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INJECTION LINE BEAM CURRENT TRANSFORMER SYSTEM FOR THE PS BOOSTER

(General description)

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1. Purpose and specifications of the system

In the BR part of the Booster injection line there are five current transformers (see Fig. 1). The first called BI.TRA 10 is placed on the Booster side of the Linac shielding and the four others are located after the vertical Distributor. They are called: BI4.TRA20, BI3.TRA20, BI2.TRA20, BI1.TRA20 (one transformer for each PSB ring).

The purpose of these five transformers is to measure the number of protons injected into the PSB and to calculate the Distributor efficiency.

The total number of injected protons is measured by BI.TRA10 and corresponds to the integral of the beam current during the injection time.

The Distributor efficiency is the ratio between the integral of the current injected into one ring and the integral of the current measured by BI.TRA10 during the corresponding time interval.

The system specification and performance units are given in Table 1.

Table No. 1 - Specifications

Sensitivity of single range	2 x 10" to $2{,}510^{13}$ppp
Resolution	10^{10} protons
Accuracy over entire range	± 0,5%
Resolution of transmission efficiency	0.1%

2. The problem and outline of the solution chosen

The existing electronics did not come up to the new specifications, tightened up on account of the wish not to irrodiate the Distributor by the more intense beam from the new Linac.

To eliminate all the drift and non linearity errors of the measuring chain (Fig. 3) the solution adopted is to generate, after each measurement a calibration sequence. This minimises the errors due to the transformer itself and the associated electronics.

The voltage on the integrator output is converted into the number of protons injected. The relation between integrator voltage output and number of protons is the following (see Annex I):

$$N = \left(V_{INT} - V_{OS} - V_{QO}\right) \frac{RC}{Kq}$$

Since almost all parameters in the formula giving N are temperature and time dependant, even a system in which the constants are prestored and used for the calculation, will be insufficient to ensure the required precision. Especially since V_{Q_0} is a function of the integration time, to compensate for it would necessitate the measurement of this time.

The diagram of Fig. 2 represents the transfer function of the integrator voltage output versus the input charge.

The line passing through zero is the ideal transfer line, the other is the real one having an off set and a slope different from the ideal.

After the measurement V_M on the unknown charge Q_X, the calibration system generates two known charges Q_1 and Q_2 corresponding to the two integrator voltages outputs V_1 and V_2 respectively

Assuming the transfer function is linear between points A and B, one can write the formula shown on Fig. 3.

Since Δt_1, Δt_2, q are known, and V_M, V_1, V_2, I_{CAL} are measured the value N is easily computed by the micro-processor and, if the calibration is done after every measurement, all drift errors in the chain are compensated.

The system reduces drastically the preventive maintenance and gives a certitude of the results in the time.

Notice that the only absolute measurements in the whole system are the measurements of the five calibration currents.

Practically, to simplify the problem, instead of generating two calibration points around the measured value, a calibration sequence of four fixed points will divide the transfer function line in three parts and the calculations will be made using the appropriate segment.

During the reading cycle (Fig. 4) the value of the beam current measured by BI.IRA10 is sampled and held. The CALIBRATION CURRENT GENERATOR generates a current roughly equal to half the beam current since the calibration winding has two turns.

This current is injected in the five transformers during three different fixed time intervals, with normal integration and digitization.

At the end of the cycle the calibration current is again sent to the transformers during a longer time to measure its exact value.

The three integration times are produced by a binary divider driven by a quartz oscillator and their values are:

$$Q_4 = I_{CAL} \cdot 25.6 \; 10^{-6} \, \text{s full-scale}$$

$$Q_3 = I_{CAL} \cdot 6.4 \; 10^{-6} \, \text{s} \; \tfrac{1}{4} \; \text{full-scale}$$

$$Q_2 = I_{CAL} \cdot 1.6 \; 10^{6} \, \text{s} \; {}^{1}/_{16} \; \text{full-scale}$$

A fourth calibration is used to measure the transfer function origin (fourth point).

3. System's layout

This layout is shown in Fig. 2.

The beam at the LINAC output is a bunch train of 200 MHz having a maximum duration of about 150μs.

Since the beam transformer has a band width much lower than 200 MHz at its output the beam appears as a dc current corresponding to the average of the bunched beam.

The transformer features a high permeability toroidal core with two windings. The first, a twenty-turn winding, is used to measure the current beam; the second, a two-turn winding, is used for calibration purposes.

The CURRENT AMPLIFIER connected on the twenty-turn winding has an input impedance near to zero allowing the transformer to work as current generator.

The amplifier band width is from 1.6 Hz to 4 MHz and its output is differential.

The other element placed in the machine tunnel near the transformer is the CALIBRATION CURRENT GENERATOR; its purpose is to inject in the transformer a current corresponding as closely as possible to the beam. The current generator receives two control signals: one to define the value of the current to be generated and the second to define its duration.

The rest of the chain is situated outside the machine tunnel in the BOR.

The DIFFERENTIAL RECEIVER transforms the balanced output of the CURRENT AMPLIFIER into a single ended positive signal giving $10V/mA_{BEAM}$. Buffered outputs of this signal are used for observation purposes and sent via coax cables to MCR and/or to the SOS.

The GATED INTEGRATOR integrates the signal proportional to the beam during a time equal to the injection time. BI.TRA10 drives four integrators each one integrating a different part of the beam, while every BI.TRA20 drives its own integrator.

