EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/80-42
8 April 1980

ELECTRONICS AND RESULTS OF THE CENTRAL DETECTOR

M. Calvetti, S. Cittolin, C. Cochet, C. Engster, B. Hallgren, H. Hoffman, V. Karimaki*), L. Van Koningsveld, J.P. Laugier**), B. Lovstedt, G. Maurin, A. Norton, P. Petit, G. Piano Mortari, A. Placci, P. Queru, M. Rijssenbeek, C. Rubbia, B. Sadoulet, W. Scott, K. Sumorok***), C. Tao and H. Verweij

UA1 Collaboration, CERN, Geneva, Switzerland

ABSTRACT

The electronics system for the read-out of a large drift chamber (25 m^3, 6110 sense wires) with image read-out, to be used at the CERN $p\bar{p}$ collider, is described. The system uses a flash analog-to-digital converter and is able to measure directly the drift-time, the charge division, and the energy losses for many tracks on each wire. The results obtained with chamber and electronics prototypes are reported.

Presented at the
Wire Chamber Conference, Vienna, Austria,
27-29 February 1980

*) Visitor from the University of Helsinki, Finland.

**) Visitor from Saclay, France.

***) Visitor from the University of Birmingham, UK.

1. INTRODUCTION

At 540 GeV, the centre-of-mass energy of the CERN $p\bar{p}$ collider, new phenomena are expected. The large c.m. energy will produce very high multiplicities in the final state and the quark-quark scattering could show up with spectacular narrow jets of particles.

It is clearly necessary to have a detector which is able to measure a dense sequence of points in the tridimensional space. The central detector of the UA1 Collaboration[1)] is now under construction at CERN and is described in another contribution to this conference[2)]. Electrons produced by the ionizing particles in the detector drift through a large drift space (18 cm) to the anode wires. At each anode wire individual track coordinates are obtained by the drift-time and the charge-division methods. Each point also has a measurement of the energy loss of the particle. The gas mixture used is ∿ 50% Ar - 50% ethane, the drift electric field is 1.5 kV/cm, the drift velocity ∿ 5.3 cm/μs, corresponding to a maximum drift-time of 3.6 μs, which is smaller than the time interval between two successive bunch-crossings (∿ 3.8 μs). When an interaction takes place all the ionization (electrons) produced in the gas by the previous interaction has already reached the anode wires.

The block diagram of the electronics associated with each anode wire is shown in Fig. 1. The two preamplifiers signals at each end of the sense wire feed, via twisted-pair cables, the Charge and Time Digitizer (CTD). This unit contains two fast analog-to-digital converters (FADC) which sample the pulses every 32 ns and are described in the next paragraphs in some detail. The first FADC gives directly the track's position along the wire by the charge division method. The second FADC has a "logarithmic" response and is used for the measurement of the energy loss dE/dX.

In the time channel there is a fine time interpolator, a 3-bit TDC of the DTR 247 type. The drift time is measured within a 32 ns window with an accuracy of 3 bits (4 ns) [3)].

The digital outputs of the two FADCs and the TDC are connected to a buffer memory. During the data-taking the contents of the circular buffer memory are shifted every 32 ns and the oldest information is overwritten.

After an event trigger the buffer will contain samples of the signal on the sense wire for a time corresponding to a full drift-time.

One hundred and ten points are detected on an average for each track. The expected accuracy for the drift-time coordinate is $\sigma \simeq \pm 250$ μm, for the charge division $\sigma \lesssim 1\%$ of the wire length and ± 6% for dE/dX.

In this article we describe the features of the electronics read-out system and the results obtained with the first prototypes.

2. THE FAST AMPLITUDE-TO-DIGITAL CONVERTER

The basic element of the read-out electronics is the TDC 1014J fast analog-to-digital converter (FADC) or flash ADC.

The flash converter consists of 63 strobed differential comparators, a resistor string reference network, a 63 to 6 encoder, and an output latch (Fig. 2)[4].

One of the inputs of each comparator is connected in parallel to the signal input (V_{in}), while the other input is connected to a reference voltage. The comparator has a bandwidth of 45 MHz and an acquisition time of 15 ns. The reference voltages are developed in a resistor string between the terminals V_{RT} and V_{RB}. In the normal mode of operation, V_{RT} is connected to 0 V and V_{RB} to -1 V.

A clock signal (CONVERT) strobes the comparators on its rising edge. The 63 to 6 encoder is clocked by the falling edge of the convert signal and the coded output appears on the next rising edge. A clock rate of 31.25 MHz is guaranteed for the best version.

The response function of the FADC is given by the equation

$$H = 63 \, \frac{V_{IN} - V_{RB}}{V_{RT} - V_{RB}} \, .$$

The data from a FADC are conveniently stored in random access memories (RAM). The memory address counter is then advanced at the sampling clock rate, and successive time-shifted digitized samples of the input waveform are stored in consecutive memory locations.

3. FIRST RESULTS

A first prototype 8-channel FADC has been used for the read-out of a small image chamber. Figure 3 shows the experimental layout. The chamber was a cubic box of 20 cm side with the gas mixture and electric field previously described. The amplitude of the signal coming from each sense wire was measured by the FADC every 32 ns (clock period) with an accuracy of 6 bits and stored in successive RAM locations (256 locations). At any time t a record of the previous 8 μs (256 × 32) of each wire was then put into the memories.

A stop pulse, provided by a 4 μs delayed coincidence of the three scintillation counters, stopped the sampling process and started the read-out which was controlled by a CAVIAR computer[5]. Figure 4 shows two different representations of the same event. The eight spectra correspond to the eight wires equipped, each bin being 32 ns long (∿ 1.5 mm in space). The drift space is 20 cm (∿ 4 μs) and the distance between two wires is 1 cm.

Figure 5 shows three tracks crossing the chamber. The two-track resolution for tracks orthogonal to the electric field is about 3 mm. It is clear from Figs. 3 and 4 that the maximum number of hits per wire which can be detected is limited by the shape of the pulses. A total number of ∿ 25 hits seems to be reasonable, the geometry of the final chambers[2] being such that the angle between the high-momentum tracks and the electric field is always greater than 45° in the drift direction.

