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AN INDUCTIVE BEAM MONITOR FOR THE EXTRACTED PROTON BEAM
OF THE CERN SYNCHRO-CYCLOTRON

by

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G E N E V A

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ABSTRACT

An inductive beam monitor, as used for the extracted proton beam of the CERN synchro-cyclotron, is described.

It measures the number of protons passing through its aperture in a single burst, a second, or any other time interval, without interfering with the beam. It gives analogic and numerical displays of the result, and has got easy and fast calibration facilities.

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1. INTRODUCTION

The intensity of the CERN synchro-cyclotron extracted proton beam can be measured by several methods.

Some of them cannot be used for a continuous monitoring of the beam during the experimental work. One could mention among them :

a) The so called activation methods, like the one based upon the determination of the C^{12} (p, pn) C^{11} cross-section. They yield a precision of the order of 4 - 5%, corresponding to the precision with which the cross-section can be determined. They do not disturb heavily the beam, but are not suitable, by their own nature, to work continuously or to give immediate results.

b) The adiabatic calorimetric method, which yields again a precision of the same order of magnitude¹⁾.

c) The primary beam charge collecting method (Faraday cup) which can reportedly offer fairly good precision²⁾, but acts anyway as a beam stopper, and can be used only as a standard.

The monitors normally used for continuous measurements are the secondary effect type devices, like Secondary emission monitors³⁾ and Ionization chambers⁴⁾. They disturb the beam very little, but must be calibrated from time to time by one of the afore-mentioned methods.

To have a continuously working, non-interfering, easily calibrated beam monitor, one had to develop an electrostatic⁵⁾ or an electromagnetic pick-up⁶⁾.

For the CERN synchro-cyclotron extracted proton beam, an electromagnetic type monitor, which is described in this report, appeared to be the most suitable.

It is a modified version of the monitors of the same type already used for proton synchrotrons⁷⁾, electron synchrotrons⁸⁾ and linear accelerators⁹⁾, which takes into account the special conditions dictated by the CERN synchro-cyclotron.

The principle underlying it is that a beam of charged particles can be used as the primary current of a transformer.

To calibrate the device it is sufficient to feed current pulses of known amplitude and duration through an auxiliary winding of the transformer. The monitor can be programmed to measure the number of protons extracted from the synchro-cyclotron in a single burst, in one second or in any other time interval.

In its present version, it is able to measure beam intensities of 10^{12} down to 10^9 protons/second, with an absolute precision of 1% for the maximum value.

Flexibility of operation, simple and fast absolute calibration procedure and good absolute precision are thus the main features of this beam intensity monitor.

2. THE ELECTROMAGNETIC BEAM MONITOR

From an electrical point of view, a beam of charged particles extracted from a cyclic accelerating machine can be considered as a pulsed current :

$$i_b = \frac{dQ}{dt} \quad (1)$$

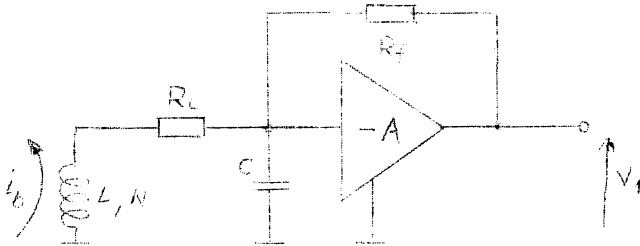
where Q is the charge of the particles flying through a plane orthogonal to the beam direction.

Such a beam can be used as the primary current of a transformer (single turn), letting it pass through the transformer aperture. The secondary current :

$$i_s = \frac{i_b}{N} \quad (2)$$

where N is the number of turns of the secondary winding, is then proportional to the beam current.

Feeding the ends of the secondary into a high gain, resistance feedback operational amplifier, the output voltage of this is proportional to the beam current :



$$V_1 = - \frac{R_f i_b}{N} \quad (3)$$

The inductance of the secondary winding, as well as its resistance R_L and its stray capacity, the cable capacity, etc., determine the frequency response of the system coil-amplifier.

The low frequency limit is given by :

$$\omega_{\text{low}} = \frac{R}{L} \quad (4)$$

where $R = \frac{R_f}{A} + R_L$ is the input resistance as seen from the coil.

The high frequency limit is given by :

$$\omega_{\text{high}} = \frac{1}{CR} \quad (5)$$

where C is the sum of all the capacities appearing at the input of the amplifier.

Feeding V_1 into an RC integrator, the output voltage V_2 of this is proportional to the total charge flown through the opening of the transformer during the time of integration :

$$V_2 = \frac{1}{RC} \int_{t_1}^{t_2} V_1 dt = \frac{R_f}{NRC} \int_{t_1}^{t_2} i_b dt = \frac{R_f}{NRC} \cdot Q \quad (6)$$

where :

V_2 = output voltage of the integrator

Q = total charge

$t_2 - t_1$ = interval of integration, equal for instance to a burst length.

V_2 is then proportional to the number of protons passed through the transformer

window during $t_2 - t_1$:

$$V_2 = \frac{R_f}{NRC} \cdot N_p \cdot q = K \cdot N_p$$

where

q = charge of a proton

N_p = number of protons

$K = \frac{R_f}{NRC}$ = constant

Depending upon the time of integration, one can have an output proportional to the number of particles extracted from an accelerator in any wanted time interval : in a single burst, in a fraction of a burst, in one second, and so on.

3. CONDITIONS DICTATED BY THE CERN SYNCHRO-CYCLOTRON

3.1 Beam Conditions

In comparison to other accelerators, for which electromagnetic beam monitors had been previously developed, a synchro-cyclotron is a faster cycled machine with an extracted proton beam of lower burst peak intensity.

For the CERN synchro-cyclotron there exist two modes of beam extraction, the so called Fast and Slow Extraction.

The protons accelerated in a machine cycle (repetition frequency about 54 c/sec) are extracted in one or more bursts, according to the mode of extraction and as illustrated in the following table :

	Number of bursts per second	Number of protons per burst	Burst length
Fast Extraction	~ 54	$10^{10} - 10^9$	100-200 μ sec
Slow Extraction	up to ~1000	$10^9 - 10^8$ and less	200-300 μ sec

From an electrical point of view, the beam current consists then of :

1. about 54 pulses/second, about 200 μ sec long, of mean pulse current intensity $8 \cdot 10^{-6} - 8 \cdot 10^{-7}$ Amp, in Fast Extraction
2. up to about ~ 1000 pulses/second, still about 200 μ sec long,

variously distanced in time and of largely different mean intensities (between 10^{-7} and 10^{-8} Amp, and still less) in Slow Extraction.

The Beam Monitor, object of this report must then be able to detect current pulses of mean intensity $\leq 10^{-8}$ Amp, about 200 μ sec long, variously distanced in time.

3.2 Environmental Conditions

In the various positions along the beam direction where the transformer can be placed, see fig. 1, the SC stray magnetic field can be as high as ~ 500 Gauss, depending upon the distance from the machine.

Apart from this, the stray magnetic fields of the magnetic lenses nearby along the beam cannot be neglected.

The whole gives rise to a heavy problem of magnetic shielding for the transformer.

Strong RF and other frequency sources of disturbance in the surroundings necessitate an accurate electrical shielding not only of the transformer, but also of the cables and of the electronic parts to be placed in the machine Hall.

There is also a problem of vibration and shock protection of the transformer. Mechanical vibrations from ground, due to vacuum pumps, vibrating condenser, etc., can disturb heavily the transformer, giving rise to strong noise across the secondary.

Last but not least, the high radiation level forbids the electronics to be put near the transformer or anyway in the SC-Hall.

Only the first amplifier, whose connections to the transformer must absolutely be as short as possible, is placed under the floor of the SC Hall, to protect it, while all the remaining electronics are about 100 m away, in the Main Control Room.

4. DESCRIPTION OF THE SYSTEM

4.1 Functions

The monitor is illustrated schematically in the block diagram of fig. 2.

The preamplifier gives a voltage signal V_1 proportional to the beam current, which is integrated by the RC integrator, to obtain a voltage level V_2 , proportional to the beam charge. V_2 is converted into a time signal T after the passage of each burst of particles, and T is transformed by an electronic counter into a coded numerical information, which is displayed or stored for further integration over a certain time interval.

The integrator is reset to zero at the end of the conversion.

A time sequence unit, driven by a pulse delivered by a discriminator which works on the frequency programme of the synchro-cyclotron, assures the synchronization of these functions to the beam. The calibration unit provides current pulses of well known and constant intensity and length, which are fed into an auxiliary winding of the transformer.

The calibration pulses can be synchronized either to the frequency programme of the SC or to the time bases of the electronic counter.

4.2 Specifications

4.2.1 The Preamplifier

The transfer ratio of the device must allow the detection of current pulses of mean intensity of the order of 10^{-8} A. The bandwidth must be such as to give a droop as small as possible for a burst length of 200 μ sec, and a rise-time such as to allow a partial observation of the particle intensity distribution in the bursts.

The noise, and overall the low frequency noise level, must be kept as low as possible, because it puts the ultimate limit to the possibilities of signal detection.

4.2.2 The Integrator

It is an integrator of the classical RC type. To restore the dc level of the beam or calibration signal from the preamplifier, which is lost in the coil, and to make possible to measure low voltage signals out of the noise, switches at the input of the integrator are closed only during the beam or calibration signal time (chopper amplifier). Care must be taken to reduce as much as possible the effect of the thermal drift of the integrator amplifier. For this purpose the integrator is also reset to zero after the end of each voltage to time conversion until the next burst arrives. See fig. 3.

4.2.3 Voltage to Time Conversion System

The voltage to time conversion is accomplished by discharging to zero the feedback capacitor of the integrator by a current of a well known and constant value. This is supplied by a current source through a switch driven by a fast flip-flop, the direct output of which gives the time signal to be measured, see fig. 3.

The rise time of the flip-flop must be $\leq 0,1 \mu\text{sec}$, to match the $0,1 \mu\text{sec}$ resolution of the electronic counter which measures the time signal, while the current source must be very stable to avoid errors in conversion.

Also, even in absence of any beam or calibration signal from the transformer, there is an unwanted time signal from the conversion flip-flop. To suppress this "zero" time signal, we use a coincidence unit, which subtracts a fixed time from the total signal.

4.2.4 Time Sequence Unit and Programme

The "start conversion" pulse and the driving signals for the switches must be supplied at times and for time intervals well determined in relation to the beam bursts or the calibration pulses.

The time sequence used is shown in fig. 4. The timing signals are supplied by a Time Sequence Unit in synchronization with the machine beam bursts or with the calibration pulses. This unit does not have to fulfil strict requirements of precision, because errors in time of the order of a few microseconds are of no importance for the functions accomplished.

4.2.5 Frequency Discriminator for Synchronization to the Machine Frequency Programme

The synchronization of the time sequence and of the other parts of the monitor to the beam is accomplished by a frequency discriminator working on the main frequency programme or on the Slow Extraction frequency programme of the synchro-cyclotron. Tuning the discriminator on a frequency near to the extraction frequency, one can shift the synchronization pulse with respect to the beam bursts.

Again, there are no very strict requirements in stability or precision, errors of a few microseconds being of no importance.

4.2.6 The Electronic Counter : Transformation of the Time Interval into Numerical Information and its Display

The transformation of the time interval resulting from the voltage to time conversion into numerical information and its display are done by an electronic counter. It is the resolution of 0,1 μ sec of this instrument for time interval measurements which brings in the necessity of fast flip-flops in the conversion and "0" suppression units, to avoid errors due to long rise-times of time signals.

4.2.7 The calibration unit

Calibration is accomplished by feeding current pulses into an auxiliary winding of the transformer. In fact, if N_c is the number of turns of the calibration winding, i_c the constant calibration current intensity, and T_c the pulse length, the total charge of calibration simulating the beam burst is :

$$Q_c = N_c \int_0^{T_c} i_c \cdot dt = N_c \cdot i_c \cdot T_c$$

The precision of the calibration of the beam monitor depends upon the precision with which i_c and T_c are measured and upon their stability.

The time interval T_c must be stable to $\pm 0.1\%$, and the current i_c to $\pm 1\%$ to match the expected precision of the monitor.

4.3 Elements

4.3.1 The Transformer

The transformer must fulfil the following requirements :

a) To have a core of toroidal form, because of the good coupling to the beam and of the insensitivity to the beam position inside its aperture.

b) To have a window larger than the section of the beam, the diameter of which is ≤ 8 cm.

c) To occupy, magnetic shielding included, not more than 40 cm. in the proton flight direction.

Furthermore :

d) The magnetic core must have a relative permeability as high as

possible in the frequency range 8 c - 80 kc. In fact the secondary winding must have a low number of turns, to get a high transfer ratio for the preamplifier, and a high inductivity, to get a favourable low frequency limit of the preamplifier pass band.

Depending upon what we could get from the industry, the transformer core consists of 5 uncut strip wound toroids of Ultraperm 10, mounted together to form a single toroid, of internal diameter $D_1 = 12$ cm, external diameter $D_2 = 22$ cm, width $b = 20$ cm, and strip thickness $d = 0,05$ mm.

Ultraperm 10 is a magnetic material which has a $\mu_5 = 120,000$, and a high μ is necessary to obtain a high secondary winding inductivity when the number of turns must be kept low.