The integrator is also able to hold the integrated value during several milliseconds, allowing the necessary time for the digital conversion.

The integrator output is split to drive the local microprocessor controlled system and the remote computer controlled digitalisation.

The last element in the signal chain is the ANALOG TO DIGITAL CONVERTER which transforms the integral analog value into a 12 bit binary word.

On the other hand to measure the exact value of the calibration current the voltage across a very high precision 50 Ω resistor is also digitalized by another ADC.

4. Basic HARDWARE

The entire system (Fig. 5) comprises eight basic chains for the signals, and five channels to digitize the five calibration currents.

Apart from the CALIBRATION CURRENT GENERATOR and the CURRENT AMPLIFIER, all the analog parts of the system are housed in NIM modules.

The first module is the TWIN GATED INTEGRATOR inside which are two DIFFERENTIAL RECEIVERS followed by several BUFFERS and two GATED INTEGRATORS having buffered and split outputs. Four such modules are necessary.

The second module is the CURRENT GENERATOR CONTROLLER, it supplies to the five CURRENT GENERATORS the value of the current to be generated. This value is issued by BI.TRA10 as explained later.

Inside the module there are also the five high precision 50 Ω resistors and the five BUFFERS.

Another function of this module is the analog "OR" of the four BI.TRA20 signals to provide a SUM signal which is very useful for observation.

Only one such module is necessary. The third NIM module is the QUAD 12 bit ADC; it is controlled by a 16 bit bus and contains four 12 bit ADCs, the digital outputs are tied to a tri-state bus. Four of the sixteen bus lines are address lines and the address decoding is done with thumbwheel switches.

Four such modules are necessary: two for the eight integrators and two for the five calibration currents.

The last NIM module is the LOGIC CONTROLLER providing the fast timing and the interface with the microprocessor.

The microprocessor and the local display are housed in a 19 inch chassis under the NIM crate.

Every transformer, and its electronics, is connected to the NIM crate via a 6 QUAD VIDEO CABLE carrying all the necessary signals, including the power supplies.

5. Local microprocessor

As seen before, the BI.TRA system is not a simple data collection from integrator outputs but a complex calibration sequence followed by some calculations.

In the final set-up with the system connected via CAMAC to the central computers, calculations will be made outside the BI.TRA system; until this situation is reached the computed data are sent via a cable to the MCR to avoid a "black hole" during a year on injection transformers.

Later on the local microprocessor will be a useful tool for checking the system in the BOR and independent from the central computer system.

The tasks to be accomplished by the microprocessor are the following:

- Generate all calibration sequences
- Store all the digitized data
- Calculate the number of protons for each transformer and relative efficiencies
- Display the results on a local display
- Send the results in serial mode to MCR
- Generate a simulation to check the whole system.

The block diagram of the microprocessor is given in Fig. 6.

The hardware includes the CPU, one half K RAM to store temporary data; two ROMs to store the program; one ROM containing the monitor used as stand alone debugging tool; a memory extention card also used for development and debugging only; a serial peripheral interface ACIA to send the data to the MCR; a parallel interface PIA to connect the display/keyboard and used for the debugging; a PIA to drive the display/ selector for the DATA; a PIA to connect the logic controller and a PIA to control and read the 16 ADCs.

Notice that the keyboard/Display and the memory extension are plugged in the system only if necessary during the debugging and tests.

6. Timing

As seen before, to calculate the efficiency between BI.TRA10 and BI.TRA20 one must compare the charge seen by BI.TRA20 with the charge seen by BI.TRA10 during the time the beam is directed by the Distributor in one of the four rings.

Since the distributor switching can have a jitter too high with respect to its start pulses an internal timing is used.

There are two ways of having information about the exact time at which the beam is switched: one is to use the beam itself and the other is to use a signal issued by distributor current transformers.

The first system has several disadvantages: mainly the difference of the signal height at different intensities in addition to the noise on the flat top.

The second would be in principle the best, but some practical problems such as the distance from signal source to BI.TRA system and driving capability of the source signal, make this solution hard to implement.

In Fig. 7 are represented the wave forms and the basic network to generate a gate having, as accurately as possible, the same duration as the beam.

Both thresholds are trimmed to have a sensitivity down to 200 mV, corresponding to a beam of 20 mA.

Since the linac beam has on the flat top spikes as great as 10% of the signal, to avoid false triggering at high intensities the gate signal, derived from the general timing, make the comparators active only during a very short period around the beam commutation.

Note that the cable lengths between BI.TRA10, BI.TRA20 and the BOR are not the same; also the beam takes a certain time to go from one transformer to the other. When using BI.TRA20 to gate BI.TRA10 it is necessary to compensate the cable lengths. In fact all BI.TRA20 are delayed, after reception, by using integrated 50 Ω delay lines.

7. Conclusions

The system was installed and tested during the long shutdown of beginning 1979.

One year of service has demonstrated its precision and stability. It is certainly possible to improve its reliability by using, as timing source, a signal issued by the Distributor instead of using the beam itself.

This solution requires some modifications in the Distributor electronics and for the moment it is not planned.

