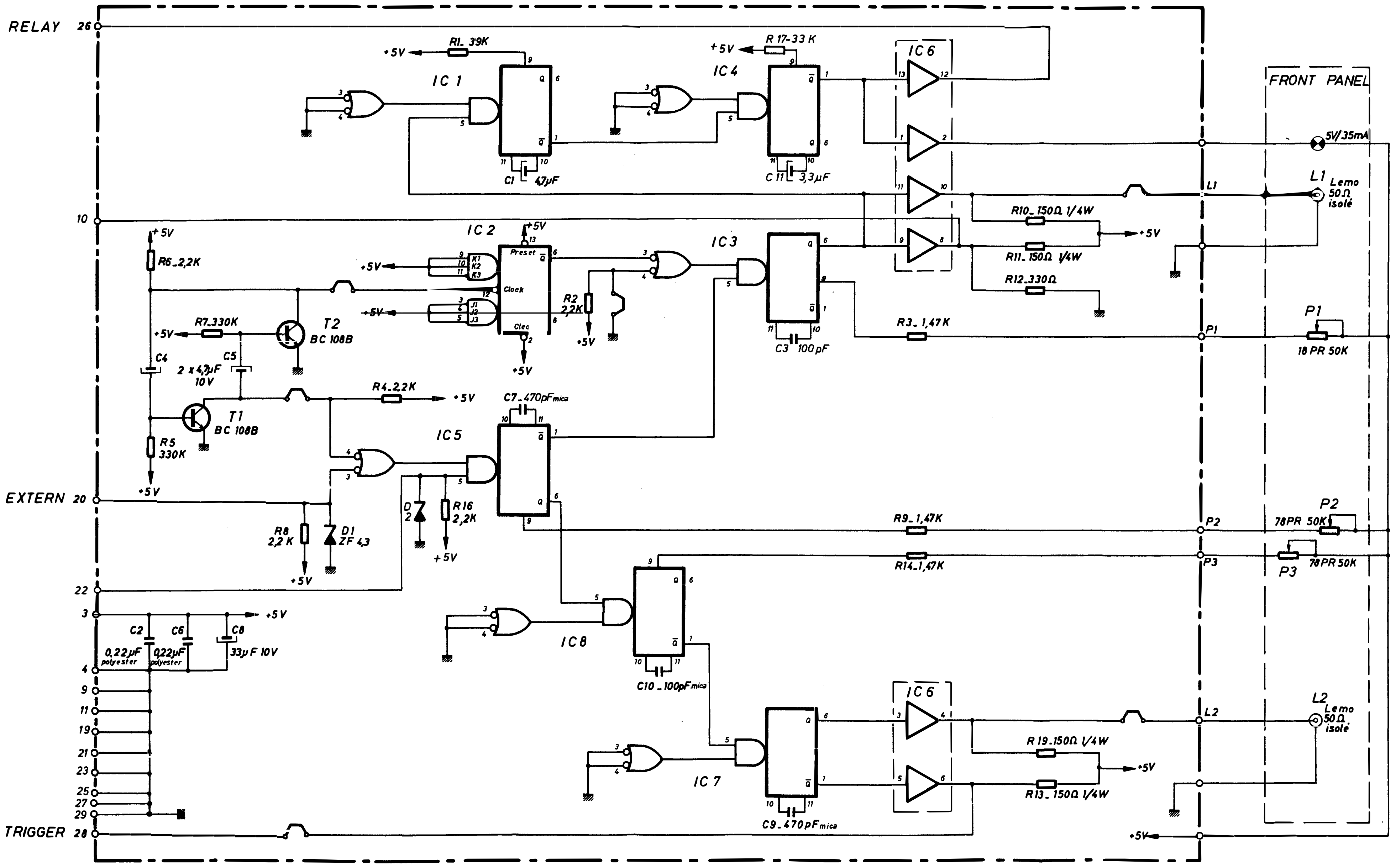

Fig. 7

PLUG IN BOARD 3Hx1L

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PULSE GENERATOR					C_ ISR. 5154/2