In fact, for a toroidal core, the inductivity of a winding is given by the formula :

$$L = 2N^2 b \log_e \frac{D_2}{D_1} \cdot 10^{-9} \cdot \mu_r \text{ (henry)}$$

where N is the number of turns, b is the length in cm, μ_r is the relative permeability.

The permeability of the Ultraperm 10 depends strongly upon the external magnetic field, see fig. 5, and we were able to shield the transformer in such a way as to get a $\mu = 50,000$ (at initial permeability). The strip thickness of 0.05 mm has been chosen because of the good μ vs. frequency characteristics, see fig. 6.

The core is put in a plastic container, filled with silicon rubber to reduce the influence of mechanical vibrations from the surroundings, and to prevent mechanical stresses of the material which would reduce its permeability. The secondary winding consists of 2 x 50 turns of thin copper wire, symmetrically wound to eliminate the effect of electrostatic pick-up from the beam and ionisation from stray protons.

It has :

$$L = 2.6 \text{ henry (for 50 turns)}$$

The auxiliary winding for calibration consists of 10 turns.

$$L = 100 \text{ mH}$$

The winding wire is fixed on the plastic case by silicon rubber to avoid

movements of the coils.

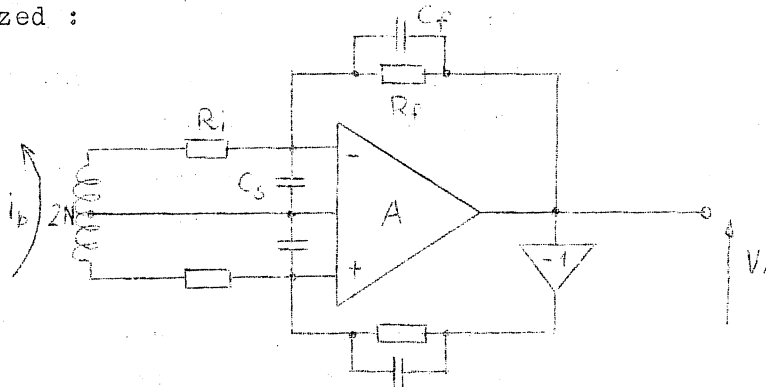
4.3.2 The Transformer Shielding and Support

The shielding consists of an external cylinder of thick iron and of 6 coaxial cylinders, 3 of 5000 H2 and 3 of mumetal. The cylinders are closed at the ends by rings of the same material and of appropriate dimensions. See fig. 7 for constructional details.

It reduces the maximum external magnetic field of 500 gauss to ≤ 1 gauss, and acts also as shielding against RF disturbances. To prevent the transmission of mechanical vibrations from ground, the shielded transformer is put on shock absorbers and rubber foam supports are interposed between the coaxial cylinders of the shielding.

4.3.3 The Preamplifier

To eliminate the asymmetry effects which could arise from scattered protons, electrostatic pick-up from the beam, radio frequency pick-up inside the opening of the core etc., the secondary ends are fed into the positive and negative inputs of the operational amplifier, while its centre is connected to the amplifier ground. The feedback circuits must be obviously perfectly symmetrical. The system can be so schematized :



- where :
- i_b beam current
 - $2N$ number of turns of the secondary
 - R_i resistance of coil + stabilization resistance
 - R_f feedback resistance
 - C_s stray capacity of coil + capacity of cable between transformer and amplifier + input capacity of amplifier
 - A amplifier nominal gain
 - V_1 output voltage

The transfer ratio of the device is then :

$$\frac{V_1}{i_b} = R_f/2N \quad (7)$$

while the low and high frequency limits of the bandwidth remain as in (4) and (5).

From (7) one can see easily that to get the high transfer ratio necessary because of the low current signals to be detected, N must be small and R_f great.

In terms of the Fourier analysis of an isolated pulse, which we take of rectangular shape to be the most difficult case, a large pass-band, extending from dc, is necessary in order to have an undisturbed output pulse.

For instance, to amplify a rectangular calibration pulse 200 μ sec long with a rise-time of about 1% of its length and a droop of about 1% of its height, a pass-band of approximately 8 c - 80 kc is required.

From (4) and (5) to get such a large pass-band, L must be high, C_s and $(R_f/A + R_i)$ small.

Moreover, one must try to get a high signal to noise ratio. The low frequency noise is most dangerous, while the RF noise is averaged out in the integrator*. These are contrasting necessities, and we were obliged to adopt a compromise solution.

One can be satisfied with a high frequency limit much lower than 80 kc, if interested chiefly in the result of the integration of the beam signal. The low frequency limit is still extremely important, because too high a droop reduces drastically the result of the second integration.

For the transformer, we chose then the above mentioned dimensions and a number of secondary turns $N = 50$, from which we obtained :

$$\begin{aligned} L &= 2,6 \text{ henry} \\ R_L &= 100 \text{ Ohm} \\ C_s &\sim 1 \text{ nF} \end{aligned}$$

We decided to use a Nexus CLA - 12 operational amplifier, which has

* The low frequency noise of the amplifier goes up at lower frequencies.

the following characteristics :

$$\begin{aligned} A &= 10^5 \\ i_{\text{drift}} &= 0.2 \mu\text{A}/^\circ\text{C} \text{ (referred to the input)} \\ e_{\text{drift}} &= \pm 3 \mu\text{V}/^\circ\text{C} \text{ (referred to the input)} \end{aligned}$$

Unity gain crossover frequency = 1.5 Mc
and the configuration of fig. 8

C_1 is inserted to have a high input impedance at dc and to achieve with R_f a high feedback factor and therefore a good dc stabilization. C_f is used to compensate the overshoot due to the input capacity C . R_1 is necessary to damp over the resonance of L and C_1 . It introduces a change of the low frequency limit.

We obtained :

$$\begin{aligned} \text{Transfer ratio } \frac{V_1}{I_b} &= 0.1 \text{ V}/\mu\text{A} \text{ (using an additional amplifier with a gain of 10)} \\ f_{\text{low}} &= 6 \text{ c} \\ f_{\text{high}} &= 20 \text{ kc.} \\ V_{\text{noise}} &= 20 \text{ mV(p.p.)} \\ V_{\text{noise}} &= 50 \text{ mV (total including external source disturbances)} \end{aligned}$$

See fig. 9 and photographs. When the repetition frequency of the beam bursts increases, the loss of dc reference level in the output signal due to the lower frequency limit, begins to introduce an important error in the integrator even if the integrator is reset to zero after each burst. To reduce this error, and to reduce also the noise level affecting conversion, a switch between the first and the second integrator is closed only for 300 μsec during the beam or calibration signal time and a switch to ground is opened in this time. In this way after each burst signal the zero level is restored before the following signal arrives. See photo.

The switch consists of a double transistor 3 N 74 driven through a transformer to insulate it. The switch to restore the dc value consists of a FET and a condenser and is driven directly.

4.3.4 The RC integrator

An operational Nexus DL-1 amplifier is used as it has enough current output to drive quickly the feedback condenser. The "reset to zero" switch across the feedback condenser consists of a FET switch. The integrator time constant is 100 μ sec.

4.3.5 The Conversion Unit

The conversion unit consists of a pulse generator to compensate the charge of the feedback capacitor of the second integrator down to zero.

This pulse generator is made of a temperature compensated voltage reference source (Fairchild RVL-1), stable at $\pm 0.1\%$, of a precision resistance, of a fast flip-flop and a gate.

The gate is driven by the flip-flop, which is set by a "start conversion" pulse. This is provided by the time sequence unit, after the opening of the output switch of the pre amplifier, to avoid the influence of the noise of this amplifier on conversion. The flip-flop is then reset by a "0" comparator amplifier (Nexus ESL-12) which detects the zero cross-over of the integrator. See diagram in fig. 3.

To avoid oscillations, which would arise in the zero detector due to the fluctuations across zero of the preceding amplifier noise, we use a fictitious, slightly negative "zero" level to stop conversion.

4.3.6 The "0" suppression unit

The time signal to be measured is given by the direct output of the flip-flop of the conversion unit. Because of the fictitious "0" level used to stop conversion, there is an unwanted time signal from the flip-flop also in absence of any beam or calibration signal from the transformer.

To suppress this "0" signal we use a monostable, the time of which is deducted from the total signal by an AND gate, see fig. 10.

4.3.7 The time sequence unit

The time sequence unit consists of a monostable and two flip-flops. See fig. 11.

A synchronization pulse, coming either from the frequency discriminator or from the 100 c or 1 kc time base of the counter, sets the monostable and the flip-flops. These open the "zero restore switch" and the "integrator reset switch", and close the "integrator output switch".

After a delay of 300 μ sec, supplied by the monostable, the conversion is started and the input switch is opened.

When the conversion is completed, a stop pulse from the "zero discriminator" resets the elements of the unit to their initial state, closing again the reset switch of the integrator and the zero restoring switch.

To be sure of starting always from the "initial" state, another resetting of the unit elements takes place when the apparatus is switched on.

4.3.8 The Frequency Discriminator

It consists of a limiter, to be free of amplitude modulation, and of a tunable narrow band amplifier. At the tuning frequency, a Schmitt trigger delivers a pulse, used for the synchronization of the system functions.

4.3.9 The Electronic Counter

A Hewlett-Packard electronic counter 5245 L, a 50 Mc counter, is presently used, exploiting its full capabilities of remote control. It measures the length of the conversion pulses coming from the "0" suppression unit. Different switching circuits for the synchronization of the time bases have been added to allow measurements per pulse, per second and per time interval, either for the beam or for the calibration pulses. See block diagram in figs. 12 and 13.

a) single pulse

The built-in 10 Mc oscillator of the 5245 L is switched to the Main Gate through the internal gate 6, actuated by the time signal to be measured. The Main Gate, which determines the time base of the measurement, is actuated by the same signal through gate 5, period trigger, gate 12 and the Gate Flip-Flop. This allows a 10 Mc pulse train, as long as the time signal to be measured, to be counted by the decimal counters.

b) per second

The Main Gate is now actuated by a one second pulse coming from the decade divider assembly, in which the 1 Mc standard frequency of the counter

is scaled down by a factor 10^6 .

The one second pulse is produced actuating gate 27 by a flip-flop, set by the synchronization pulse coming from the frequency discriminator a little before a beam burst and reset by the reset pulse of the counters, while gates 3,7,8,9,10 and 11 are actuated continuously. When calibrating the monitor, using the time bases of 100 c or 1 kc for synchronization, the gate 27 is also actuated continuously.

c) per time interval

The Main Gate is driven at will, by feeding negative voltages on the Start and Stop points of the Gate Flip-Flop.

Moreover, to have measurements of time periods of full seconds, the Start and Stop signals are synchronized on the counter time bases. Between Start and Stop, the time is measured by a mechanical counter.

4.3.10 The Calibration Unit

It consists of a temperature compensated, high stability voltage reference source (Fairchild RVL-1) stable to $\pm 0,1\%$, used already for conversion, feeding through a 100 k ohm resistance and a switch into the 10 turns calibration winding of the transformer.

The switch is closed by a flip-flop for time intervals of 100 μ sec controlled by the 1 Mc temperature stabilized quartz oscillator of the counter through a system of a decade, a monostable and an "AND" gate. See fig. 14.

A synchronization pulse coming from the frequency discriminator or from a time base of the counter sets the monostable for $\sim 150 \mu$ sec.

The "AND" gate is actuated by the direct output of the monostable and lets the 100 kc from the decade A 28 of the counter pass to the pre-set decade scaler. The leading edge of the third 100 kc pulse coming sets the flip-flop, the direct output of which closes the switch. After 100 μ sec, the flip-flop is reset by the decade scaler and the switch is blocked.

In this way the 100 μ sec interval is stable to better than $\pm 1\%$. Some additional errors are produced by residual on-resistance of the transistor switch and the effect of its storage time. The stability of the calibration pulse, in intensity and in duration is thus approximately $\pm 1\%$.

5. PRECISION OF THE MONITOR

One should distinguish between absolute and relative precision of an electromagnetic beam monitor.

The relative precision is the precision with which the monitor measures calibration pulses fed through the transformer aperture. The absolute precision depends upon the precision with which the charge of the calibration pulses is known.

For the present monitor, the charge of the pulses delivered by the calibration unit has been measured* at better than 1% and has been recognized to be stable at better than 0.2%.

So, if the relative precision of the monitor is of the same order of magnitude or worse one can speak of absolute precision, just using the aforementioned calibration pulses as standard.

Now, the electromagnetic beam monitor is fundamentally an integrator.