Acknowledgements

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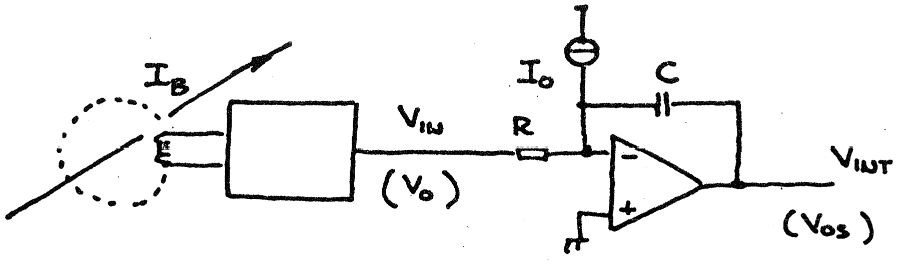
ANNEX 1

RELATION BETWEEN INTEGRATOR OUTPUT AND NUMBER OF PROTONS



$$V_{INT} = V_{os} + \frac{V_o}{RC}\Delta t + \frac{I_o}{C}\Delta t + \frac{V_{IN}}{RC}\Delta t$$

Assuming:

$$V_{IN} = K I_B \qquad \text{and} \qquad \frac{V_o}{RC}\Delta t + \frac{I_o}{RC}\Delta t = V_{Qo}$$

$$V_{INT} = V_{os} + V_{Qo} + \frac{K I_B \Delta t}{RC}$$

Since :

$$I_B . \Delta t = Q_B \qquad \text{and} \qquad N = \frac{Q_B}{q}$$

$$V_{INT} = V_{os} + V_{Qo} + \frac{K N q}{RC}$$

The formula giving N becomes :

$$N = (V_{INT} - V_{os} - V_{Qo})\frac{RC}{Kq}$$

Where :	
V_{INT}	is the measured integrator voltage output
V_{os}	is the voltage off-set of the integrator
V_{Qo}	is the voltage generated by all off-set currents
K	is the electronic chain transforming constant
q	is the proton charge $= 1.602\ 10^{-19}$ [C]