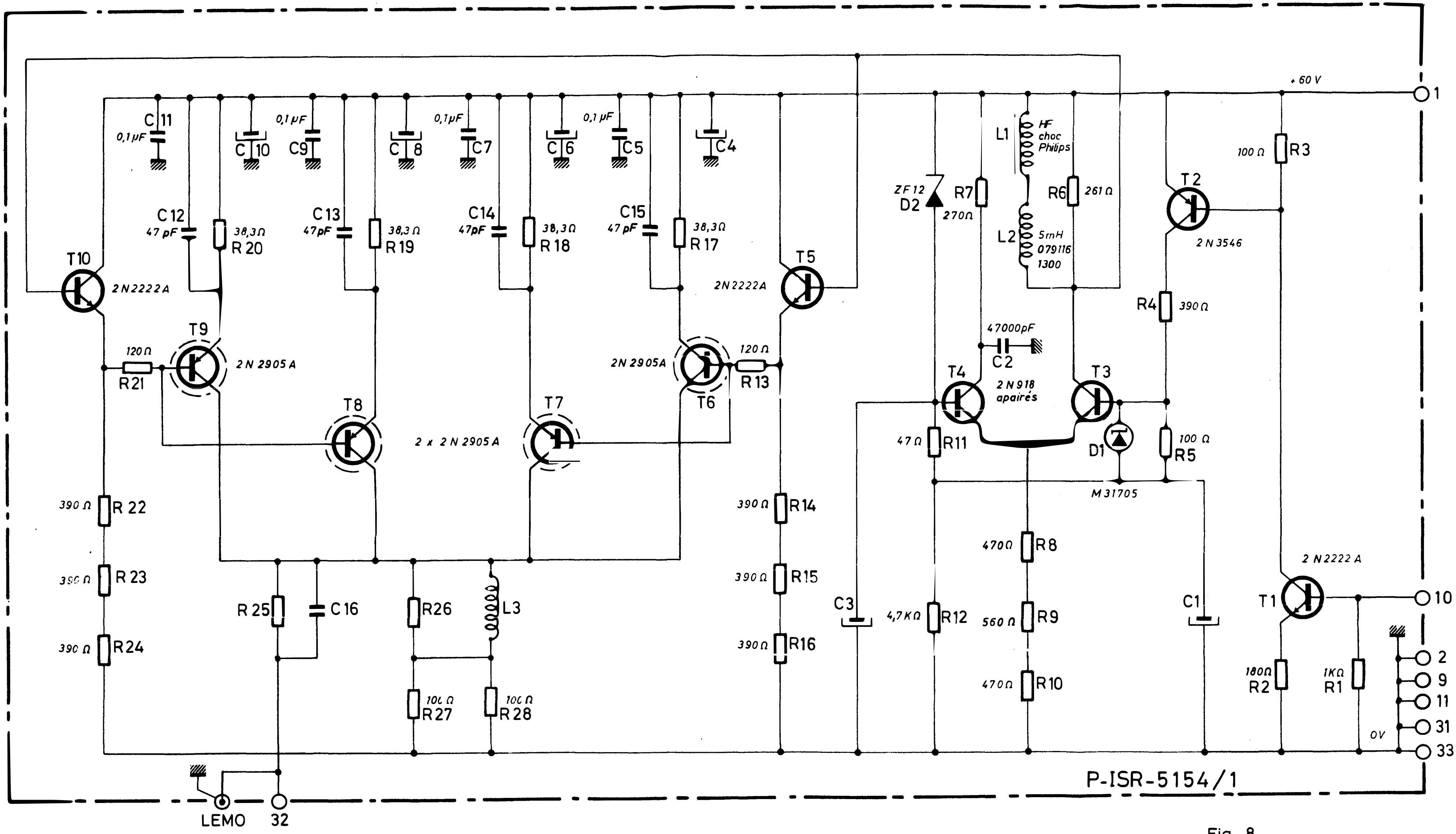

Fig : 8

PLUG-IN CARD 3 H

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B			Sheet	1/1	Checked
C					App'd
BEAM TRANSFER					CERN / ISR 1211 Genève
OUTPUT CARD					C_ISR_5154/1