In single burst measurements, the charge induced by a burst of protons is integrated and, once converted to a time signal, measured by the electronic counter. The counter's reading is then affected by an error, due mainly to the integrated noise from the coil and the preamplifier. In fact the higher frequency noise is averaged out in the integrator, but the lower frequency noise is still of importance. This error becomes more important if the burst charge decreases. In per second and long time measurements, a second integration is accomplished in the counter, and the error due to the noise is reduced again. This allows the measurement of the intensity of the beam when the value of the charge of the singlebursts is low e.g. as in Slow Extraction.**

The precision of the monitor has been determined by using the current pulses delivered by its own calibration unit as standard. The following table in which the charge of the calibration pulses has been converted into protons shows some results :

* By an integrating digital voltmeter

** The signal is inside the noise.

	calibration pulse	per second measurement
Fast Extraction (54 c/sec)	10^{10} protons	$5,4 \cdot 10^{11}$ p/sec $\pm 1\%$
Slow Extraction (500 c/sec)	$4 \cdot 10^8$ protons	$2 \cdot 10^{11}$ p/sec $\pm 2,5\%$
Slow Extraction (1000 c/sec)	$2 \cdot 10^8$ protons	$2 \cdot 10^{11}$ p/sec $\pm 2,5\%$

Measurements of the CERN synchro-cyclotron Extracted Proton Beam yielded the following results :

Fast extraction	$3,8 \cdot 10^{11}$ p/sec $\pm 2\%$ (instability of the machine) $\pm 2\%$ (precision)
Slow extraction (1000 c/sec)	$2,2 \cdot 10^{11}$ p/sec $\pm 2,5\%$
Slow extraction (500 c/sec)	$1,6 \cdot 10^{11}$ p/sec $\pm 2,5\%$

ACKNOWLEDGEMENTS

We gratefully acknowledge the valuable advice and the material help of the PS Electronic Laboratory, especially in the persons of Messrs. S. Battisti and K. Unser, which made it possible to start the project.

We are much indebted to Dr. H. Beger and Dr. A. Fiebig for helpful discussion and advice, and we would also like to thank Dr. G. Brianti for his constant support and kind encouragement.

REFERENCES

- 1) Private Communication
- 2) P.H. Burr, CEAL - 1008.
- 3) G.W. Tautfest, H.R. Fechter, Rev. Sci. Instr. 26, 229 (1955).
S.I. Taimuty, B.S. Deaver, Jr., Rev. Sci. Instr. 32, 1098 (1961).
- 4) C.E. Swartz, G.S. Levine, 87 Electronique Nucléaire 1963.
- 5) C.E. Swartz, Rev. Sci. Instr. 24, 851 (1953).
H. Zullinger, MPS/Int. DL 64-21.
- 6) R. Yamada, Japanese Journal of App. Phys., 1, 92 (1962).
J.B. Sharp, MPS/Int. CO 62-15.
- 7) J.B. Sharp, MPS/Int. CO 62-15.
K. Unser, MPS/Int. 65-20.
S. Battisti, MPS/Int. 66-1.
- 8) L. Holcomb et al., Nucl. Instr. and Methods, 24, 399 (1963).
- 9) R.W. Dressel, Nucl. Instr. and Methods, 24, 61 (1963).

APPENDIX

- A. RATIO MEASUREMENT
 - B. THE AUTOMATIC "ZERO" SUPPRESSION
 - C. MAGNETIC SHIELDING TESTS
 - D. SUPPORT OF THE TRANSFORMER
-

A. RATIO MEASUREMENT

To measure the ratio of two beam signals (i.e. the beam before and after a bending magnet or a target) a second transformer is used with its preamplifier and integrator. See fig. 15.

Both signals are simultaneously integrated in the time t_1 until t_2 then stored in the integrating condensers until t_3 .

At t_3 two constant tensions are available at the outputs of the integrators A and B. The values are proportional to the charge of one burst of beam A and one burst of beam B respectively.

Now, in the normal intensity measurement the charge stored in the condenser of the integrator is compensated down to zero by a pulse with a fixed level of + 10 V. Here, in the ratio measurement, the fixed level is replaced by a level produced by the beam itself : in fact, the larger integrated beam value is used for the compensation (conversion),

Then

$$V_{a_2} = -\frac{1}{R_a C} \cdot \int_{t_1}^{t_2} V_{a_1} \cdot dt + V_{a_0} \quad \text{at } t_0 \dots t_1$$

$$V_{b_2} = -\frac{1}{R_b C} \cdot \int_{t_1}^{t_2} V_{b_1} \cdot dt + V_{b_0}$$

$$V_{a_0} = V_{b_0} = 0$$

Using for instance V_{a_2} to compensate V_{b_2} it will be :

$$-\frac{1}{R_c C} \int_{t_2}^{t_3} V_{a_2} dt + V_{b_2} = 0$$

when the compensation is accomplished.

V_{a_2} is each time a constant voltage. Then :

$$-\frac{1}{R_c C} \cdot V_{a_2} (t_3 - t_2) + V_{b_2} = 0$$

$$\frac{1}{R_c C} \cdot V_{a_2} (t_3 - t_2) = V_{b_2}$$

from which :

$$t_C = t_3 - t_2 = \frac{V_{b_2}}{V_{a_2}} \cdot R_c C$$

The time constant $R_c C$ is chosen so that on our counter a reading of 1.000.... is displayed when $\frac{V_{b_2}}{V_{a_2}} = 1$. The number of digits after the decimal point depends upon whether the ratio of one burst or the mean value over 10 or 100 bursts is measured.

For

1 burst	-	1.000	*
10 bursts	-	10.000	*
100 bursts	-	100.000	*

Normally $\frac{V_{b_2}}{V_{a_2}} < 1$. Nevertheless also values between 1 and 2 can be measured if signal B should be larger than signal A.

The precision is also of the order of $\pm 2\%$ for 100 bursts measurements in Fast Extraction.

For lower values, the influence of random noise reduces the precision.

B. THE AUTOMATIC "ZERO" SUPPRESSION.

The simple "zero" suppression unit described above subtracts from the total time signal a mean value of the unwanted "zero" signal, calculated once over a certain number of cycles, in the absence of the beam.

Such a fixed time subtraction works satisfactorily for high burst signals, but if the signal to noise ratio is very low, as it is in the Slow Extraction mode of the synchrocyclotron, it becomes an important source of error.

In the automatic "zero" suppression unit here described, the "zero" signal is measured for each burst signal, and then subtracted from it.

* The last 2 digits are not significant

This is done by starting an additional "zero" measuring cycle after each burst - therefore in very similar conditions of internal and external source noise. This cycle has exactly the same characteristics (opening times of the switches etc.) as the normal measuring cycle. The incoming noise, the temperature and time drift, etc., are then integrated in the same manner as in the beam measuring cycle.

The "zero" signal so obtained is put in digital form, stored and then subtracted from the beam signal ("zero" included) of the next cycle. The digital storage has been chosen because of its freedom from drift, which is a serious problem in analogue integrators.

The storage device is a reversal counter consisting of solid state flip-flops, which acts as a variable preset delay. The preset delay is produced by the "zero" signal in the "count down" position of the reversal counter*. When the burst signal arrives, the counter is switched to "count up" and the beginning of a coincidence signal to an AND-gate is delayed until the preset delay time is over. Then the burst signal, from which the "zero" value has been deducted, can pass the AND-gate and be fed into the 5245 L counter to be measured and displayed. See fig. 16.

C. MAGNETIC SHIELDING TESTS.

The shielding of the magnetic core described before has been tested with an AC field of 50 c produced by two copper coils with a diameter of 1 m placed at a distance of 1 m from each other (Helmholz coils).

The transformer was placed in the centre first without, then with the shielding.

It has been found that the worst case is with the field in the direction of the toroid axis (= beam direction). In this case, the shielding factor is :

$$F = 330$$

For a magnetic field at 90° to the beam direction, the shielding is about 10 times better with a sharp maximum of ≈ 10.000 at an angle of around 90° .

The above mentioned copper coils have been put with their field

* The "count up" and "count down" signals come from the modified time sequence unit.

at 90° to the beam direction and at 90° to the direction of the DC stray field of the synchrocyclotron.

The values of the shielding factor are then between the worst case and the best case conditions :

No DC magnetic field	:	shielding factor after demagnetization	1800
With DC magnetic field 500...700 G (with 1800 A)	:		600*

D. SUPPORT OF THE TRANSFORMER.

There is a high level of vibrations in the place where the transformer is put, produced by the tuning fork (with a frequency of 54 c), and also by the vacuum pumps and the water pumps (with a frequency of ~ 30 c) of the synchro-cyclotron.

If the shielded transformer is put directly on a rigid frame support, a 54 c sinusoidal voltage as high as the maximum beam signal, appears at the output of the preamplifier. This disturbance, in phase with the beam (synchronous noise) introduces a big error in the measurements.

To reduce these microphonic effects, the transformer, with its shielding, has been fixed on antivibration mounts. As the insulation increases nearly with the square of the ratio of the exciting frequency to the resonance frequency of the system "shielded transformer-antivibration mounts" the latter frequency should be kept as low as possible. Moreover, to avoid strong and long lasting oscillations at this resonance frequency, the damping factor of the system should be high, also if this reduces slightly the insulation.

Using 4 shock absorbers, consisting of a metallic spring with a steel-wool damper inside, the following values have been obtained

$$\text{Resonance frequency } f_n \approx 4 \text{ c}$$

$$\text{Q-value } Q \approx 2,5$$

Using the following formula to calculate the attenuation factor

* due to saturation of the external shielding parts

$$A \approx \frac{\sqrt{1 + \left(\frac{1}{Q} \cdot \frac{f}{f_n}\right)^2}}{1 - \left(\frac{f}{f_n}\right)^2}$$

where f is the frequency, one obtains for 54 c :

$$A = 0,03$$

Measurements gave the following results :

54 c voltage at the output of the preamplifier without shock absorbers	: 1,3 V _{pp} *
54 c voltage at the output of the preamplifier with shock absorbers	: 40 mV _{pp}

which correspond to :

$$A \approx 0,03$$

The antivibration mounts used are Vibrachoc Type W 227-11.

(Vibrachoc,
39, rue des Mathurins,
PARIS VIIIe.)

* For comparison, the maximum beam produces a signal of 1,6 V_{pp}.

LIST OF FIGURES

1. SC Hall
2. Block diagram of the beam monitor
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11. Block diagram of the time sequence unit
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- 13a-f Time bases of the counter
14. Block diagram of the calibration unit
15. Block diagram of the ratio measurement unit
16. Block diagram of the automatic "zero" suppression unit
17. Photos of the instrument.

