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EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

**WINDOW DISCRIMINATOR WITH  
TUNNEL DIODES**

by

**E. SATTLER**

1967



Joint Nuclear Research Center  
Geel Establishment - Belgium

Central Bureau for Nuclear Measurements - CBNM



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## SUMMARY

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The propagation delay jitter is only determined by the dynamic range of input pulse amplitudes and rise times. Quenching circuitry is provided to allow faultless operation of the realized unit for high pulse rates and for high overload factors. The general characteristics and physical dimensions of the discriminator conform to the ESONE rules.

**Keywords:** PULSE ANALYZERS, SEMICONDUCTORS, PULSES, ELECTRIC POTENTIAL, TIME, CIRCUITS, OPERATION.

**Additional Terms:** Discriminators, tunnel effect, threshold detectors, triggers, amplitude.

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## 1. Introduction

In nuclear physics experiments there often exists a need for suitable fast window discriminators with sufficient input sensitivity. The scope of application can be quite large and some of the most important examples should be mentioned:

Direct coincidence experiments with fast pulses of small width in selected amplitude ranges and up to high rates;

precision counting measurements where the dead time influence of the discriminator has to be minimized;

measurements with semiconductor detectors delivering small pulse amplitude levels.

Window discriminators covering this range of application can sometimes be used for pulse spectrum analysis experiments, but even more as two-threshold devices with a range of the width equal to that of the base line level.

Nowadays fast discriminators can be built with tunnel diode stages, which have the advantage of high input sensitivity combined with sufficient threshold stability and fast switching time. Thus the expense of preamplification, with all its inherent sources of errors, can be minimized.

Due to the fast switching time of tunnel diodes, a dependence of the discrimination level on pulse width is not given down to very small values.

## 2. Principles of Window Discriminators

The basic principle of window discriminators is well known from the literature. Their task is to select from a given amplitude spectrum, which is applied to the input, all the pulses having a preset amplitude range, and to deliver in form of digital signals to

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the output the information, how much of the pulses are within this amplitude range. In order to determine an interesting amplitude range, a window discriminator needs two threshold stages. Their level difference defines the "window width"; the lower threshold level is normally called the base line level or "base line".

If "sliding window" technique is required, window width and base line level must be adjustable independently.

For a window discriminator the two threshold stages have to be connected to an anticoincidence device, in order to fulfill the condition, that only those input signals, with an amplitude within the preselected window, deliver an output signal to the terminals. This is possible if the upper level threshold delivers an inhibiting signal to the anticoincidence stage for each input pulse, which has reached the upper threshold level too. This principle of operation implies certain time problems. Because of the rise time of the input pulses the front edge of the inhibiting signal from the upper level threshold can only be generated a certain time interval later than the front edge of the lower level threshold output.

A well known solution of that problem is the application of the so-called trailing edge trigger technique (1). In this case the lower level threshold stage delivers its output signal at the moment, the trailing edge of the input pulse crosses the lower threshold level. By that means, the upper level threshold stage is able to deliver the inhibiting signal early enough to obtain sure blocking for pulses overriding the window range. This principle has the advantage to work properly without regard to the applied input pulse shape, but a certain disadvantage is a considerable time jitter of the output signals with respect to the input pulses, namely for an exponential decay of their trailing edge.



In such case a smaller time jitter can be reached for window discriminators following the leading edge trigger technique.

Here only the leading edge of the input signal is significant. The lower level threshold stage delivers its output signal at the moment, the leading edge of the input pulse reaches its threshold level. For faultless operation the lower threshold trigger has to be delayed by a fixed time interval being greater than the length of the leading edge of the input pulse in order to allow blocking by the upper level threshold output.

Therefore the rise time range is restricted by the fixed delay to be inserted.

### 3. Fast Discriminators and their Threshold Stages

It is an obvious fact, that the speed of a discriminator depends chiefly on the switching speed of the threshold stages. To obtain a fast discriminator unit, the introduction of tunnel diodes as threshold elements is very useful. As for the threshold circuits used for transistorized types up to now, regenerative circuits as univibrators or Schmitt trigger elements are most suitable and are known from the literature, e.g. (2) (3) (4) (5).

Schmitt trigger stages (see fig. 1a) are more stable than univibrators and have better linearity of their threshold level vs. bias current. Their disadvantages are lower threshold sensitivity and slower switching speed.

In order to obtain faster switching behaviour and higher threshold sensitivity tunnel diode univibrators are more suitable.