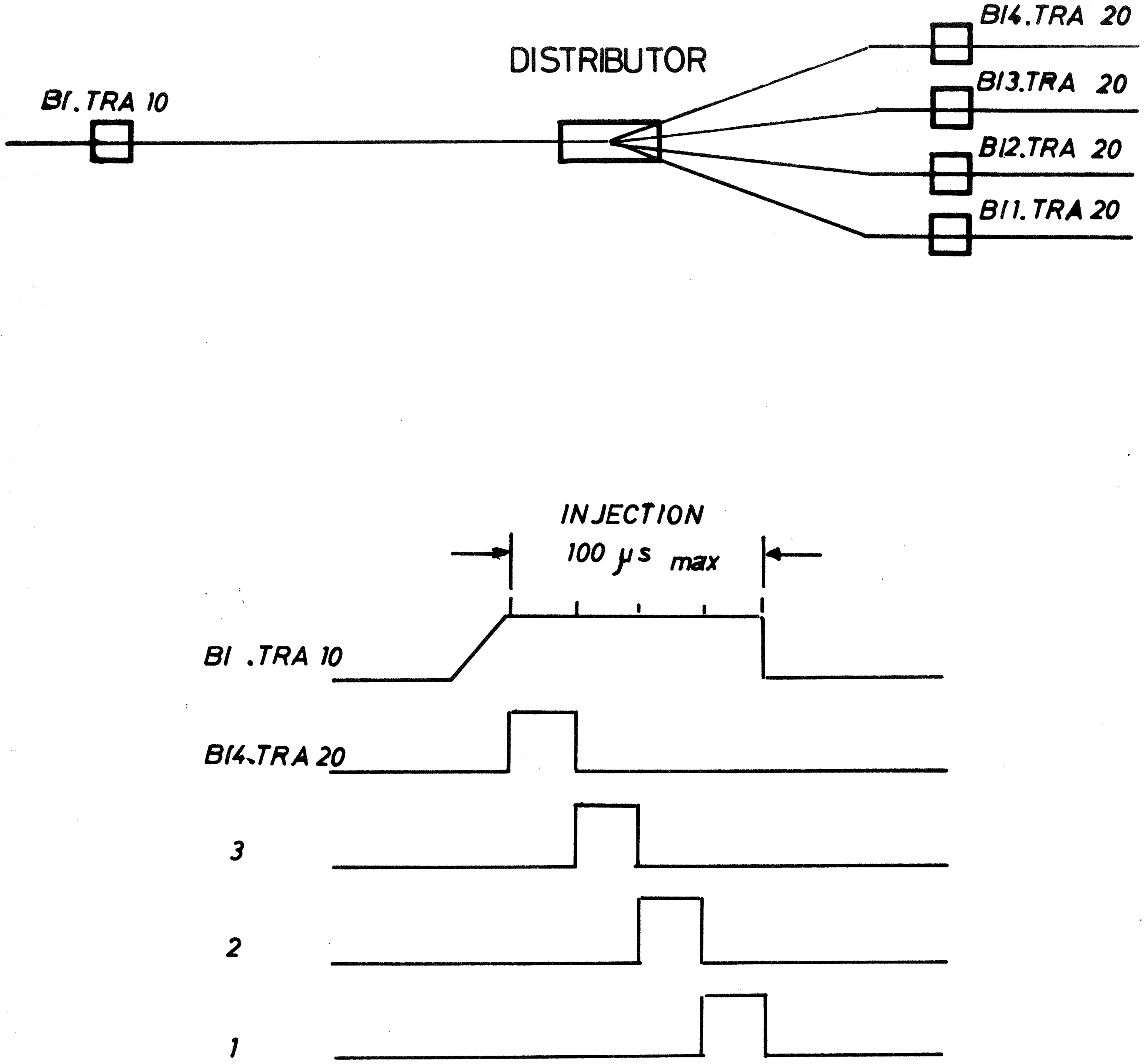


FIG 1

INJECTION LINE CURRENT TRANSFORMERS

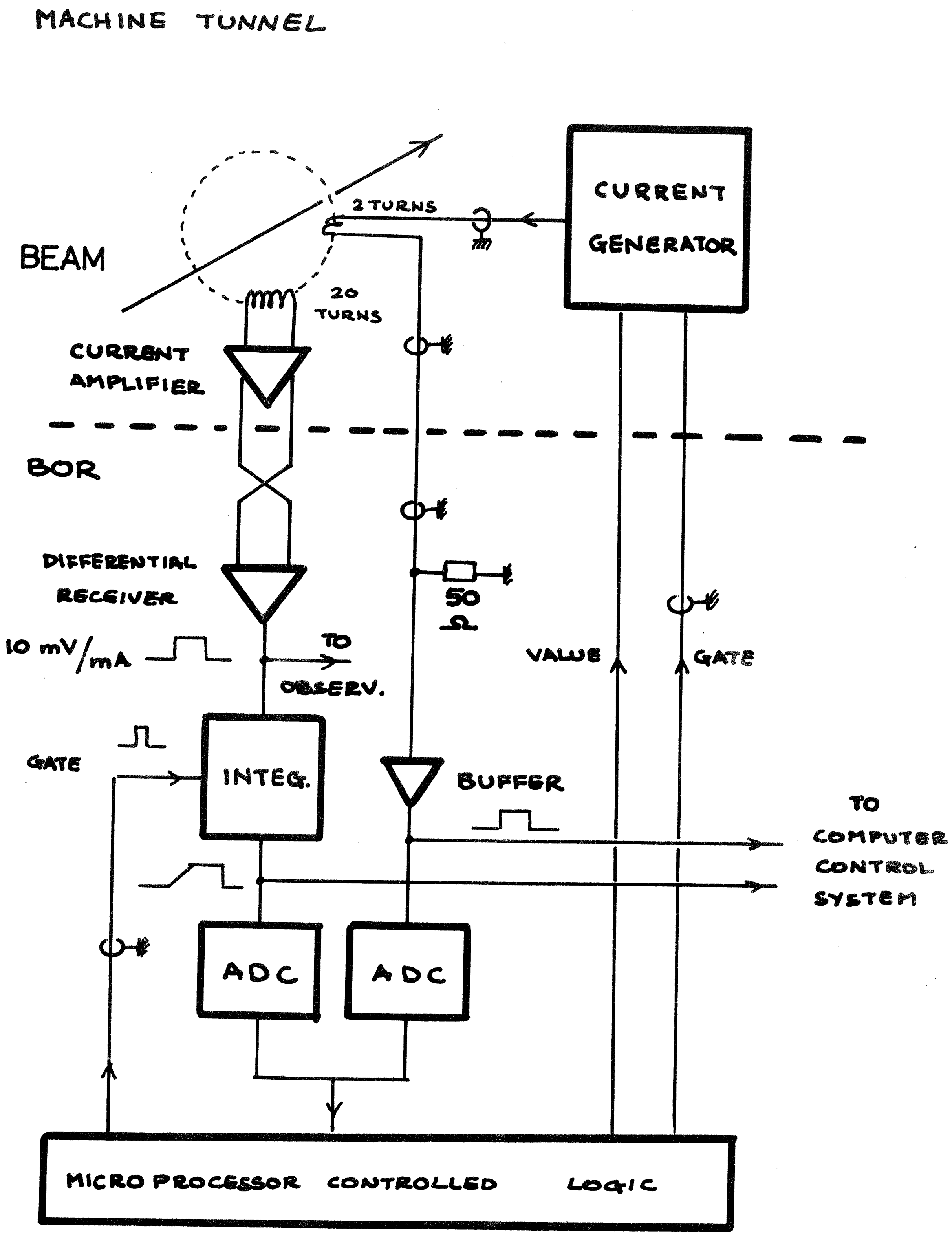
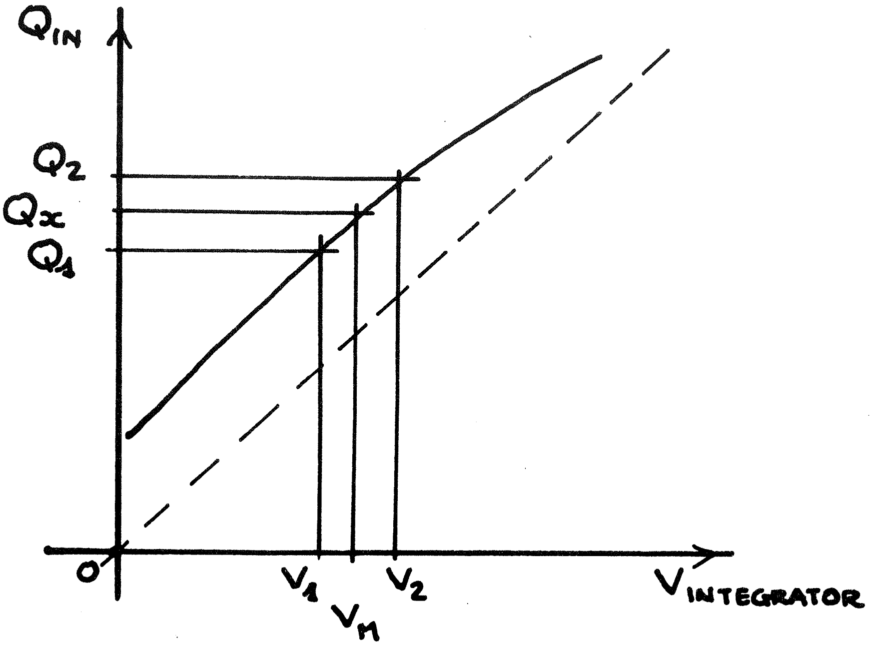