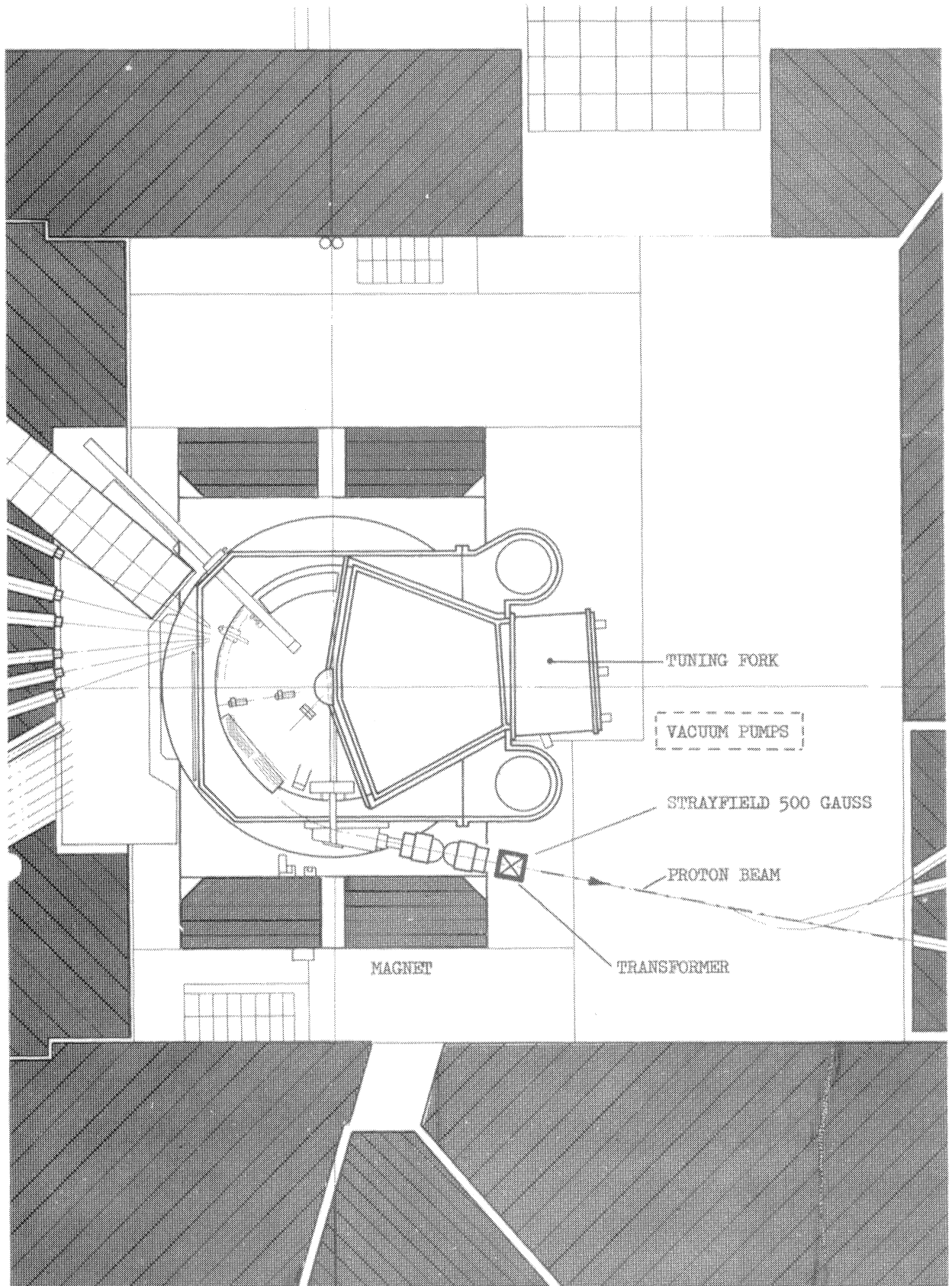


Fig. 1 POSITION OF THE TRANSFORMER IN THE CERN - SC HALL

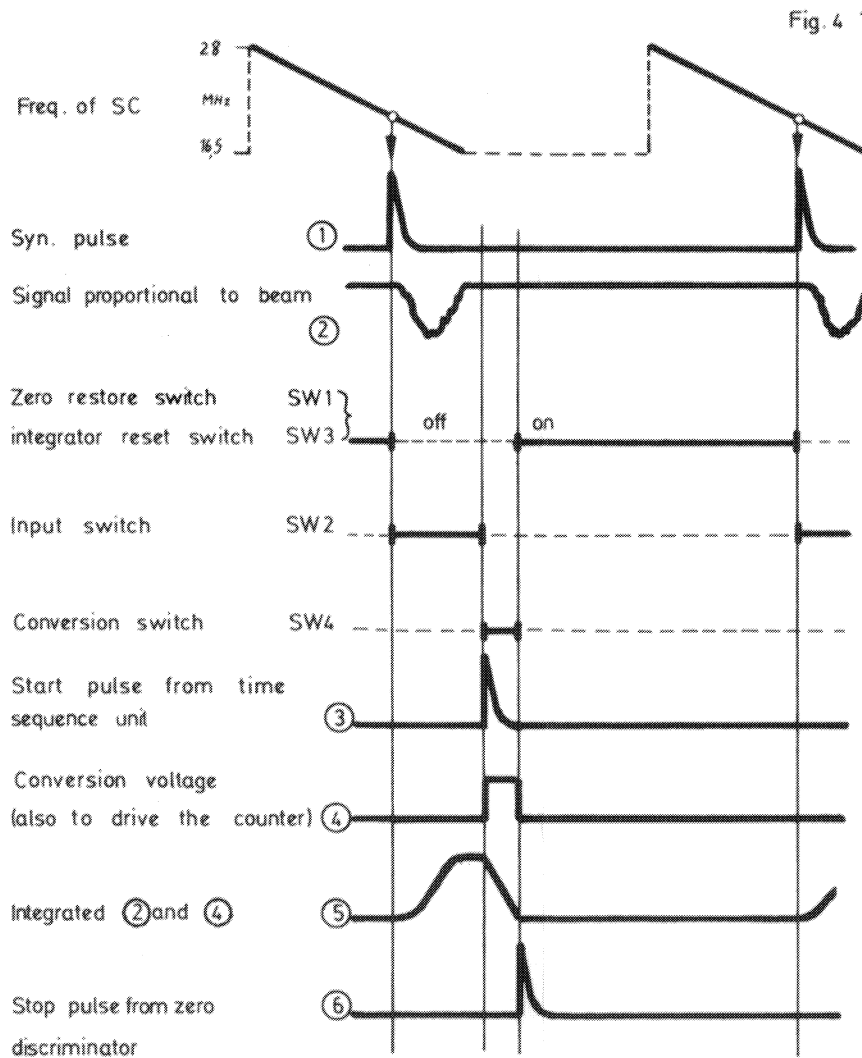
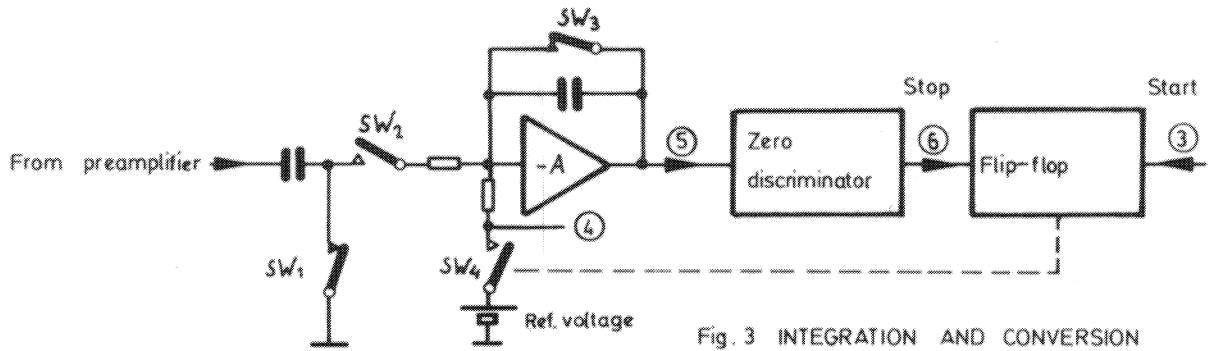
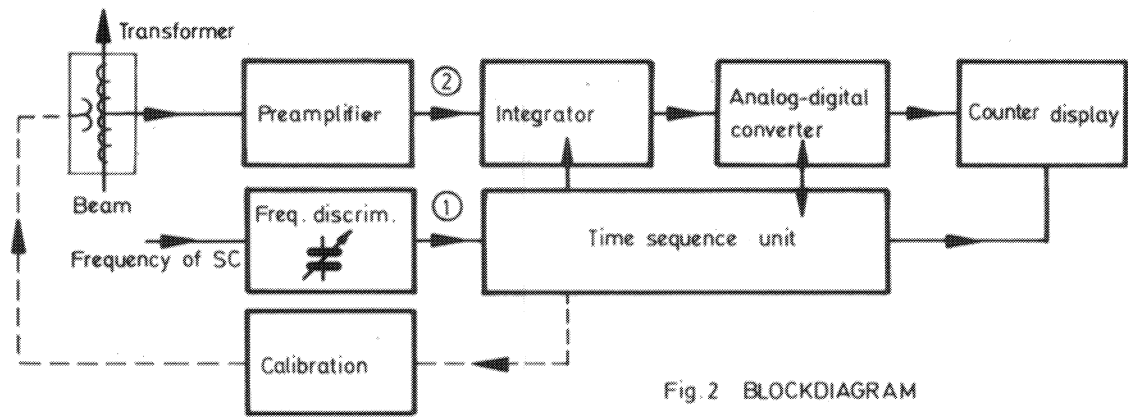


Fig 5 RELATIVE PERMEABILITY

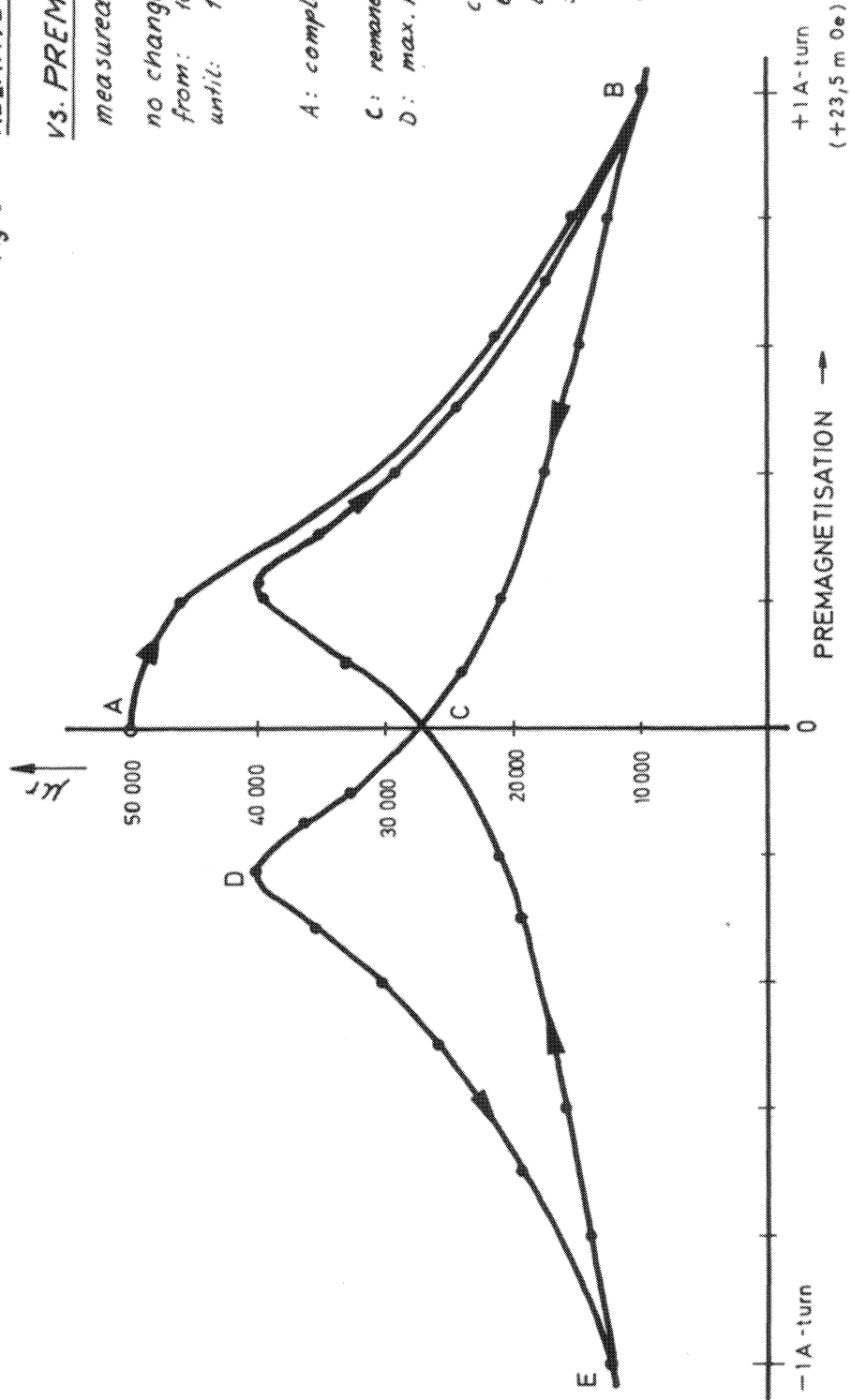
vs. PREMAGNETISATION

measured with AC of 100Hz

no change of result when magnetized
 from: $100 \mu A_{pp}$ -turns ($\approx 2,3 \mu Oe_{pp}$)
 until: $10 mA_{pp}$ -turns ($\approx 2,50 \mu Oe_{pp}$)

- A: completely demagnetized
 (max $40 A_{pp}$ -turns, 50Hz)
- C: remanent Permeability
- D: max. reversible Permeability

core: **ULTRAPER 10**
 ext. ϕ 220mm, int. ϕ 120mm
 length 200mm
 strip thickness 0,05mm
 fixed in silicon rubber
 magnetically shielded.