For the basic circuit of a tunnel diode univibrator (fig. 1b) the relatively poor linearity of the threshold level vs. bias setting becomes evident. This is due to

the splitting effect the bias current  $I_B$  underlies, because a considerable fraction of  $I_B$  flows directly into the (low ohmic) load of the univibrator. This splitting ratio varies due to the nonlinear characteristic of the tunnel diode. As a Schmitt trigger the nonlinear behaviour of the tunnel diode does not influence the linearity of bias setting if an ideal enough current source is used for biasing.

A considerable improvement of linearity of a univibrator threshold can be reached, if provision is made, that the total bias current  $I_B$  can flow into the tunnel diode. A capacitive coupling between load and tunnel diode would lead to unwanted resonance effects, thus the introduction of a backward diode between tunnel diode and load is a better suitable solution. Fig. 1c shows a tunnel diode univibrator with inserted backward diode. Here the total bias current  $I_B$  flows into the tunnel diode, because in the quiescent state of the univibrator the potential across the backward diode is held at zero voltage. Small deviations from "zero" would not influence the threshold linearity considerably, because a suitable backward diode is high-ohmic enough around the zero point of its characteristic.

The definition of the threshold level for univibrators and for Schmitt triggers with tunnel diodes is given by

$$I_{in} \approx I_p - I_B.$$

$I_{in}$  represents the necessary input current pulse amplitude to trigger the threshold stage,  $I_p$  is the peak current of the chosen tunnel diode and  $I_B$  is the bias current.

For univibrators the minimum threshold level is limited by its requested stability, which is in-



fluenced by the temperature dependence of  $I_p$ . The relation  $I_p > I_B > I_V$  indicates the usable threshold level range. ( $I_V$  is the valley current of the tunnel diode.)

The threshold level range of the Schmitt trigger is quite limited and can only be chosen between the valley current  $I_V$  and the maximum admitted inverse current  $-I_{inv, max}$  of the tunnel diode:

$$I_V > I_B \geq -I_{inv, max}$$

#### 4. General Survey of Window Discriminators with Tunnel Diode Thresholds and their Problems

Window discriminators with tunnel diode threshold stages employing the trailing edge trigger technique are quite simple to realize, if the thresholds have Schmitt trigger behaviour.

In this case the requested time relations can be satisfied by using directly the trailing edges of the threshold output pulses. The principle of leading edge trigger discriminators, however, allows to exploit the advantages of univibrators as thresholds, but the necessary time relations for the two threshold pulses must be re-established by additional circuitry, e.g. incorporation of a delay.

To make use of the advantages of the two different threshold circuits, i.e. threshold output of a Schmitt trigger (pulse width equals the effective trigger pulse width), sensitivity, dynamic range and speed of a univibrator, it is useful to simulate the response of a Schmitt trigger element with univibrators e.g. in order to realize a fast window discriminator with trailing edge trigger.

It is known, that a tunnel diode univibrator delivers a train of output pulses if the resolving time of the

univibrator is small compared with the input pulse width exceeding the trigger level. In this case one obtains a simulated Schmitt trigger output, if the pulse train is fed to an integrating circuit. The principle of such a threshold circuit is shown in fig. 2.

For leading edge trigger types with tunnel diode univibrators, the basic circuit can be quite simple and consists preferably of two additional pulse shapers, each following the two threshold stages and an anticoincidence device. These three additional stages can be realized with tunnel diode univibrators as well, whilst the pulse shaper following the lower level threshold can serve, moreover, as a delay generator to obtain the necessary delay for faultless operation.

The use of several univibrator circuits includes certain time problems, influencing the logic function of the discriminator which may lead to false output signals.

Because the two pulse shapers, necessarily producing different output pulse widths, have different resolving times and furthermore are triggered at different moments, there exists no time-correlation between the actions of the threshold circuits. In such a case an input pulse, overriding the window range, can produce an unwanted output signal, if occurring at a moment, when the upper level pulse shaper is still dead due to a preceding input pulse.

A second problem due to the use of the univibrators is their multiple triggering behaviour, which is, at any rate, forbidden for the two pulse shapers, in order to avoid multiple outputs.



These two considerable draw-backs of the basic circuit can be overcome by additional logic circuitry, which has to suppress possible multiple triggering of the pulse shapers and, moreover, should allow time correlation between actions of the two threshold circuits.