Nevertheless before a FADC can be used conveniently in a drift chamber two problems have to be solved. First of all the dynamic range of 6 bits is not enough to take care of the energy-loss variations due to Landau fluctuations, double-ionizing particles, tracks which run parallel to the wire, slow particles, etc. Furthermore, the third coordinate is measured with the charge division method and hence we have to measure the total charges of the pulses (not the amplitudes) independently of the clock phase. The method used to overcome these two problems is described in the next sections.

4. THE PHASE PROBLEM AND INTEGRATION BOX

In order to obtain the total charge with the FADC, which measures the amplitudes, we have to transform the charge information into amplitude information. The measured charge must also be independent of the clock phase with respect to the pulses. There are two analog pulses per wire, left and right, Fig. 6.

In each analog channel there is a preamplifier mounted directly on the chamber, and some 50 m away through a twisted-pair cable, a line receiver with programmable gain, a clipping stage (32 ns), and an integrator. (The response for a δ function input pulse is a square signal of 32 ns length.) The pulse amplitude from the integrator at the time t is always proportional to the total charge collected in the previous 32 ns. It is clear that sampling the amplitude of such a pulse with a period of 32 ns, and adding together all the measured amplitudes we obtain the total charge independently of the phase.

The left and right signals after the integration are, respectively, summed (Σ) and substracted (Δ). The total energy signal Σ is fed into a FADC with non-linear response for the total energy measurement; the Σ and Δ signals are used to drive another FADC for the charge division as described in the next sections.

5. DYNAMIC RANGE

While the resolution of a 6-bit FADC is in general sufficient to measure the energy losses on each sense wire, this is not true for its dynamic range. An elegant method of achieving any compressing or expanding response function of the FADC is described in Ref. 4. Because the FADC can be driven by fast input and reference pulses it can be used as a fast analog divider. Applying a fraction of the input pulse plus a bias as the reference pulse, the response function becomes:

$$n = 63 \frac{V_{in}}{a\,V_{in} + V_b} .$$

The full scale is obtained at

$$V_{in_{max}} = \frac{V_b}{1 - a} .$$

In the linear operation mode the $V_{in_{max}}$ is V_b, so the expansion factor is $x = 1/(1 - a)$ and the dynamic range $R = 6$ bits$/(1 - a)$.

Figure 7 shows the measured response function of a FADC. Because of possible pedestal variation due to rate effects (the electronics is AC coupled), the response function starts from channel 6. Positive values of the pedestals can be measured and subtracted. The expansion of the dynamic range from 6 to 9 bits clearly is at the expense of the resolution for high input values, which is generally acceptable. Figure 8 shows the resolution of a 6-bit FADC in the linear mode and the chosen non-linear mode. The electronics chain is adapted to have the minimum ionizing energy losses in the region of optimal resolution (∿ channel 32).

6. THE CHARGE DIVISION

The information on the hit coordinate along the wire direction is given by the total charges collected at the two ends of the sense wire, Q_L and Q_R. If $\Sigma = Q_L + Q_R$ and $\Delta = Q_L - Q_R$ the Z-coordinate is given by

$$Z = \frac{\Delta}{2\Sigma} .$$

The FADC is used as an "analog" divider to measure directly the ratio $\Delta/2\Sigma$.

To measure the accuracy of the charge division we used a proportional tube 2.5 m long and a ^{55}Fe X-ray source. The wire was of Ni-Cr, with a diameter of 30 μm and a total resistance of 3 kΩ.

The left and right pulses are clipped, integrated, and respectively summed and subtracted in the integration box. The four signals from the integration box are then used to drive two FADCs, one for the charge division and the other for the total energy measurement. The two pieces of information are digitized and stored in the memories (Fig. 9).

The final accuracy is determined by the 6 bits of the FADC, the wire being divided into 64 subintervals. Every 32 ns the total energy collected in that time window and the equivalent Z-coordinate are measured. Figure 10a shows the total energy histogram for one event, each bin being 50 ns long (for technical reasons this electronics prototype was built to work at 20 MHz). Figure 10b shows the corresponding Z measurement. The vertical range is the whole wire length divided into 64 intervals. This particular event was taken with the source at the centre of the wire.

The measured Z's in the three time bins below the pulse are equal, because the intrinsic accuracy of the electronics chain is far better than the 6-bit accuracy of the FADC. The avalanche charge collected in 150 ns ($\sim 10^6$ electrons) is such that the stochastic noise from the wire and the preamplifier is so small with respect to the pulses that the various measured Z's below the pulse remain in the wire interval determined by the FADC. Away from the pulse the Z is undetermined. Another interesting event is shown in Fig. 11, where the source was placed between the centre and one extremity of the wire.

Because of the different time propagations between the two ends of the wire and of the pulse deformations due to the different frequency propagations, the measured Z's are no longer constant. The Z coordinate is then given by the centre of mass of the Z_i's weighted with the total energy E_i, measured in the same time bin

$$Z_i = \frac{\Delta_i}{E_i} , \quad Z = \frac{\Sigma\, Z_i\, E_i}{\Sigma\, E_i} = \frac{\Delta}{2\Sigma} .$$

In order to have $\langle Z \rangle = Z_{true}$ an infinite integration should be performed. In practice a good measurement can be obtained with a gate width between 100 and 150 ns depending on the shape given to the pulse.

One of us (V.K.) wishes to thank the Finnish National Research Council for Natural Sciences for financial support.

REFERENCES

1) A. Astbury et al., A 4π solid angle detector for the SPS used as a $\bar{p}p$ collider at c.m. energy of 540 GeV, CERN/SPSC/78-06, SPSC/P 92, 30 January 1978.

2) M. Barranco Luque et al., The construction of the central detector for the CERN $\bar{p}p$ collider (CERN UA1 Collaboration), contribution to this conference.

3) L. Van Koningsveld, H. Verweij and V. Senko, private communication (Dec. 1979).

4) B. Hallgren and H. Verweij, New developments in time and pulse height digitizers, preprint CERN-EP/79-133, presented at the IEE Nuclear Science Symposium, 17-19 October 1979, San Francisco.

5) S. Cittolin and B.G. Taylor, Proc. Conf. on Microprocessors in Automation and Communications, Univ. Kent at Canterbury, 1978, IERE Conf. Proc. No. 41, p. 309.

Figure captions

Fig. 1 : Schematic block diagram of the electronics associated to each sense wire.