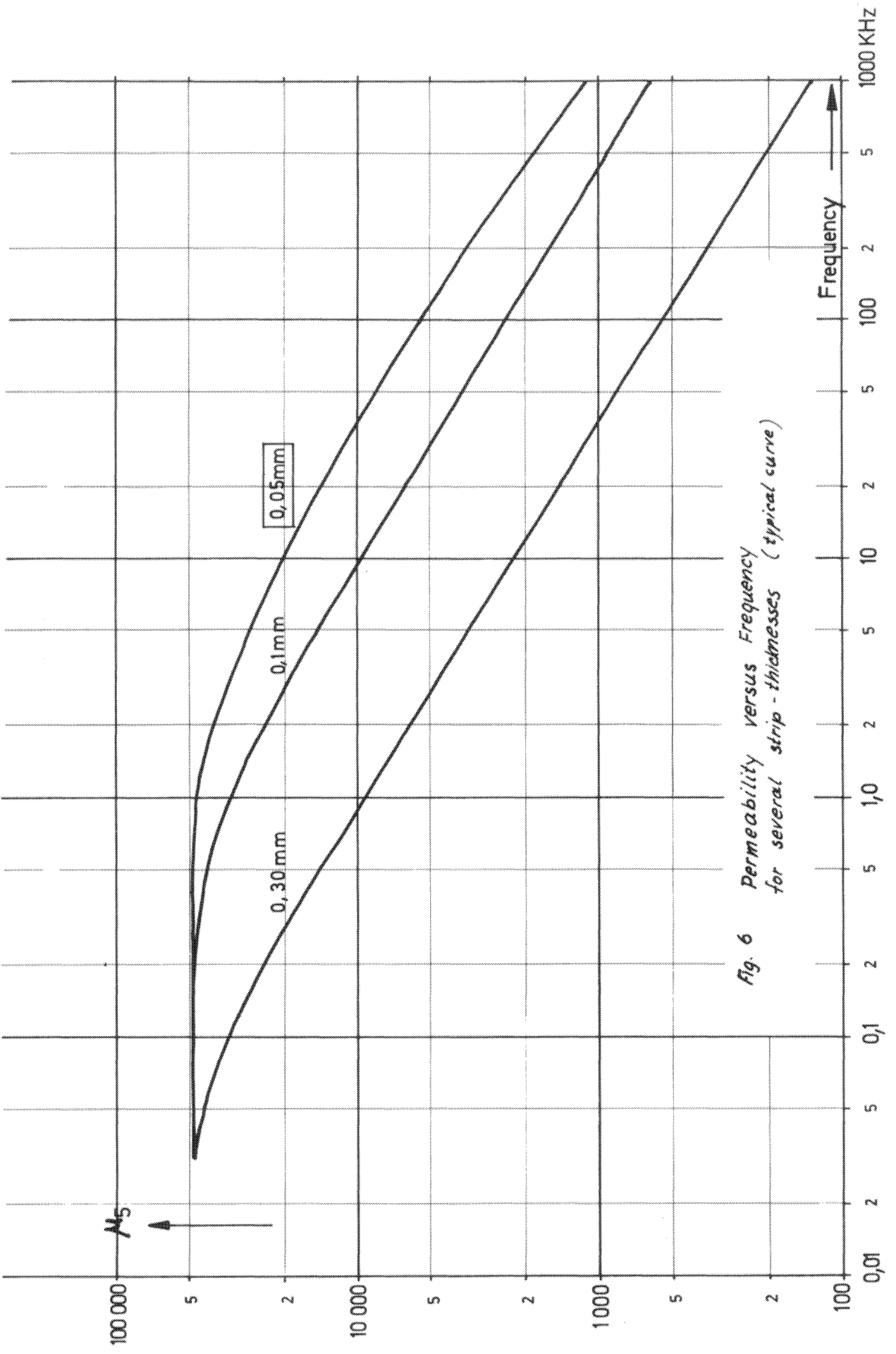
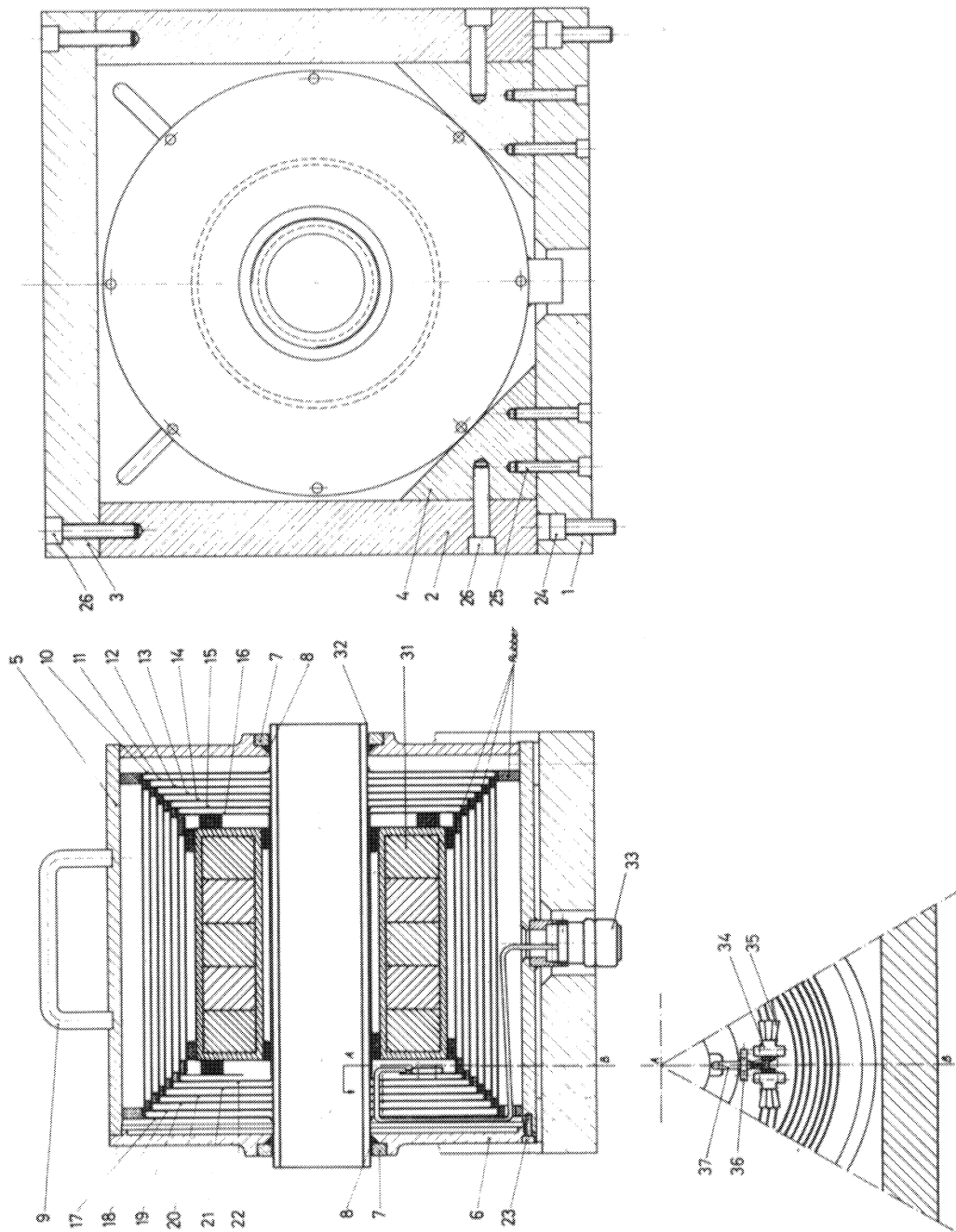


Fig. 6 Permeability versus Frequency for several strip - thicknesses (typical curve)



No.	Designation	Material	Quantity	Remarks
37	Cable			
36	Connector main Shield			
35	Connector female Shield			
34	Connector female Shield			
33	Table 1753			
32	Transformer Uulperem 10			
31	Socket Head Cap Screw			
30	Shielding Cover			
29	Shielding Cover			
28	Shielding Cover			
27	Shielding Cover			
26	Shielding Cover			
25	Shielding Cover			
24	Shielding Cover			
23	Shielding Cover			
22	Shielding Cover			
21	Shielding Cover			
20	Shielding Cover			
19	Shielding Cover			
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17	Shielding Cover			
16	Shielding Cover			
15	Shielding Cover			
14	Shielding Cover			
13	Shielding Cover			
12	Shielding Cover			
11	Shielding Cover			
10	Shielding Cover			
9	Shielding Cover			
8	Shielding Cover			
7	Shielding Cover			
6	Shielding Cover			
5	Shielding Cover			
4	Shielding Cover			
3	Shielding Cover			
2	Shielding Cover			
1	Shielding Cover			

Fig 7 Shielding of Transformer

Fig 7

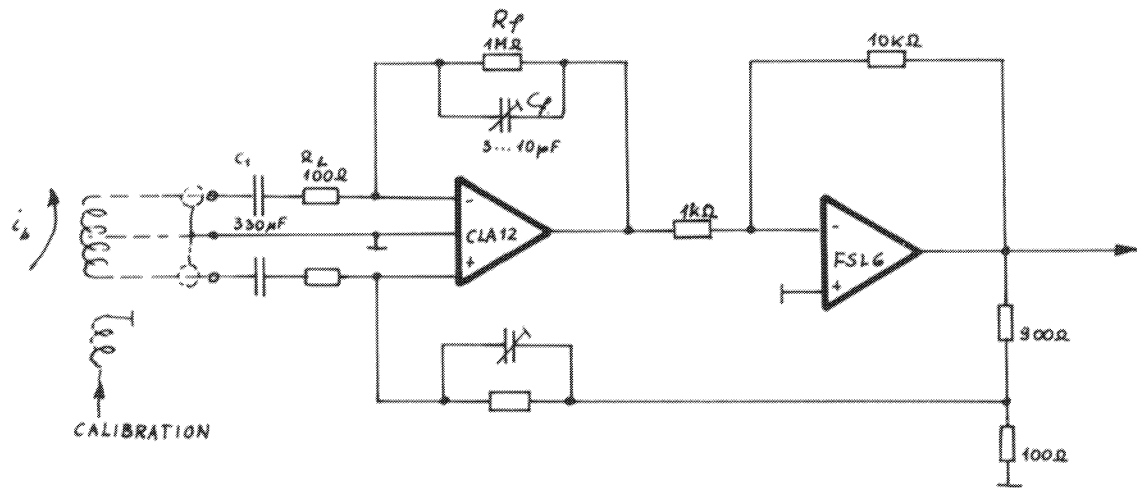


Fig. 8 PREAMPLIFIER

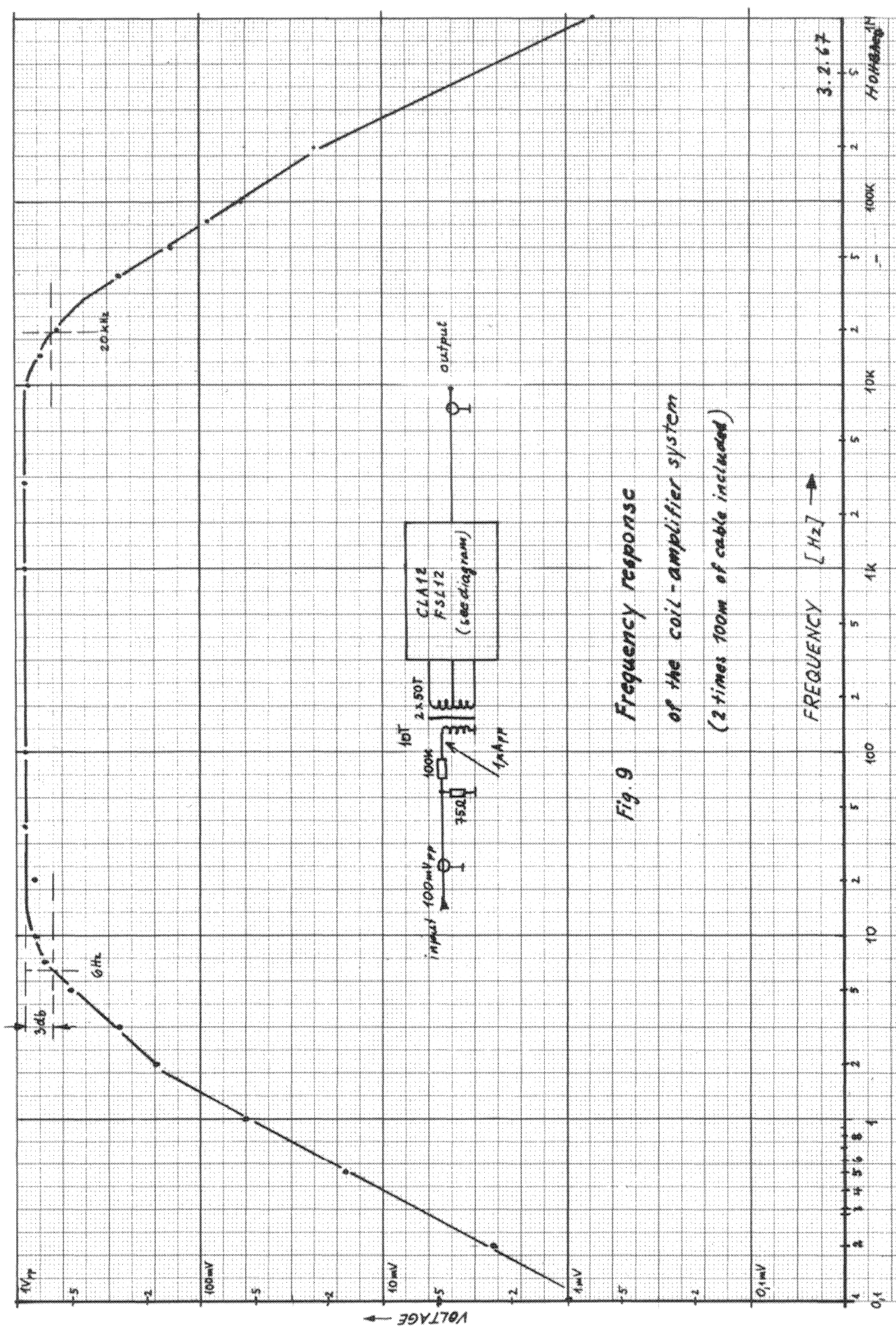


Fig. 9 Frequency response of the coil-amplifier system (2 times 100m of cable included)