## 5. The Realized Unit

The aim of developmental work was to perfect a unit type, capable of handling input signals down to some nanoseconds width with sufficient accuracy, having an input sensitivity of approx. 10 mV with agreeable threshold stability and good timing accuracy. The principle of a leading edge trigger had been chosen and a so-called quenching arrangement was added to the circuit to overcome the intrinsic draw-backs of the basic unit. In fig. 3 the block diagram is shown and fig. 4 gives the complete circuit diagram.

### 5.1. Principle of Operation

Referring to fig. 3, the signal applied to the input of the unit passes the input stage and reaches the two thresholds delivering equal trigger current amplitudes to them.

Both the thresholds are univibrators with additional backward diodes as shown in fig. 1c. Their resolving time is held small (approx. 20 ns), and their only task is to indicate, whether the input signal has reached their threshold levels or not. If the effective trigger pulse width exceeds their resolving time, a train of output pulses is allowed.

If an input pulse has triggered the lower level threshold (LLT), the output pulse, resp. the first pulse of the produced pulse train triggers via a buffer stage

the following LL-pulse shaper, likewise a tunnel diode univibrator.

This stage serves as a delay generator. The delay is equal to the width of the output pulse, because the trailing edge of it senses after differentiation the following anticoincidence stage. If the input pulse has reached the upper level threshold (ULT) too, the generated pulse (or pulse train) sets a tunnel diode flip-flop, the UL-pulse shaper, via a buffer stage. The flip-flop, in its "set" position, inhibits the delayed action of the LL-pulse shaper output at the anticoincidence stage. The LL-pulse shaper output with its trailing edge is used to reset the flip-flop.

Due to the use of a flip-flop instead of a univibrator as UL-pulse shaper, correlation of the reset-moments of the two pulse shapers is obtained.

The anticoincidence stage is a tunnel diode univibrator too. Its output pulse reaches, passing an output amplifier, the terminal.

In addition, a quenching arrangement is incorporated, which has to overcome the imperfection of the basic circuit.

When a sufficiently wide input pulse reaches the thresholds, the pulse train from the LLT is fed to the quenching flip-flop together with the differentiated trailing edge of the LL-pulse shaper output pulse. As long as the pulse train lasts, the tunnel diode receives a "holding current".

The trailing edge of the LL-pulse shaper output brings the flip-flop into its "set"-position, i.e. the tunnel diode switches into its high voltage state. In this state of the tunnel diode both the pulse shapers become inactive due to switching-off their bias currents.



The flip-flop remains in the "set"-position as long as the holding current is present. If the pulse train at the LL-threshold output disappears, i.e. the input pulse has finished, the holding current goes back to zero and the quenching flip-flop reaches again its initial "reset" state. At this moment the unit is free again to accept a new input pulse.

By that arrangement, not only the reset-moments the two pulse shapers, but also the dead times are correlated and unwanted output pulses are suppressed. In consequence the best time resolution for wide input pulses is obtained.

For short input pulse widths quenching action is not needed and will not be initiated, because the holding current disappears earlier than the trailing edge of the LL-pulse shaper arrives at the quenching flip-flop. In this case the time resolution of the unit is given by the pulse width and deadtime of the LL-pulse shaper, which in each case determines the maximum tolerable risetime by its generated delay.

## 5.2. Some details of lay-out

The detailed circuit description of the realized unit refers to the circuit diagram, fig. 4.

### 5.2.1. Input stage

The input stage, consisting of 3 transistors, 2N709, is dc-coupled and feeds the two threshold univibrators with equal input current pulses. The conversion factor is approx.  $10 \mu\text{A}/\text{mV}$  with respect to each threshold. The system rise time (10--90%), measured at the thresholds, is less than 1.8 ns. The maximum pulse current amplitude available at the thresholds is approx. 8 mA each. By that means the thresholds are sufficiently protected against overload.

### 5.2.2. Threshold stages and biasing

The two threshold univibrators are represented by a matched pair of tunnel diodes with 5 mA peak current. (Type TDP3, General Electric). Only these types are found to assure equal enough trigger behaviour of the threshold stages for sufficient switching speed.

The univibrator with TD1a works as LL-threshold stage, the other one (TD1b) as UL-threshold. Both the thresholds receive the same bias currents,  $J_B$ , the base line level of the discriminator.  $J_B$  itself is determined by the output voltage of the feeding emitter followers (T6, T7) and the series resistors  $R_B$ , because  $R_B$  is made much larger than the effective nonlinear resistance of the tunnel diode.