Fig. 2 : The fast analog-to-digital converter.

Fig. 3 : Schematic representation of the set-up used "to see" the tracks using the FADC.

Fig. 4 : Two different representations of the same track in the chamber.

Fig. 5 : One event with three tracks at the same time in the chamber.

Fig. 6 : Description of the integration box principles.

Fig. 7 : The response function of a FADC working in a non-linear mode.

Fig. 8 : Curves showing the resolution of a 6-bit FADC in the linear mode and an applied non-linear mode.

Fig. 9 : Schematic block diagram of the electronics used to measure the charge division accuracy with a 2.5 m long proportional tube.

Fig. 10 : The X-ray source is at the centre of the tube.
a) Total energy measurement of an X-ray pulse.
b) Charge division for the same X-ray pulse.

Fig. 11 : The source is placed between the centre and one extremity of the proportional tube.
a) Total energy measurement.
b) Charge division measurement.

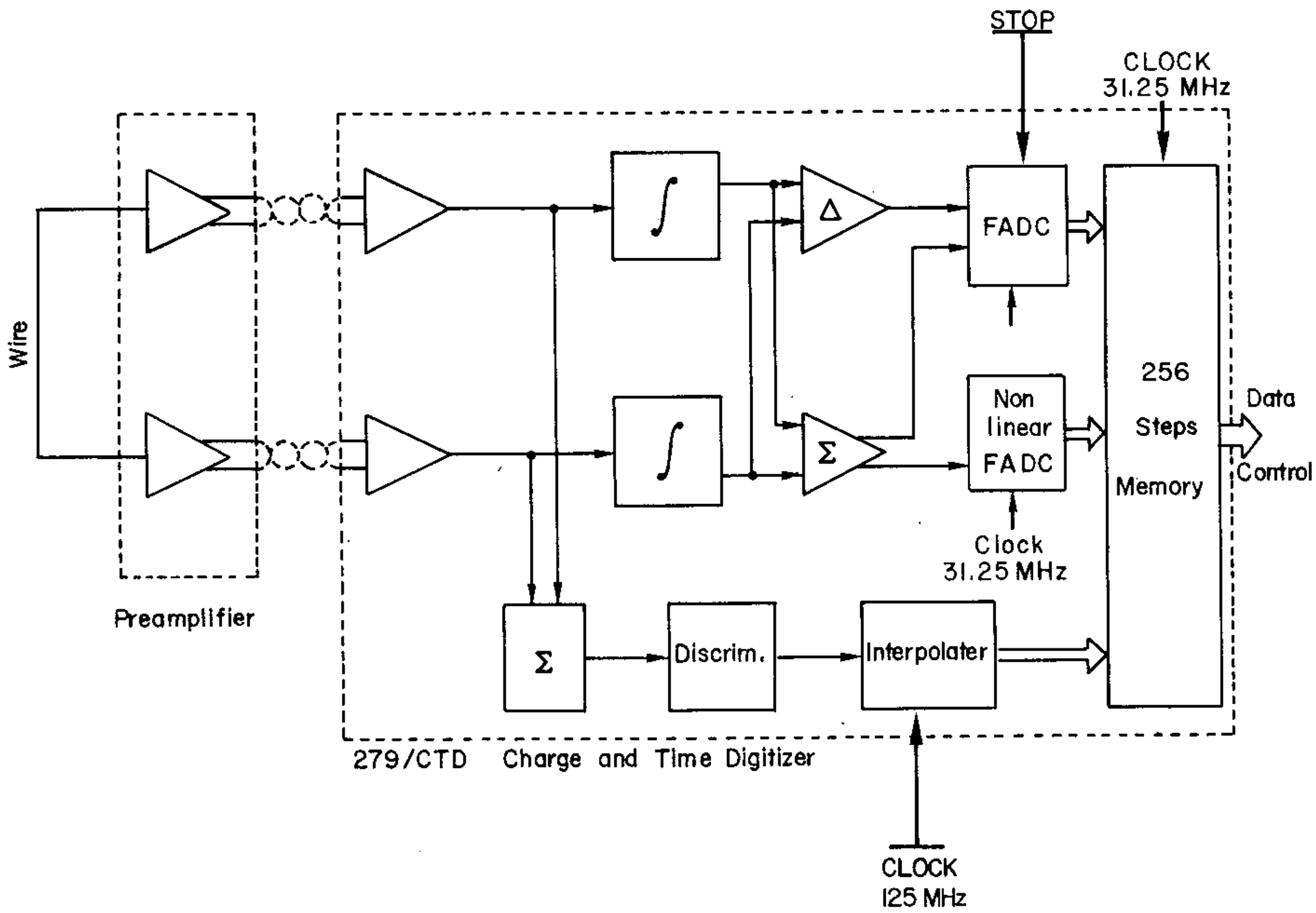

STOP
CLOCK
31.25 MHz
Wire
Preamplifier
FADC
Non
linear
FADC
Clock
31.25 MHz
256
Steps
Memory
Data
Control
Σ
Δ
Discrim.
Interpolater
279/CTD Charge and Time Digitizer
CLOCK
125 MHz