3.2.67

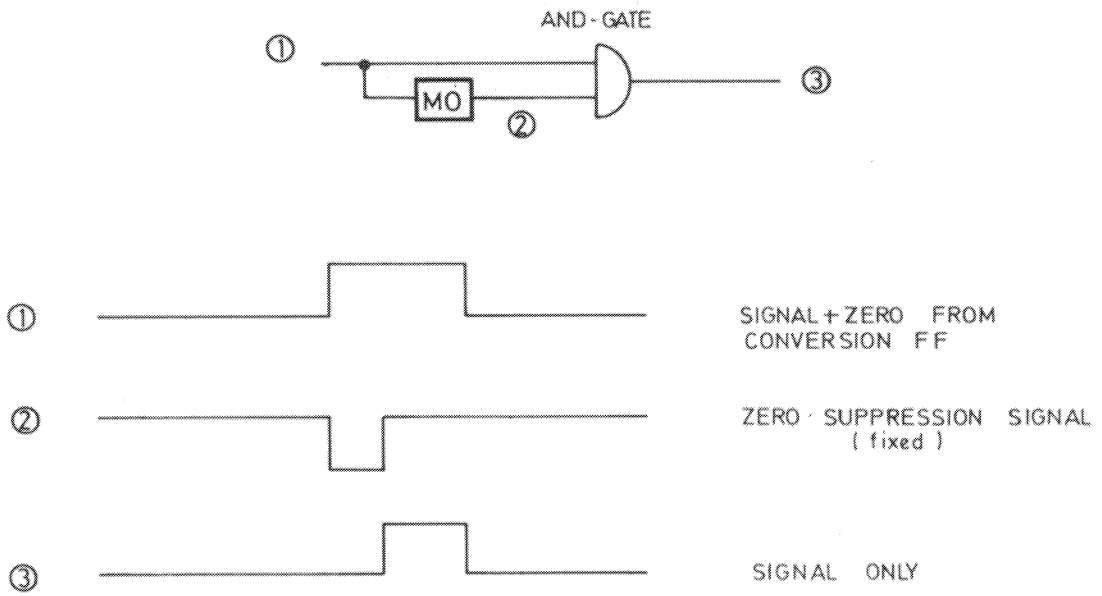


Fig 10 ZERO SUPPRESSION BLOCK DIAGRAM

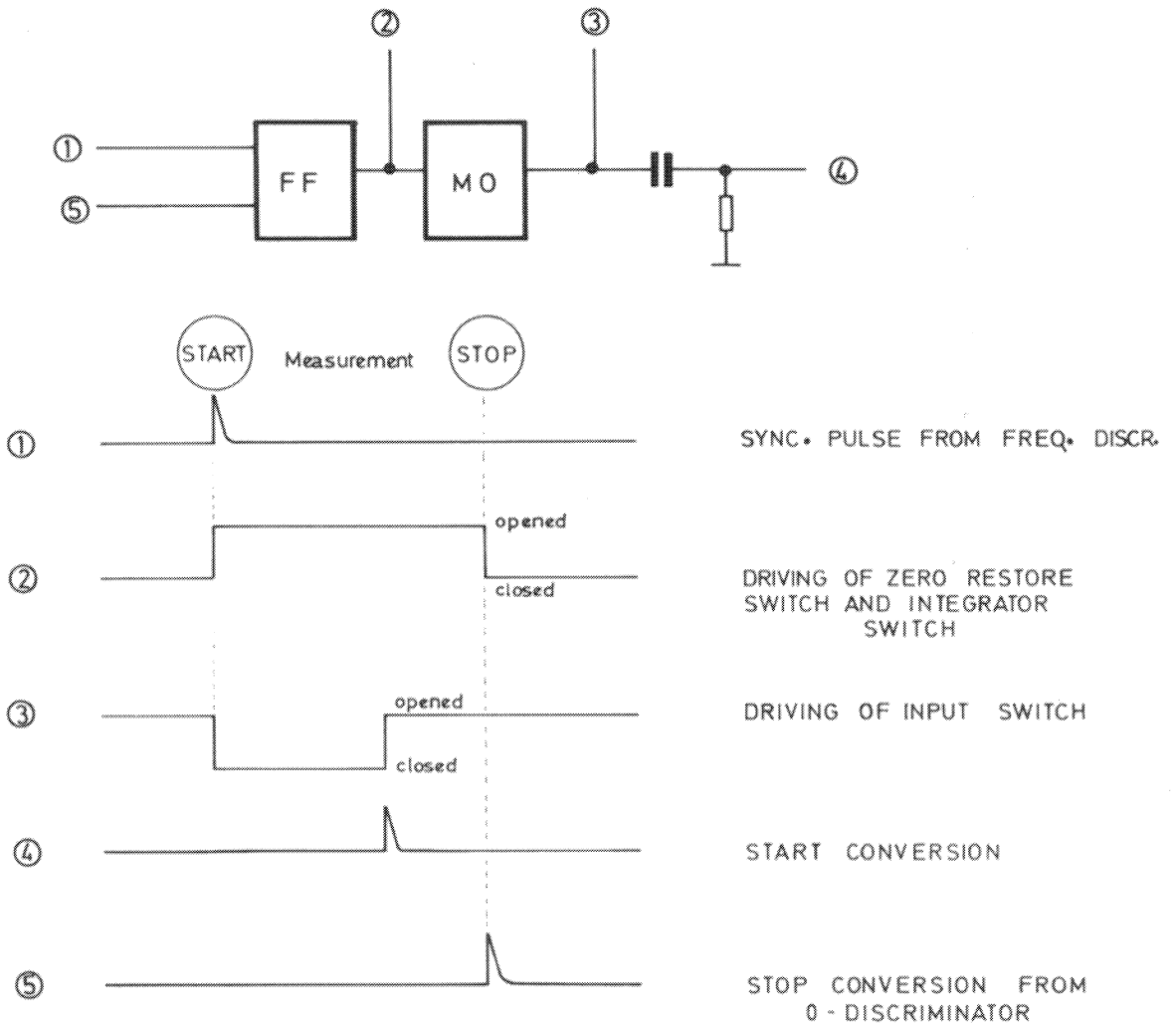


Fig 11 TIME SEQUENCE UNIT BLOCK DIAGRAM

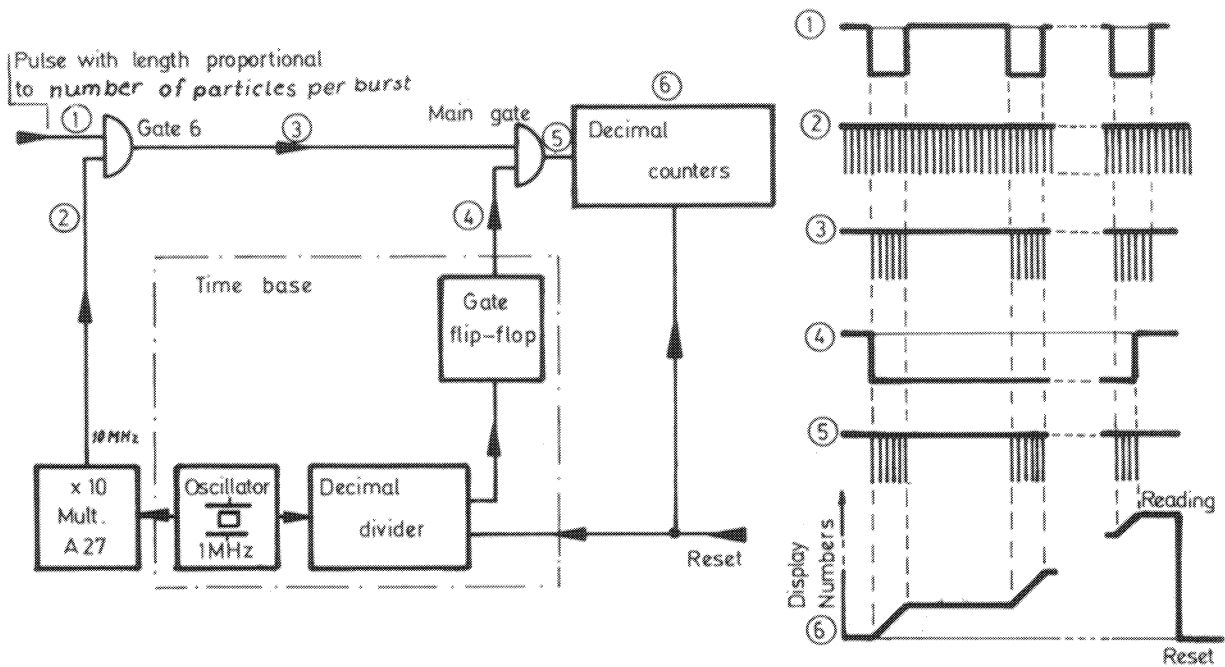


Fig. 12 BLOCKDIAGRAM OF THE COUNTER (Hewlett-Packard)

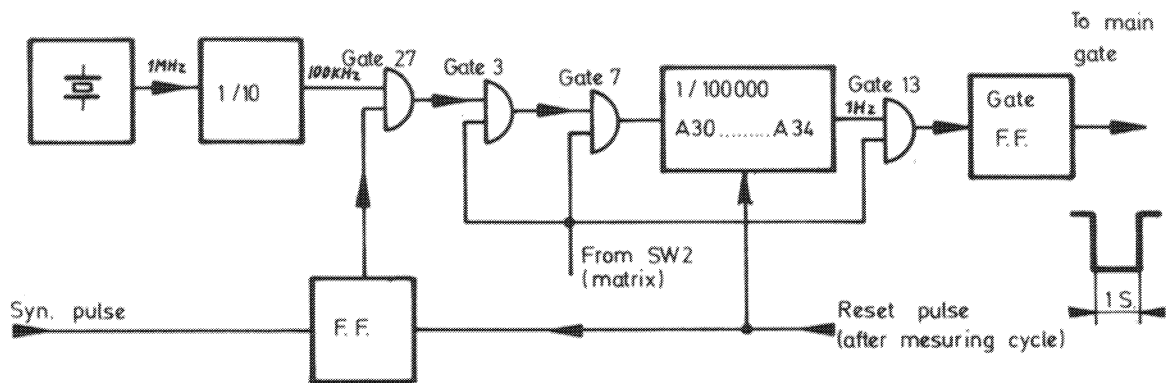


Fig. 13a TIME BASE FOR 1 S.

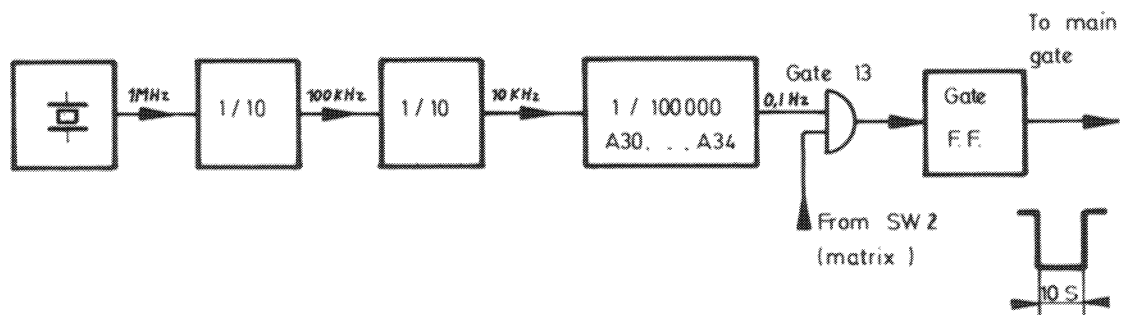


Fig. 13b TIME BASE FOR 10 S.

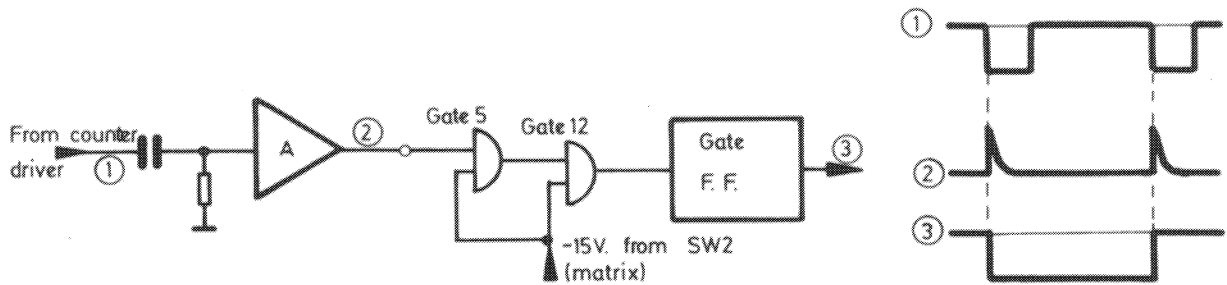


Fig. 13c TIME BASE FOR 1 PULSE MEASUREMENT

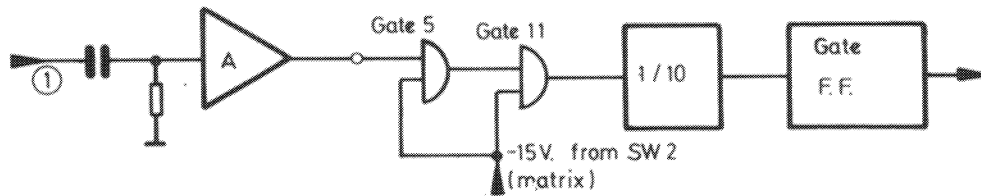


Fig. 13d TIME BASE FOR 10 PULSES MEASUREMENT (mean value over 10 pulses)

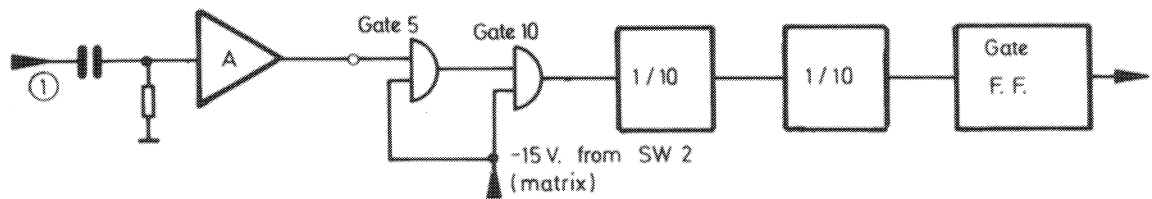


Fig. 13e TIME BASE FOR 100 PULSES MEASUREMENT (mean value over 100 pulses)