$J_B$  flows nearly totally into the tunnel diodes, because of the inserted backward diodes (Type BD4, General Electric), which are held at zero voltage by floating voltage dividers. Thus the requested linear dependence between  $J_B$  (resp. the threshold level) and the BASELINE potentiometer setting is achieved. The UL-threshold, moreover, receives a second opposite bias current,  $-J'_B$ , from separate emitter followers, which can be, likewise, set linearly by the WINDOW WIDTH control potentiometer. By that means, sliding window technique is achieved, because  $-J'_B$ , representing the threshold level difference of the two univibrators, defines the window width of the discriminator and is independent on the base line control setting.

The lower limit of the LL-threshold range is fixed at 0.1 mA. Referred to the input a maximum input sensitivity of 10 mV is reached. Temperature

stability of the threshold at lower levels is improved by insertion of a small NTC-resistor between T6 and T7.

The base line level and window width have equal dynamic ranges of 21 and can be controlled from 10 mV to 210 mV.

### 5.2.3. Overload performance and time resolution

The realized unit works in a correct way for a nearly unlimited pulse shape range due to the quenching arrangement. Only the maximum rise time of input pulses remains restricted. The maximum allowed input signal amplitude is 5 volts, that means, within a dynamic range of 500, faultless operation is reached.

For sufficient narrow input signals, if no quenching action is necessary, the resolving time of the LL-pulse shaper is approx. 125 ns, which is the resolving time of the whole unit. The width of the LL-pulse shaper output pulse was made to be 40 ns, which is also the maximum admitted total rise time of the input signals.

### 5.3. Comparison with other units known up to now

Recent literature describes already fast window discriminators of the leading edge type.

One unit (6) works without quench. The device underlies restrictions concerning the shape of input signals, and the actions of both the thresholds are not correlated in time.

Another unit (7) shows some conformity with the unit described in this paper. A quenching unit is used as well, which has nearly the same performance as the described one. For the threshold stages so-called "hot carrier diodes" are employed instead of tunnel diodes.



## 6. Measurements and Tests

To examine the performance of the unit, pulses with a width of 5, 10 and 20 ns and a width-to-rise time ratio between < 2 and 20 were used. (Rise and decay time of the input pulses were equal.)

### 6.1. Linearity

The integral linearity error  $\Delta C_i$  for the base line was determined by measuring the conversion factor  $C_i$ , (i.e. the scale reading of the control potentiometer versus the pulse amplitude which is necessary just to trigger the threshold) at 10 equidistant points of the lower threshold level range.

For  $\bar{C}$ , the mean value of  $C_i$ , it follows

$$\bar{C} = \frac{1}{10} \cdot \sum_{i=1}^{10} C_i \quad (1)$$

The integral linearity error  $\Delta C_i$  is then given by

$$\frac{\Delta C_i}{\bar{C}} = \left( \frac{C_i}{\bar{C}} - 1 \right) \times 100\% \quad (2)$$

The measuring results are shown with fig 5.

It is seen that for a given pulse width a change of input rise time has no influence on the integral linearity error, which remains between  $\pm 1\%$  down to a pulse width of 5 to 10 ns.

### 6.2. Constancy of the base line (lower threshold) level vs. pulse shape

The constancy of the base line vs. input pulse shape was measured.

In fig. 6, the dependence of the threshold level vs.

pulse width (at minimum rise time) is shown. The deviation for small input pulse widths is due to the rise time of the input stage and the charge sensitivity of the tunnel diode threshold stage because of the capacitance of the diode. The results are valid for arbitrary base line settings, at least between 10 and 100% of the maximum value.

In fig. 7, the stability of the base line vs. pulse rise time is given. The pulse width was set at 20 ns. The influence of different rise times on the base line stability is practically negligible up to nearly triangular shapes.

The obtained results show a further advantage of the employed threshold stages. Due to the inserted backward diode, the trigger behaviour of the tunnel diode is not affected by the low-pass characteristic of the load. The result is a quite stable threshold level up to considerably long signal rise times.

### 6.3. Window width, variation vs. pulse shape and base line setting

The constancy of the window width vs. base line setting was measured. Typical results are shown in fig. 8 a-c. The deviations must be explained by a slightly different switching characteristic of thresholds when set at different levels together with small gain differences of the input stage for its two outputs.