Fig. 1

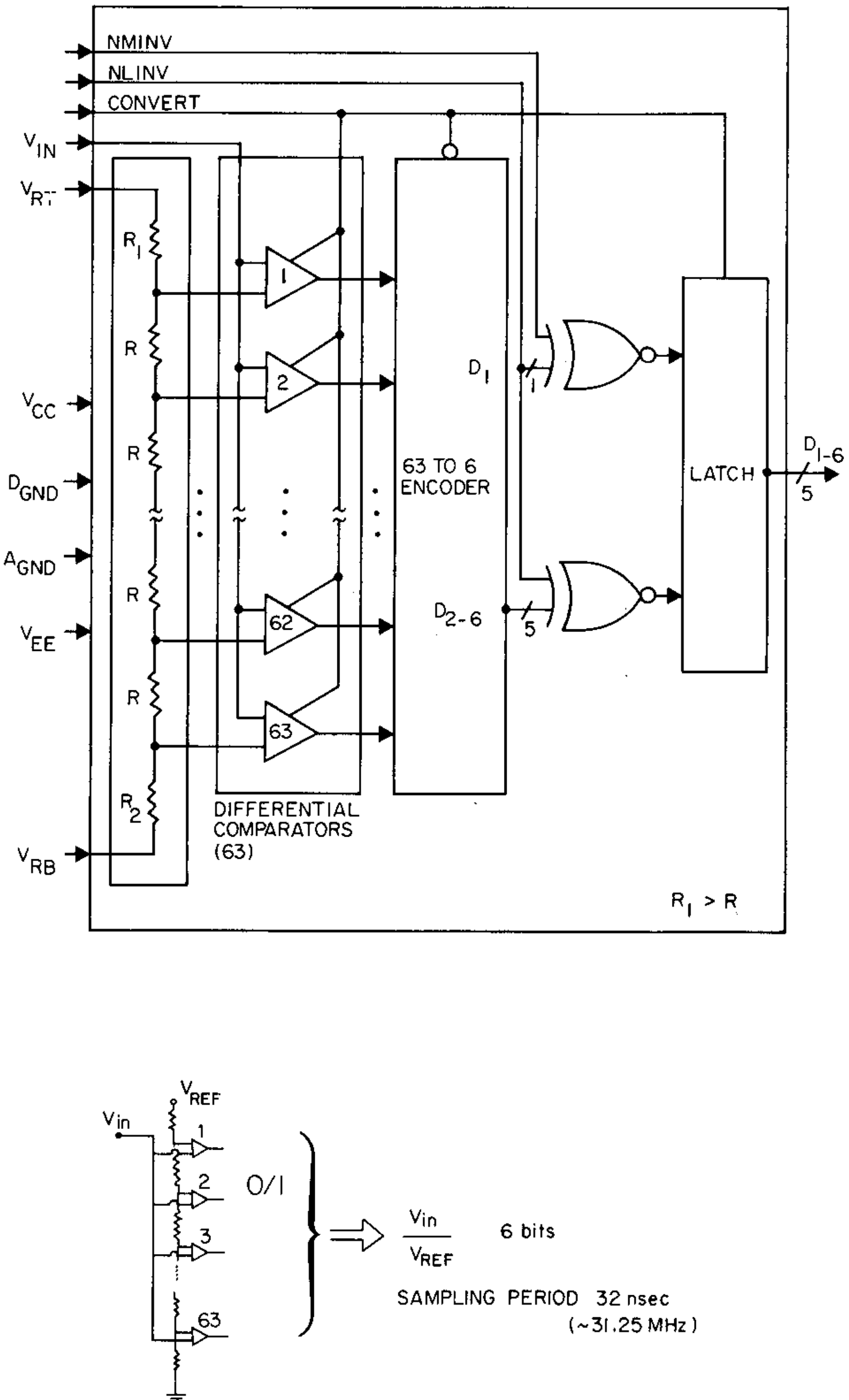

NMINV
NLINV
CONVERT
V_{IN}
V_{RT}
V_{CC}
D_{GND}
A_{GND}
V_{EE}
V_{RB}
R_1
R
R_2
1
2
62
63
DIFFERENTIAL
COMPARATORS
(63)
63 TO 6
ENCODER
D_1
D_{2-6}
1
5
LATCH
D_{1-6}
5
$R_1 > R$
V_{REF}
V_{in}
1
2
3
63
0/1
$\frac{V_{in}}{V_{REF}}$
6 bits
SAMPLING PERIOD 32 nsec
(~31.25 MHz)