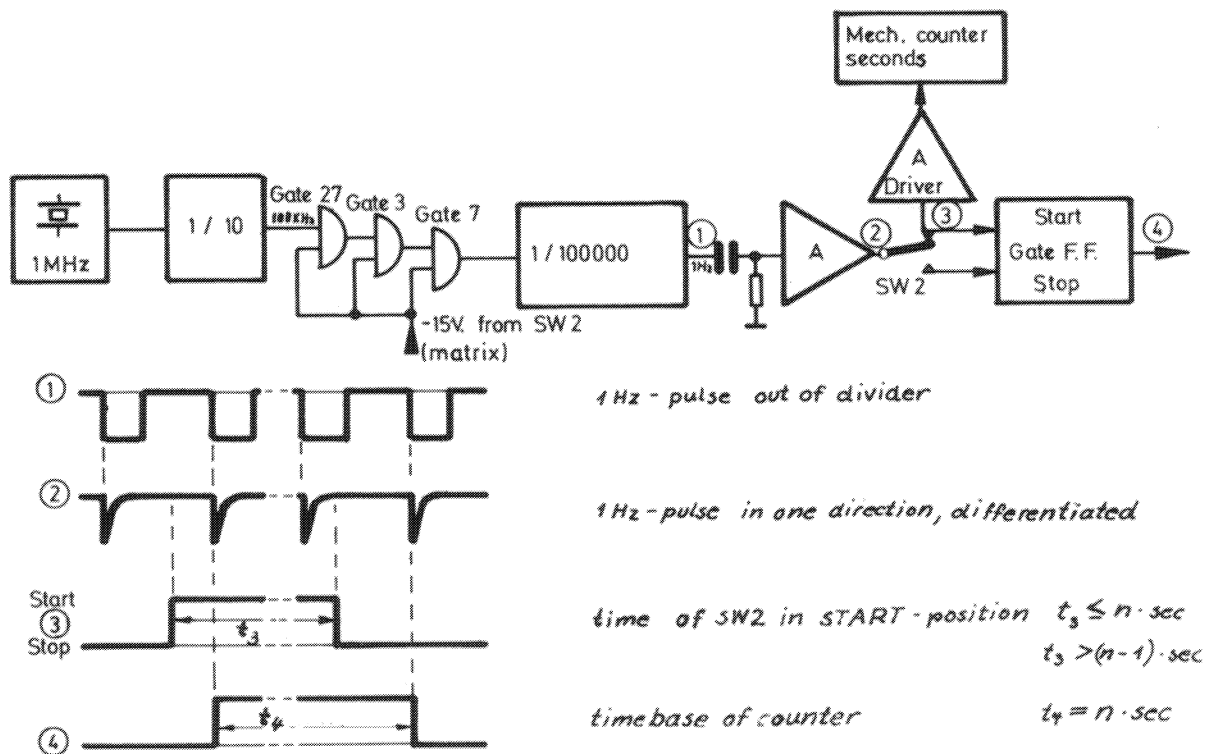


Fig. 13f MANUAL (in one sec. multiples) IT MEASURES ALWAYS EXACTLY FULL SEC.

CALIBRATION

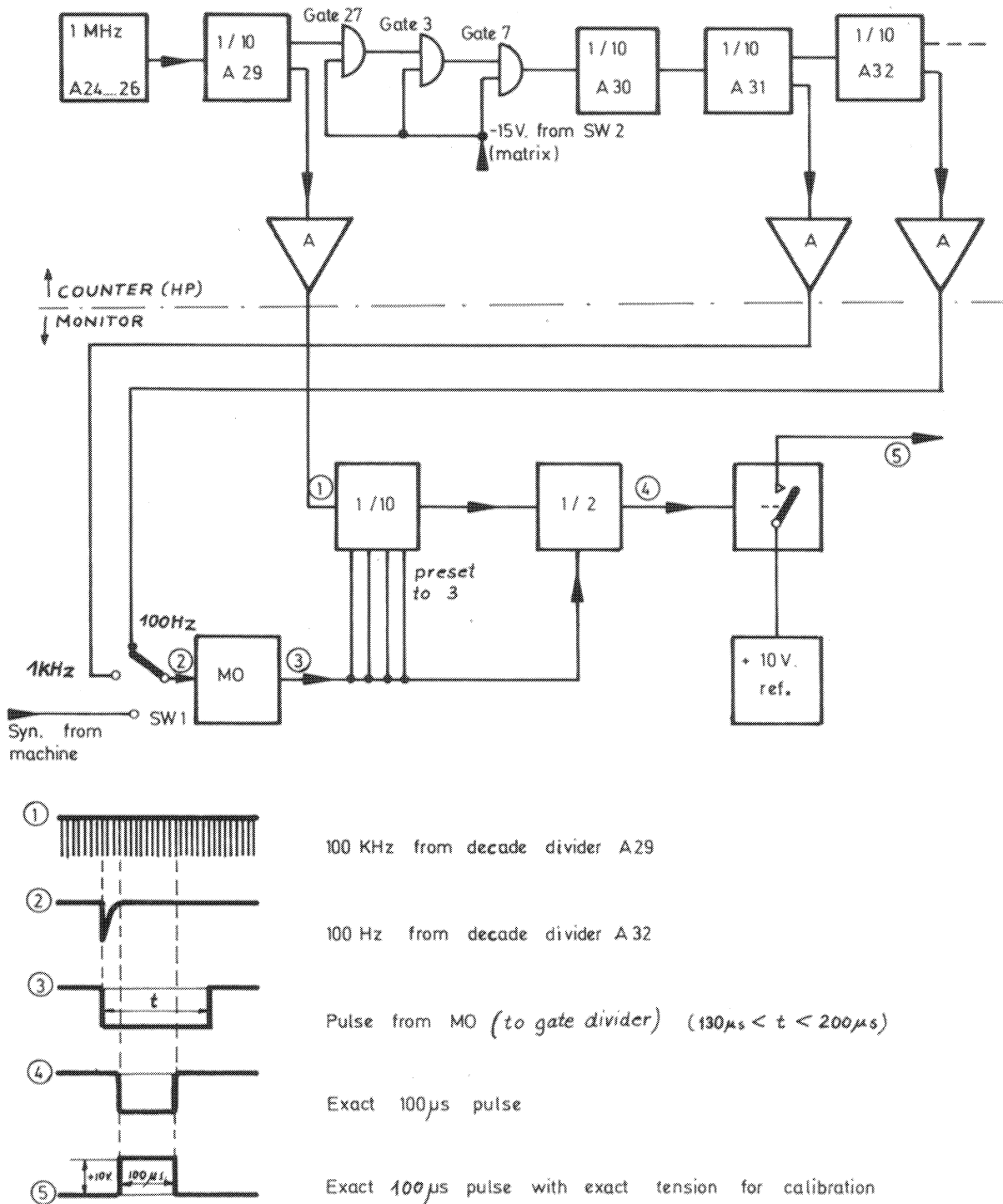
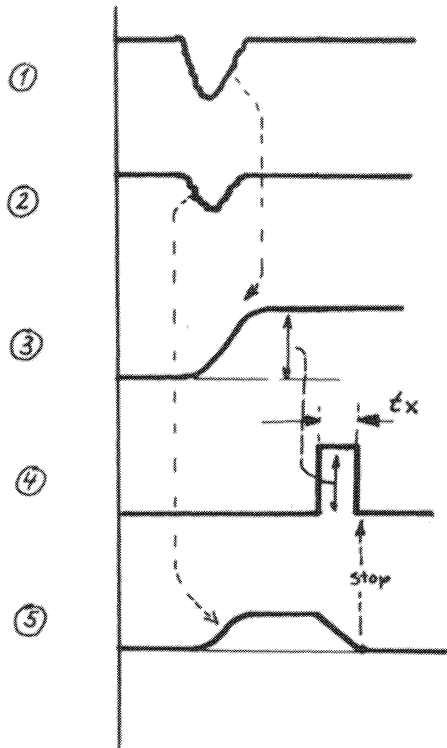
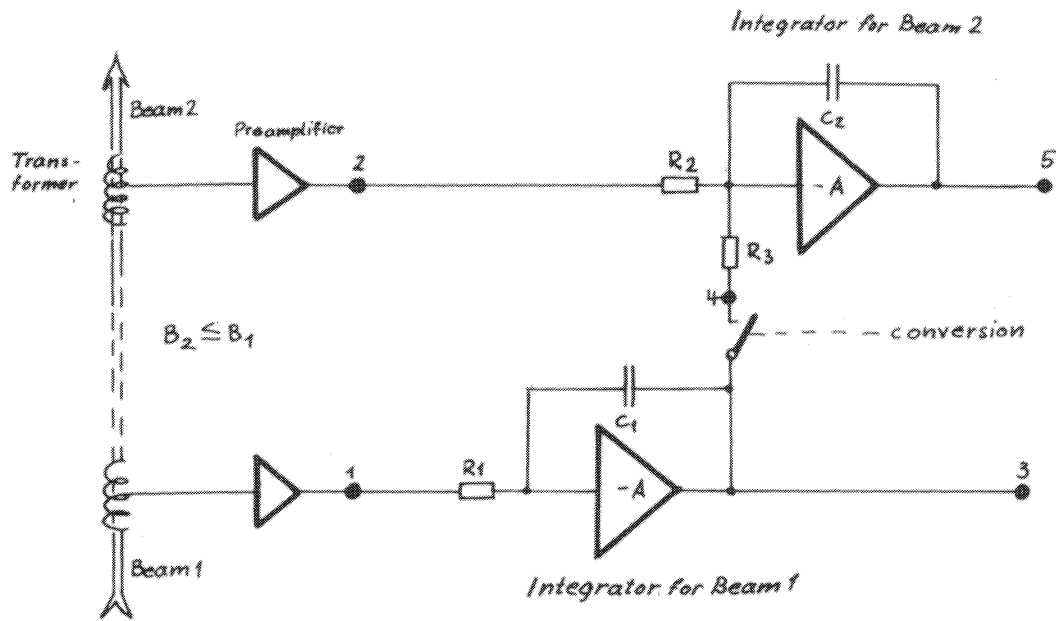


Fig. 14 TIME BASE FROM COUNTER FOR CALIBRATION PURPOSE



Voltage proportional to beam 1

----- 2

integrated voltage of beam 1
to be used as conversion voltage

conversion pulse, started by time seq.
unit. Stopped by Zero-passing of ⑤.
Length is proportional to Ratio B_2/B_1