FIG 2

BASIC LAYOUT OF INJECTION LINE BEAM CURRENT TRANSFORMER SYSTEM



$$\boxed{\frac{V_2 - V_1}{Q_2 - Q_1} = \frac{V_M - V_1}{Q_x - Q_1}}$$

$$Q_x = Q_1 \frac{V_2 - V_M}{V_2 - V_1} + Q_2 \frac{V_M - V_1}{V_2 - V_1}$$

$$N = \frac{Q_x}{q} = \frac{Q_1}{q} \frac{V_2 - V_M}{V_2 - V_1} + \frac{Q_2}{q} \frac{V_M - V_1}{V_2 - V_1}$$

$$\boxed{N = \frac{I_{CAL} . \Delta t_1}{q} \frac{V_2 - V_M}{V_2 - V_1} + \frac{I_{CAL} \Delta t_2}{q} \frac{V_M - V_1}{V_2 - V_1}}$$

FIG 3

CALIBRATION PRINCIPLE

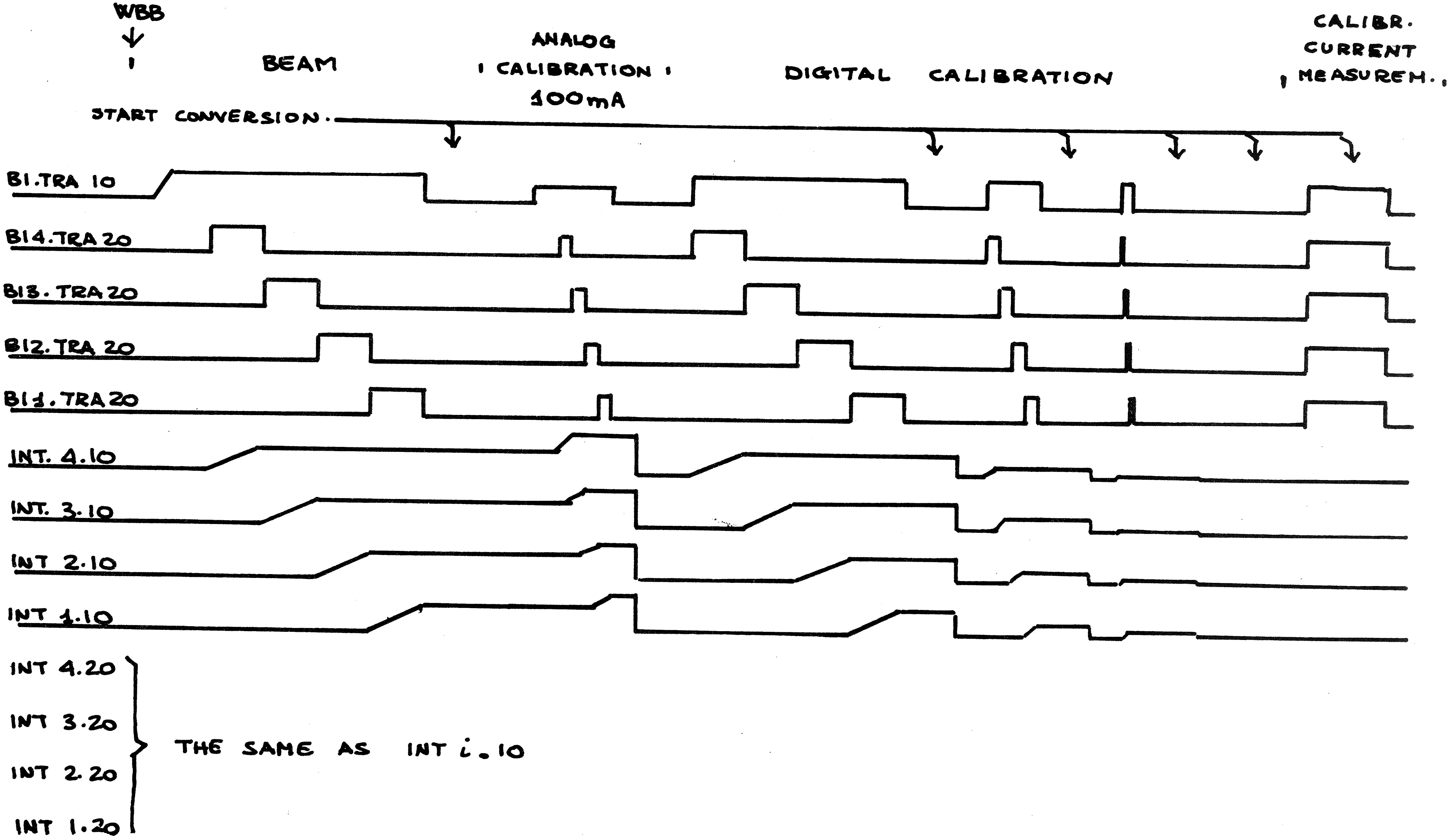


FIG 4

INJECTION LINE TRANSFORMERS - TIMING

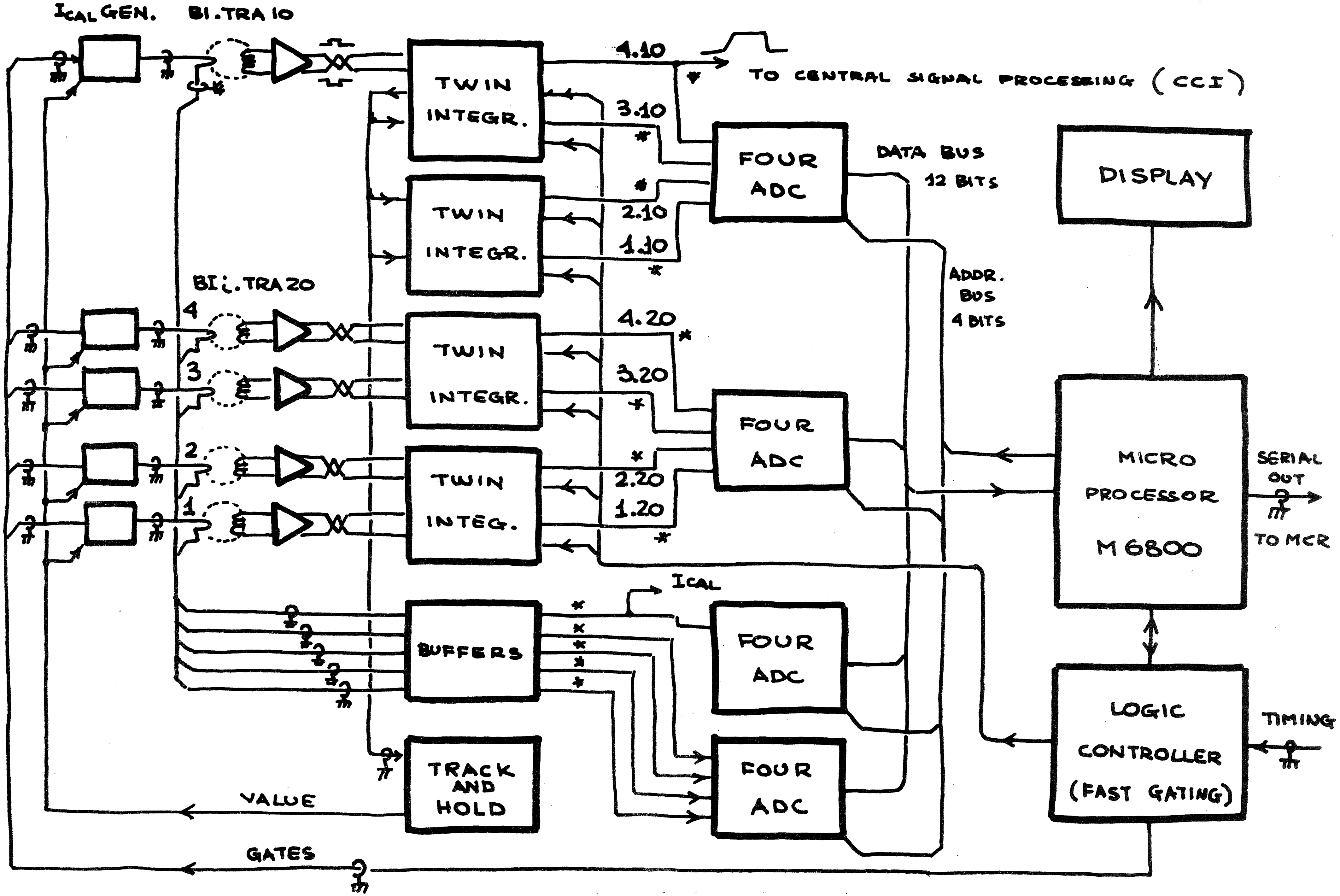


FIG 5
LAYOUT OF THE INJECTION LINE BEAM CURRENT TRANSFORMERS

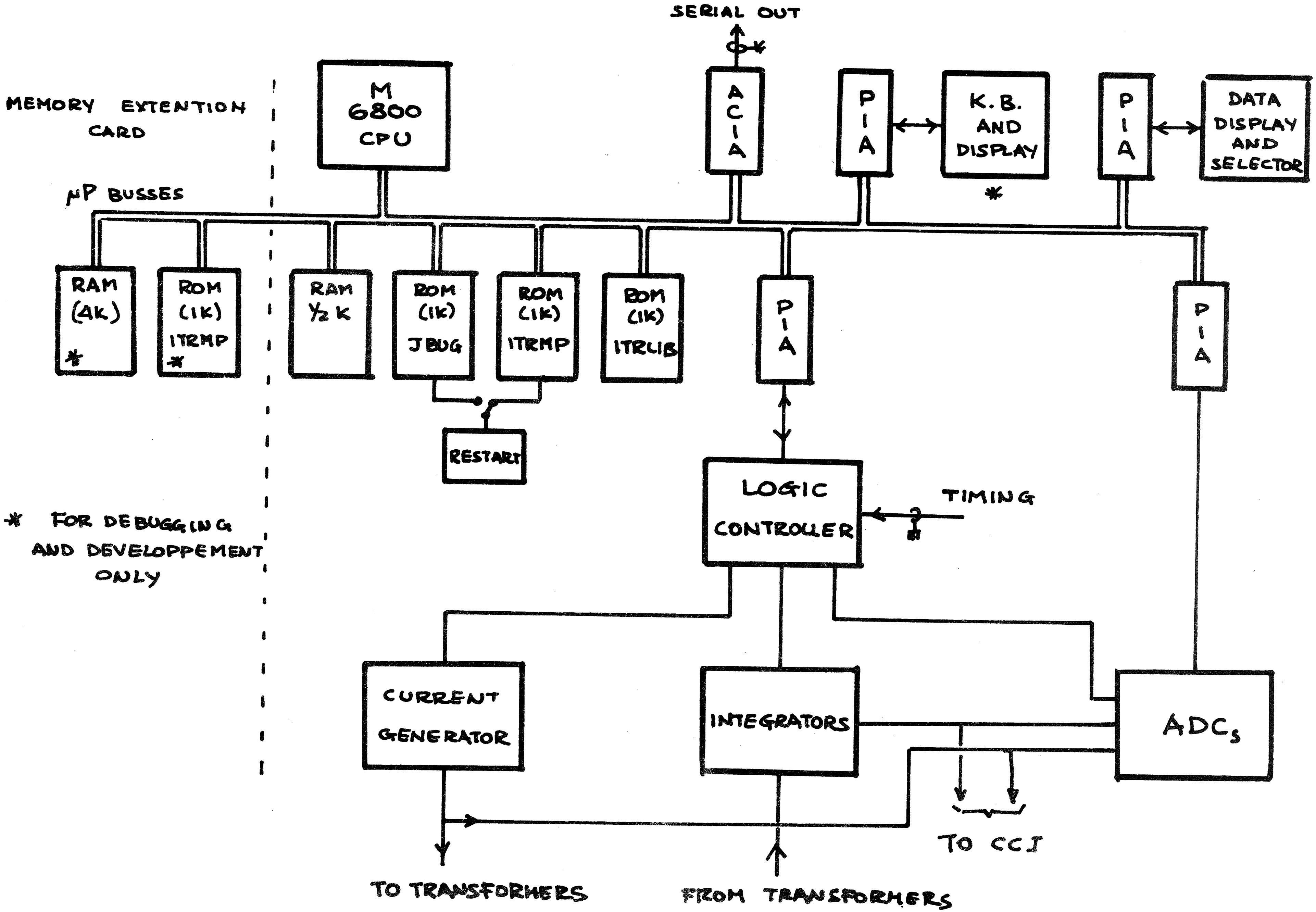
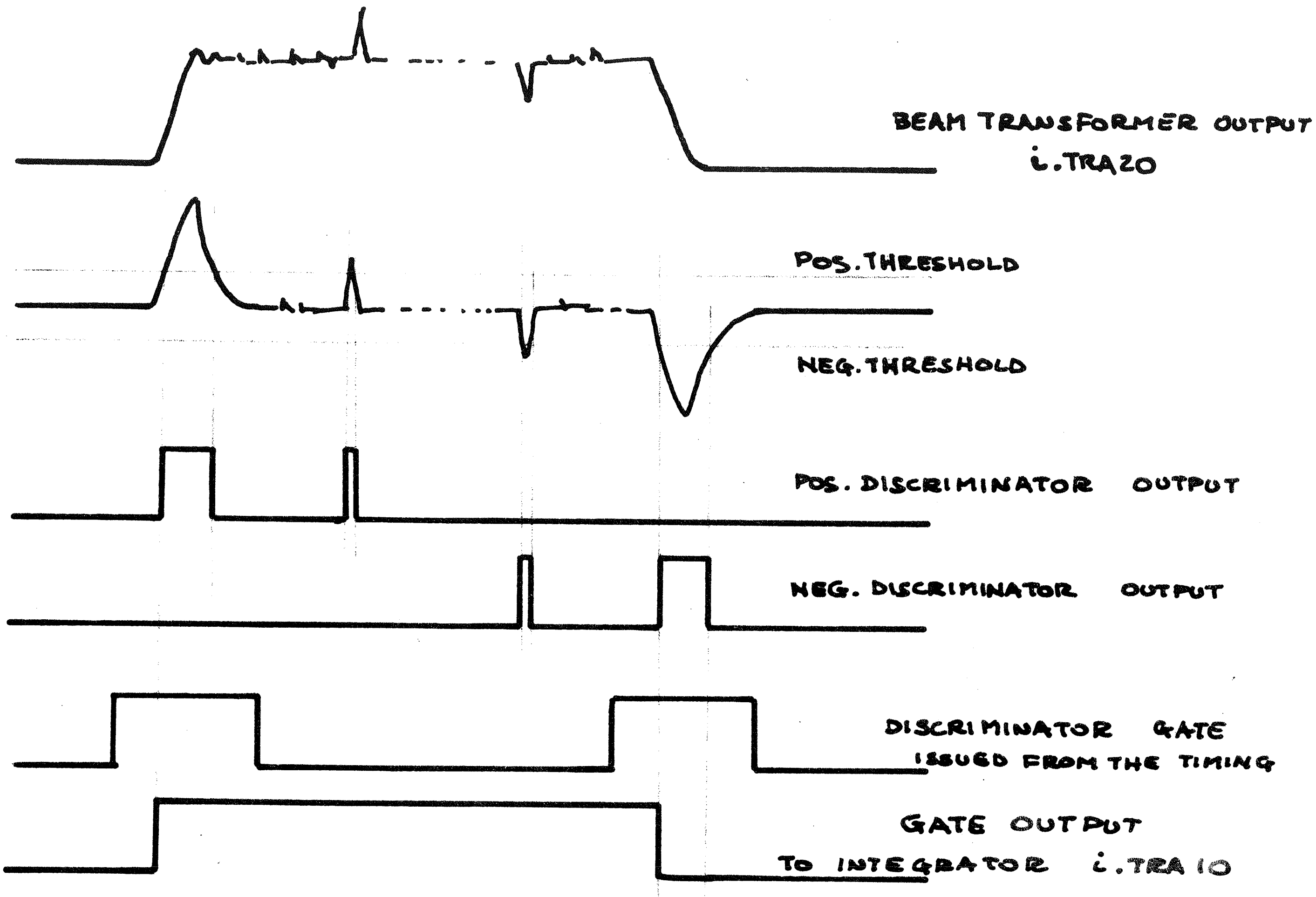