Fig. 2

COSMIC RAYS

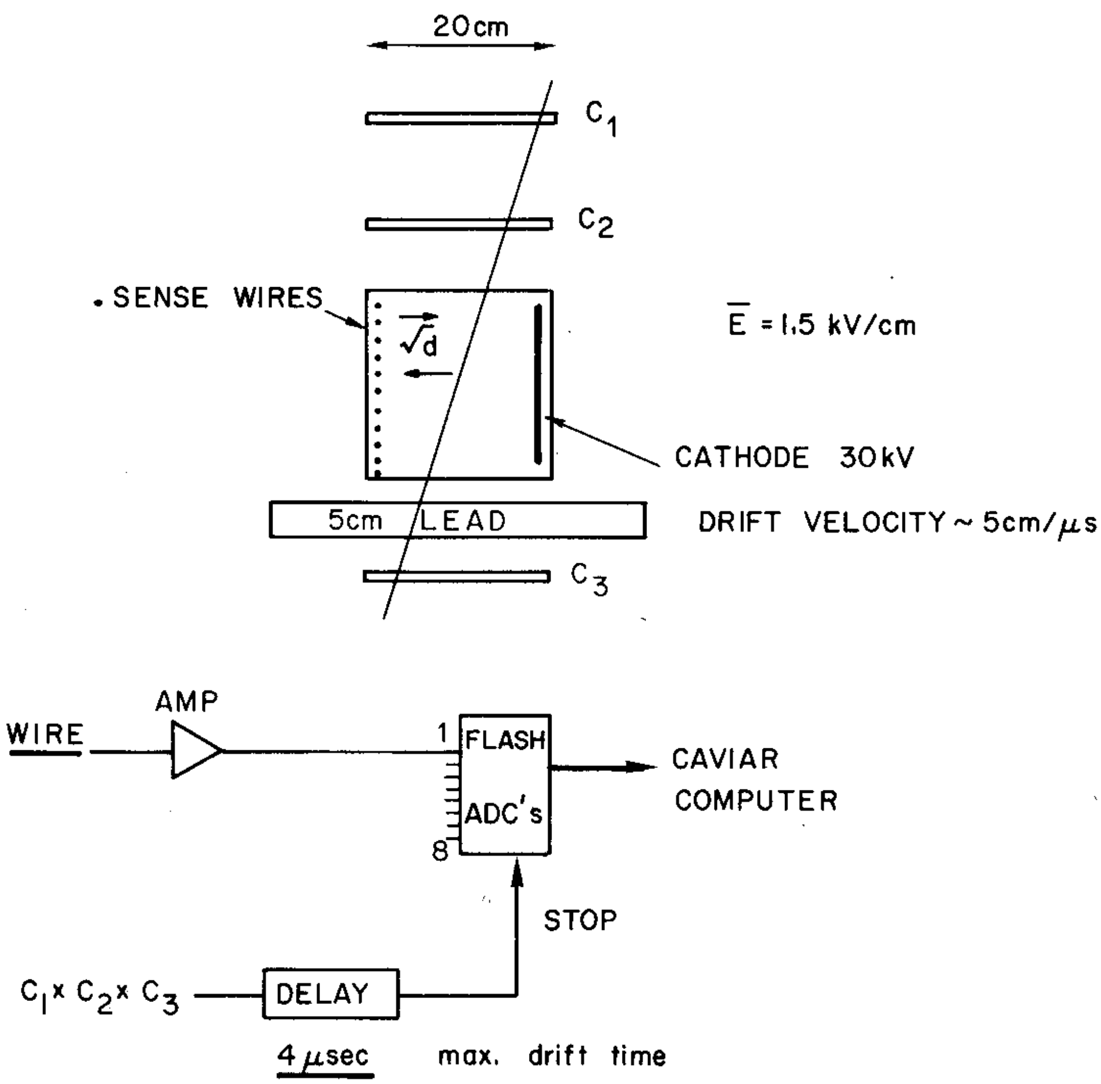


Fig. 3

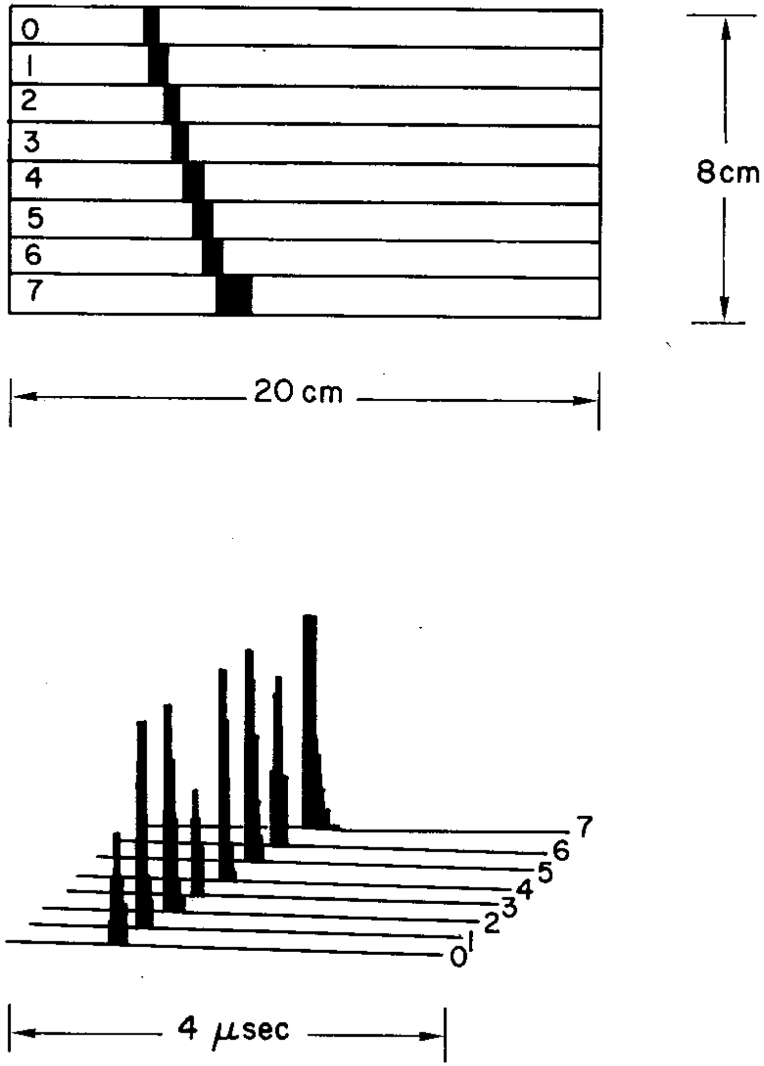