Integrated voltage of beam 2 with
integrated conversion pulse,

$$t_x \approx \frac{B_2}{B_1}$$

Fig. 15 RATIO - Measurement

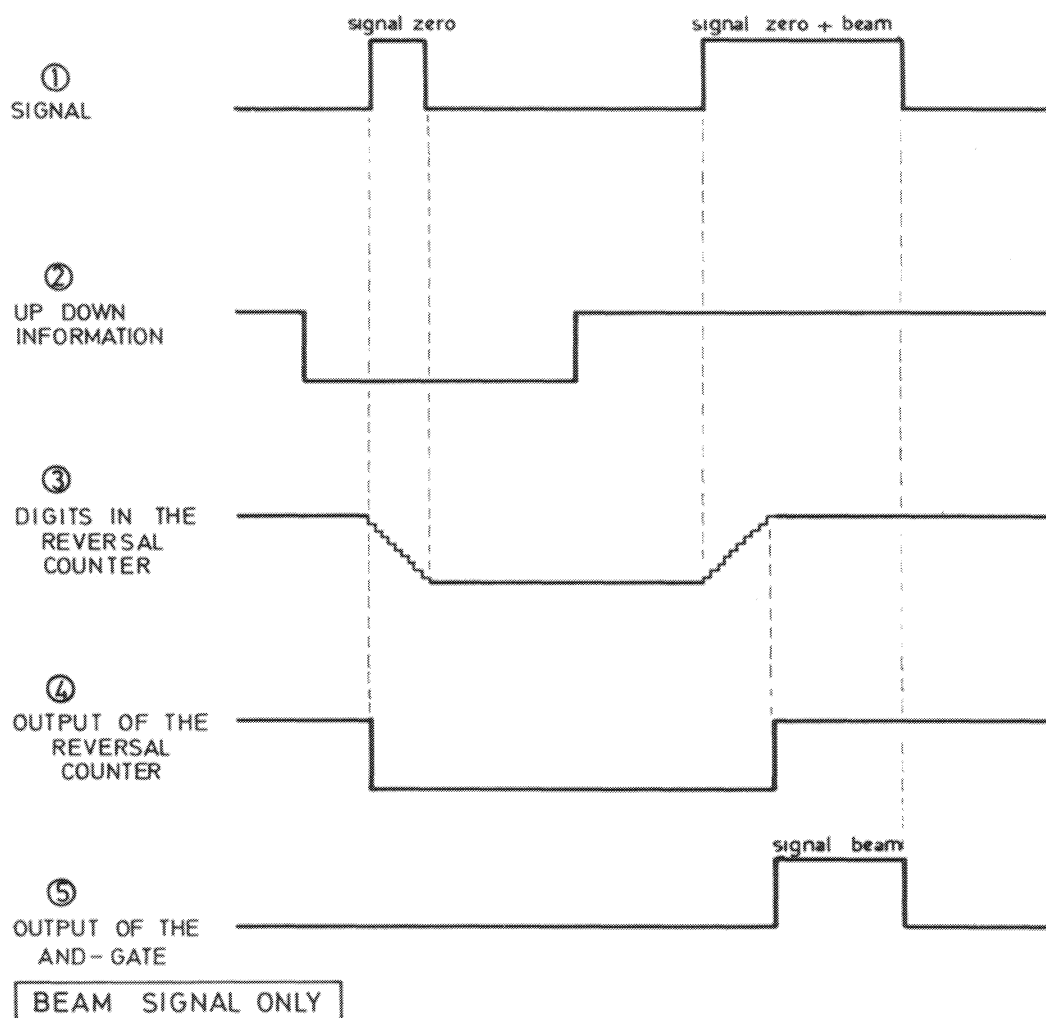
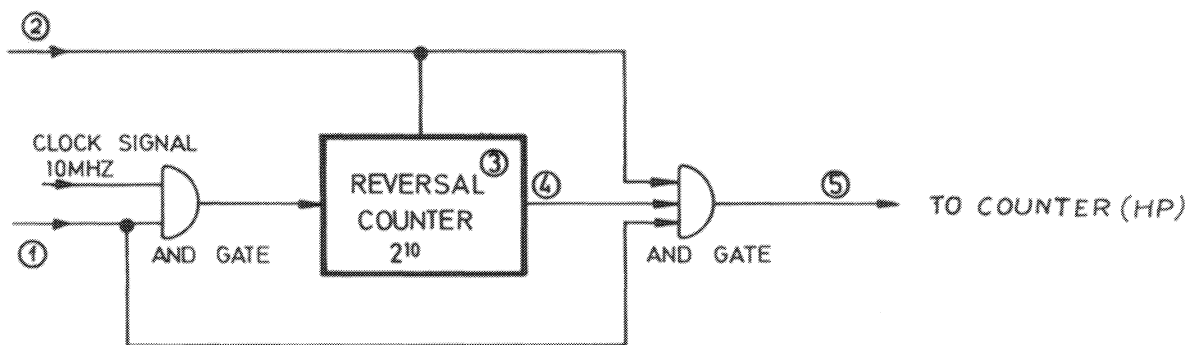
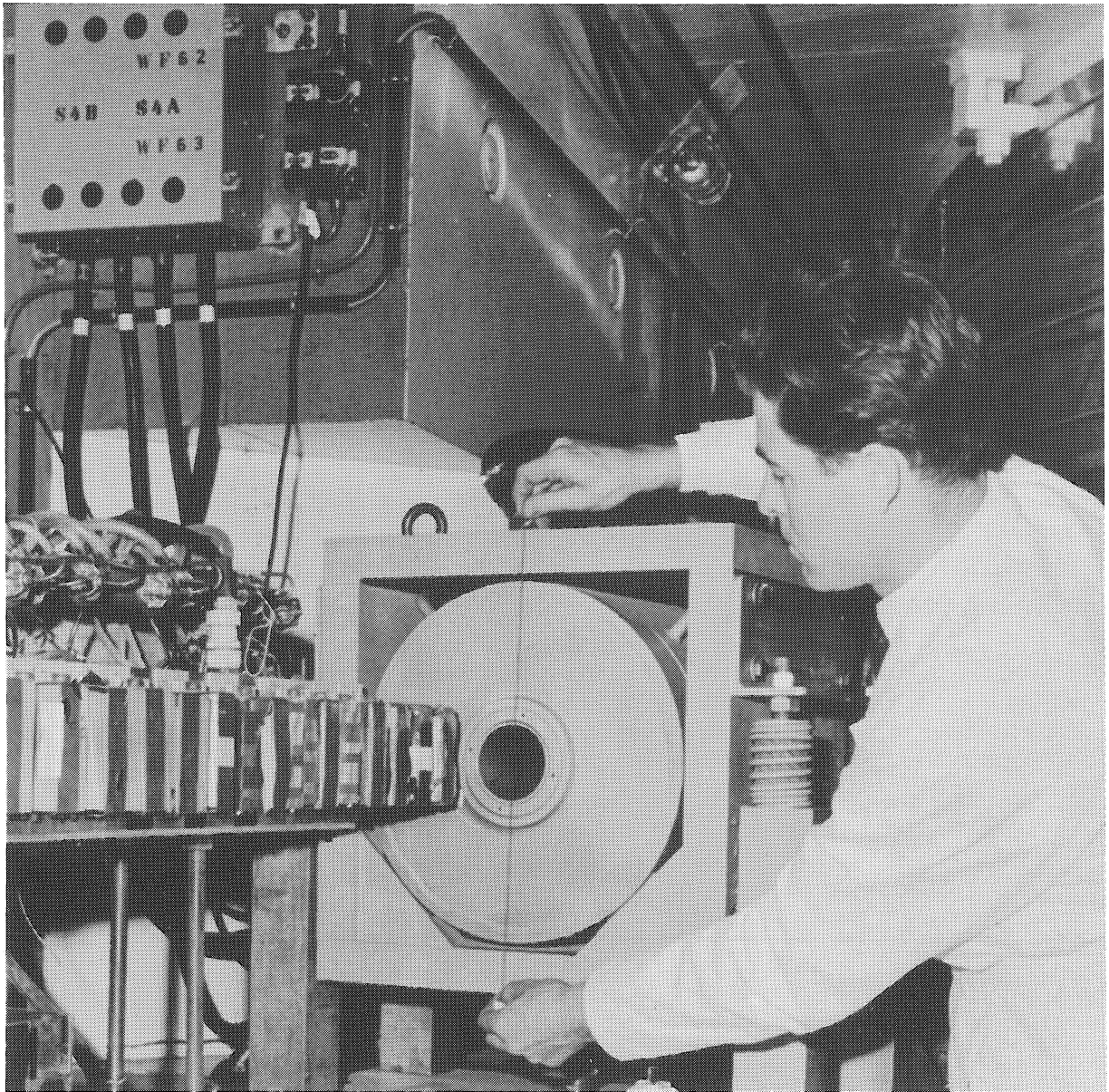


Fig. 16 AUTOMATIC ZERO SUPPRESSION

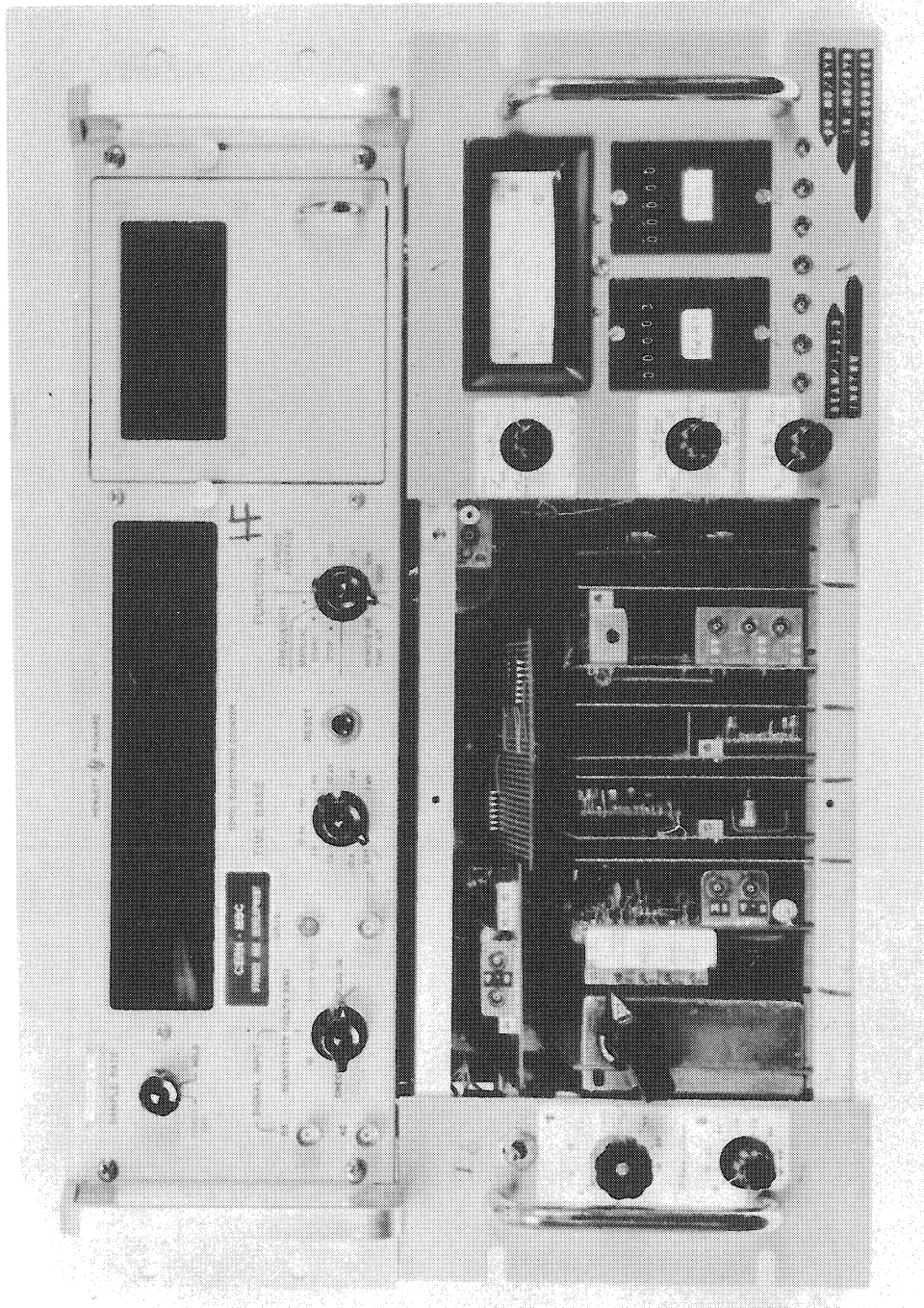


Transformer at the proton beam output of the Synchro Cyclotron
(with antivibration mount and magnetic shielding)

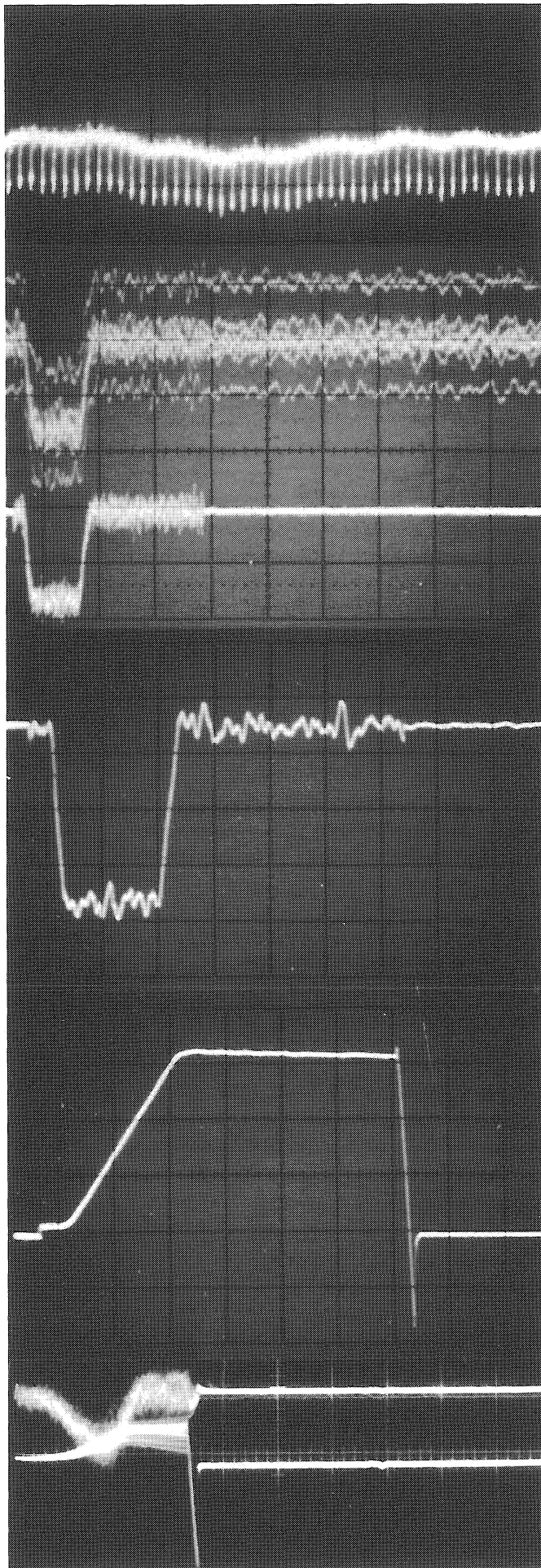
in the background: the SC magnet

in the foreground : some moveable targets

Photo 1



Monitor in connection with the Hewlett-Packard counter



Suppression of the low frequency noise influence with the zero restore switch (with calibration signal of $0,8 \mu\text{App}$ and $100 \mu\text{s} = 5 \cdot 10^8$ protons/pulse as in slow extraction mode)

a) Preamplifier output voltage
(5 ms/cm, 0,1 V/cm)

b) As above, but 50 $\mu\text{s/cm}$, 50 mV/cm

c) After the zero restore switch

d) Preamplifier output voltage after the zero restore switch, with calibration signal of $1,6 \mu\text{App}$ and $100 \mu\text{s} = 5 \cdot 10^9$ protons/pulse
(50 $\mu\text{s/cm}$, 50 mV/cm)

e) Integrator output voltage,
positive slope: integration
negative slope: conversion

f) Preamplifier output voltage after the zero restore switch, with slow extraction beam

g) Integrator output voltage (integration of the above signal)