FIG 6

MICROPROCESSOR BLOCK DIAGRAM



BASIC NETWORK

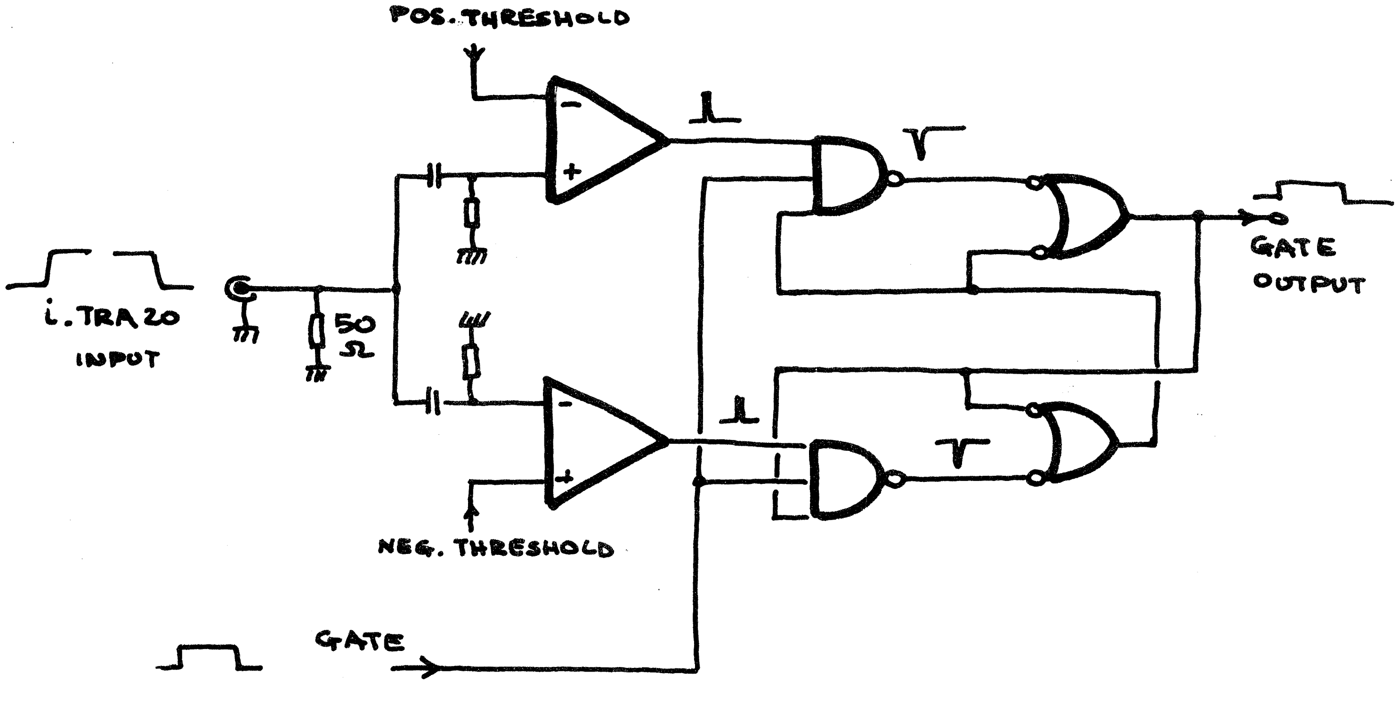


FIG 7

TIMING GENERATION BASED ON THE BEAM