Fig. 4

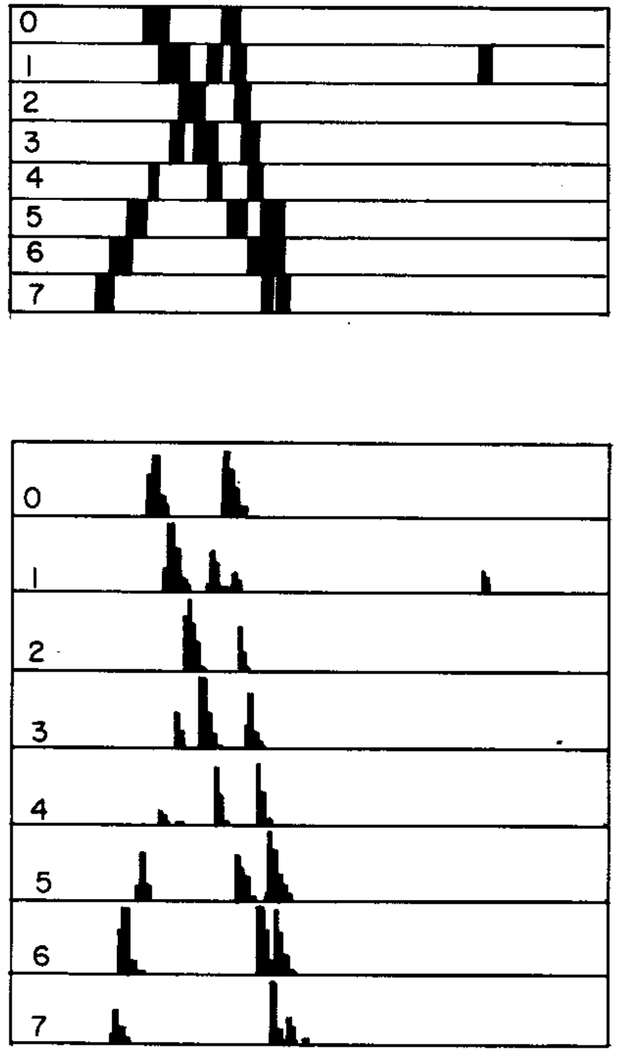
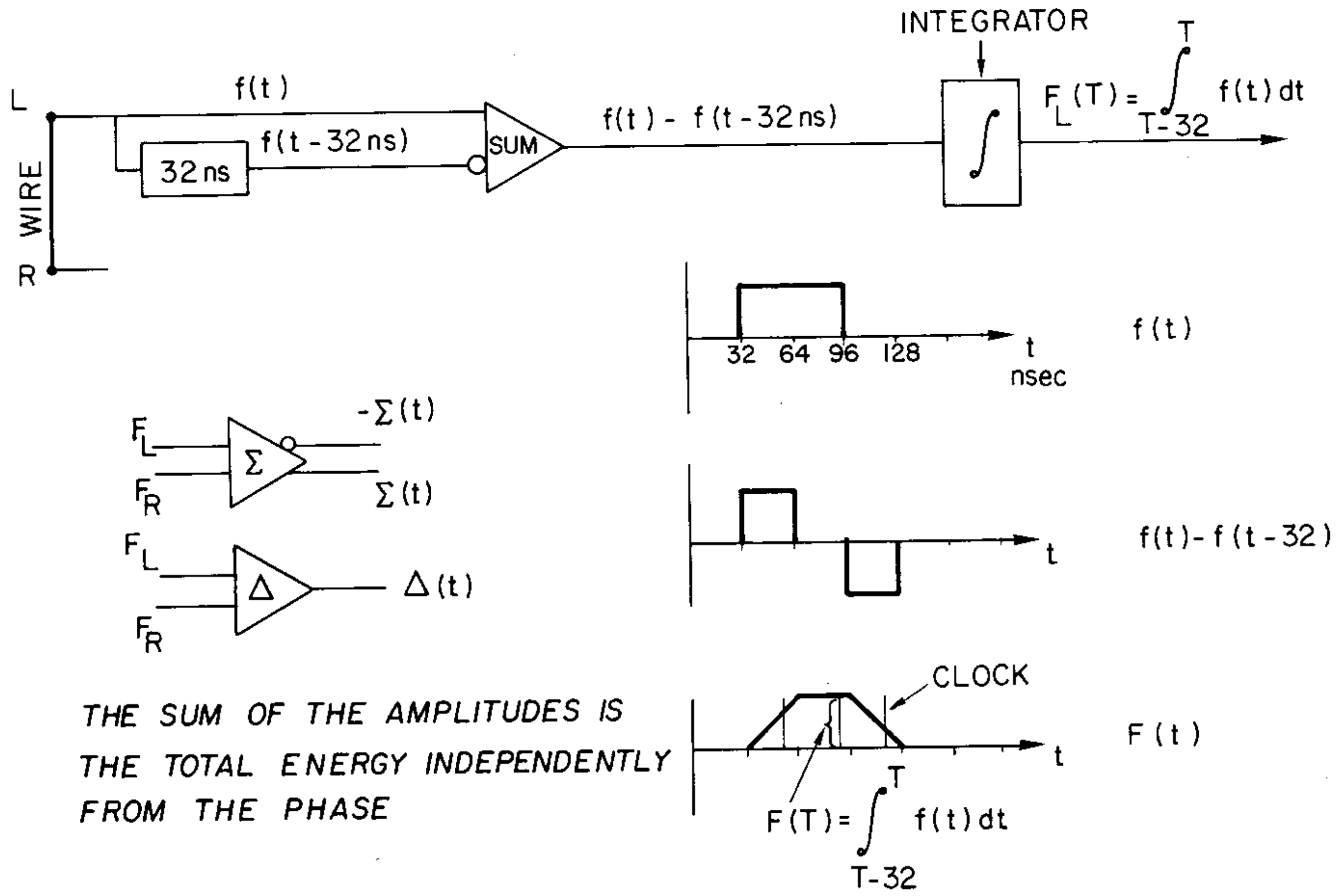


Fig. 5

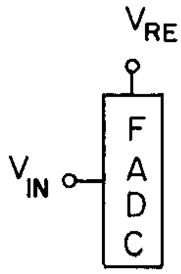
INTEGRATION AND PHASE



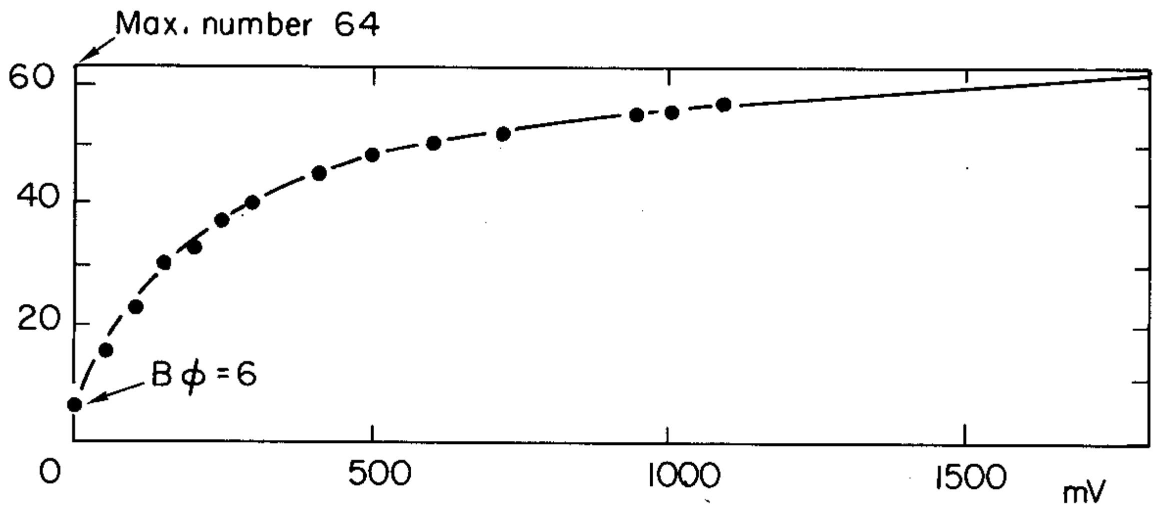
THE SUM OF THE AMPLITUDES IS THE TOTAL ENERGY INDEPENDENTLY FROM THE PHASE

Fig. 6

TOTAL ENERGY



$$\frac{V_{IN}}{V_{REF}} = \frac{V_{IN}}{A \cdot V_{IN} + B}$$



$$n_{CH} = \frac{(64 - B\phi)\cdot V}{A\cdot V + B} + B\phi$$

SATURATION ≈ 3 V

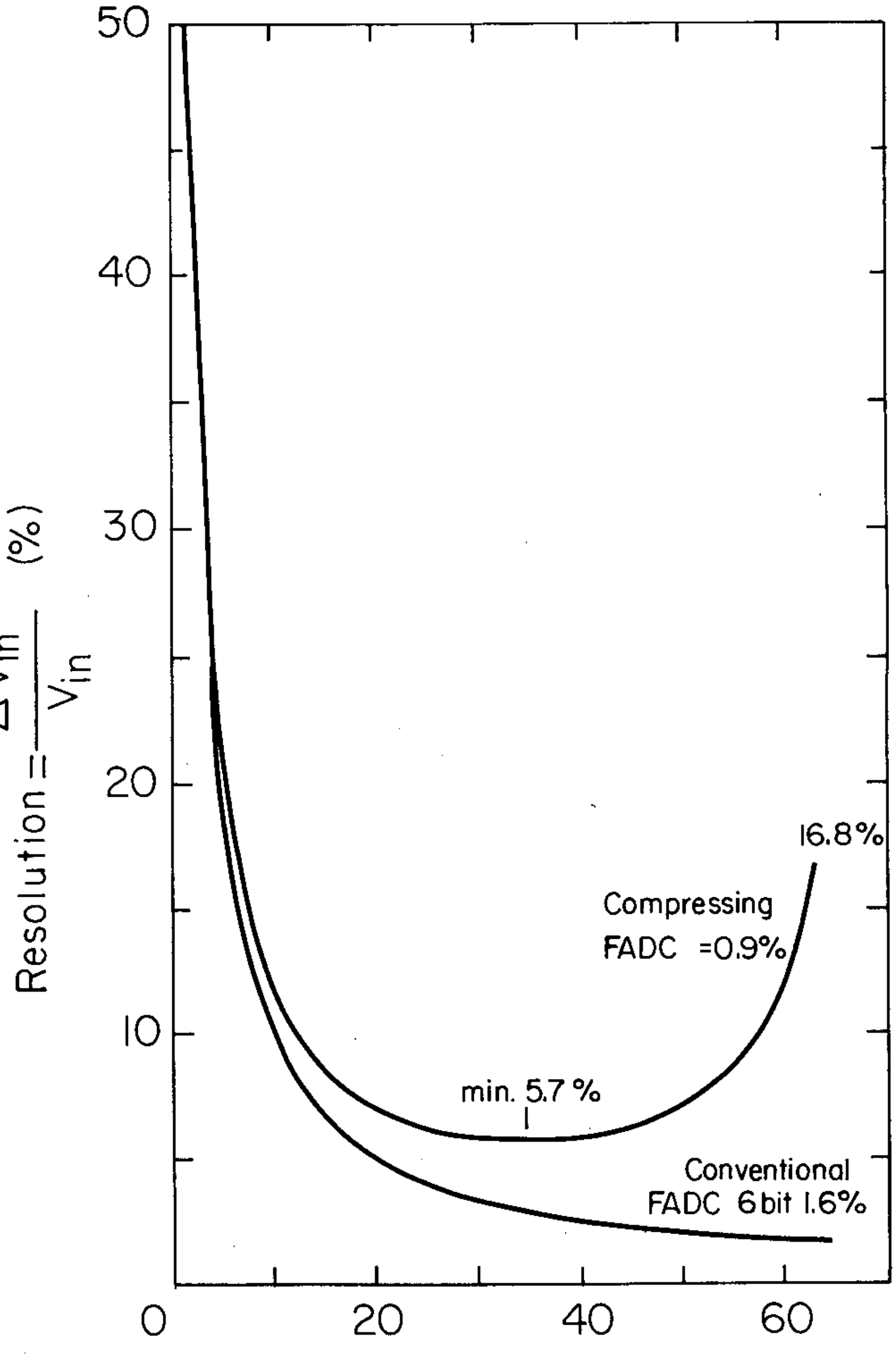
$B\phi = 6$
$A = 0.93$
$B = 238$ mV

CONVERSION TABLE Channel ⟶ Energy

E_i Every 50 nsec

$$E_{TOT} = \sum_i E_i$$

Fig. 7



50
40
30
20
10
0
20
40
60
Resolution = ΔVin / Vin (%)
Channel No.
16.8%
Compressing
FADC =0.9%
min. 5.7 %
Conventional
FADC 6bit 1.6%

Fig. 8

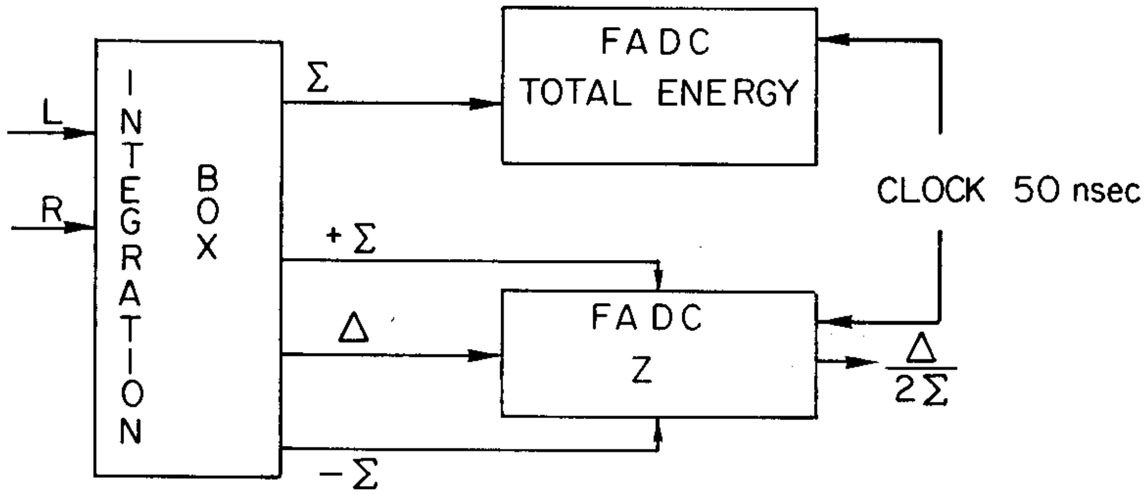

FADC
TOTAL ENERGY
INTEGRATION
BOX
L
R
Σ
+Σ
Δ
−Σ
FADC
Z
Δ/2Σ
CLOCK 50 nsec

Fig. 9

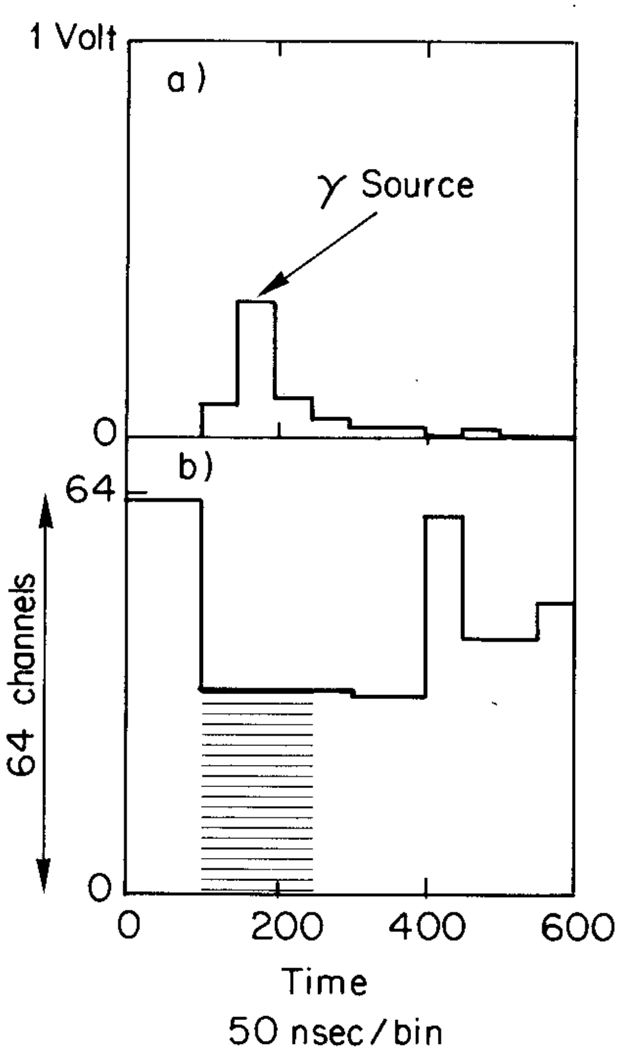
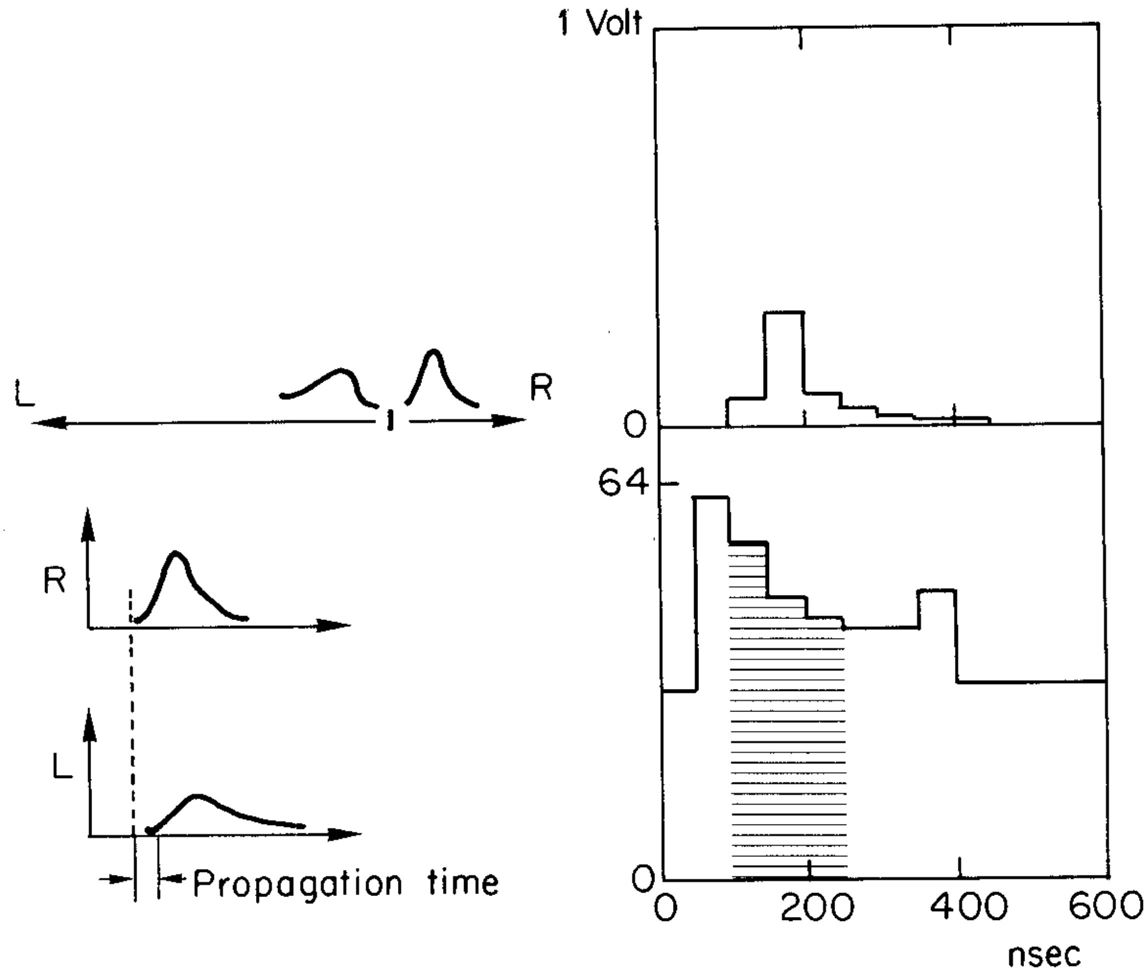

1 Volt
a)
γ Source
0
b)
64
64 channels
0
0
200
400
600
Time
50 nsec/bin

Fig. 10



$$Z = \frac{\sum_i Z_i E_i}{\sum_i E_i} = \frac{Q_L}{Q_L + Q_R}$$

Fig. 11