### 6.4. Propagation delay

The propagation delay, chiefly given by the width of the LL-pulse shaper, was measured vs. overdrive factor for minimum threshold level and a width and rise time of the input signals of 5 and 3 ns resp. (Fig. 9)

### 6.5. Temperature test

Care was taken for the lay-out of the different

stages of the unit to assure faultless operation between 10° and 50°C.

The stability of the base line level was measured to be better than -0.15 mV/°C at the lower limit, continuously varying to + 0.08 mV/°C towards the upper limit of the range.

The window width has a temperature dependence of better than + 0.2 mV/°C at the lower limit, resp. + 0.3 mV/°C at the upper limit of the range at arbitrary base line setting.

A test of propagation delay vs. temperature was carried out as well. The input pulse conditions were as given in 6.4. (Pulses, 50% greater than the threshold level, with a fixed overdrive factor of 1.5 were used at the threshold.) The stability was better than 1 ns between 10 and 50°C.

## 7. Conclusions

### 7.1. Discussion

The versatility of the discriminator can be further improved when necessary.

Because the LL-pulse shaper defines the maximum admitted input rise time as well as the time resolution of the whole unit, the utilisation of a "deadtimeless" LL-pulse shaper circuitry would either improve the time resolution or increase the max. total input rise time by a factor of two to three.

A better timing accuracy of the realized unit can be reached by reduction of the propagation walk within the dynamic range of pulses for instance by introduction of an additional threshold, triggering always at a small percentage of pulse amplitude.



## 7.2. Future work

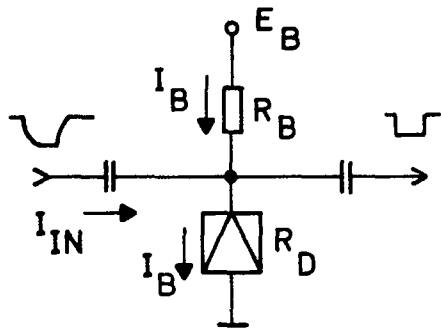
Work is in preparation to realize a simple (but slower) type of window discriminator with integrated circuits. For instance an available comparator circuit, (type  $\mu$ A 710, Fairchild) is suited to obtain stable and sensitive thresholds. A unit with 100 ns resolving time, e.g. of the trailing edge type, would be advantageous for general purpose applications.

## 8. Acknowledgements

The author wishes to thank Dr. H. Meyer for numerous valuable suggestions and discussions. Furthermore the helpful collaboration of Messrs. H. Nerb and K. Hofmans in connection with the realization and test of the equipment should be gratefully acknowledged.

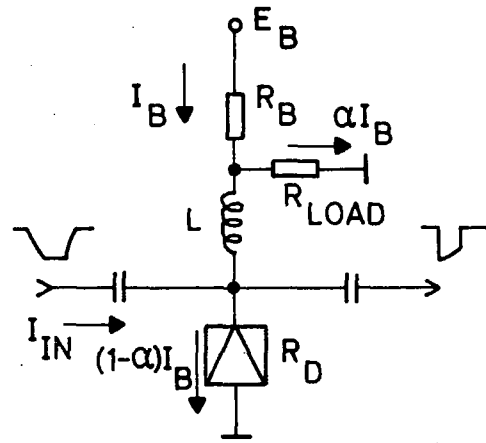
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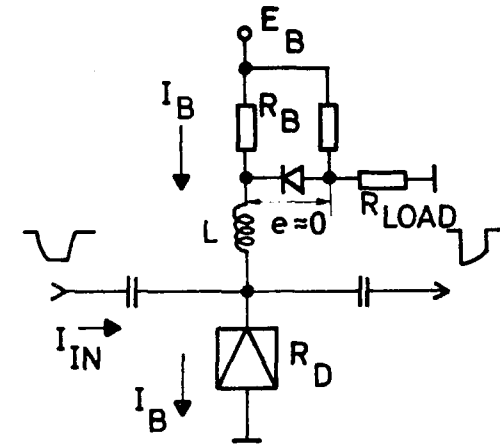
(a)

Threshold only within linear range of TD-characteristic. Sufficient linearity, but small dynamic range.



(b)

Greater dynamic range, but poor linearity, because of current splitting into load.



(c)

Dynamic range corresponds to (b). Better linearity conditions.

Fig.1

Principles of Tunnel Diode Thresholds

a) Basic Schmitt Trigger

b) Basic Univibrator

c) Modified Univibrator

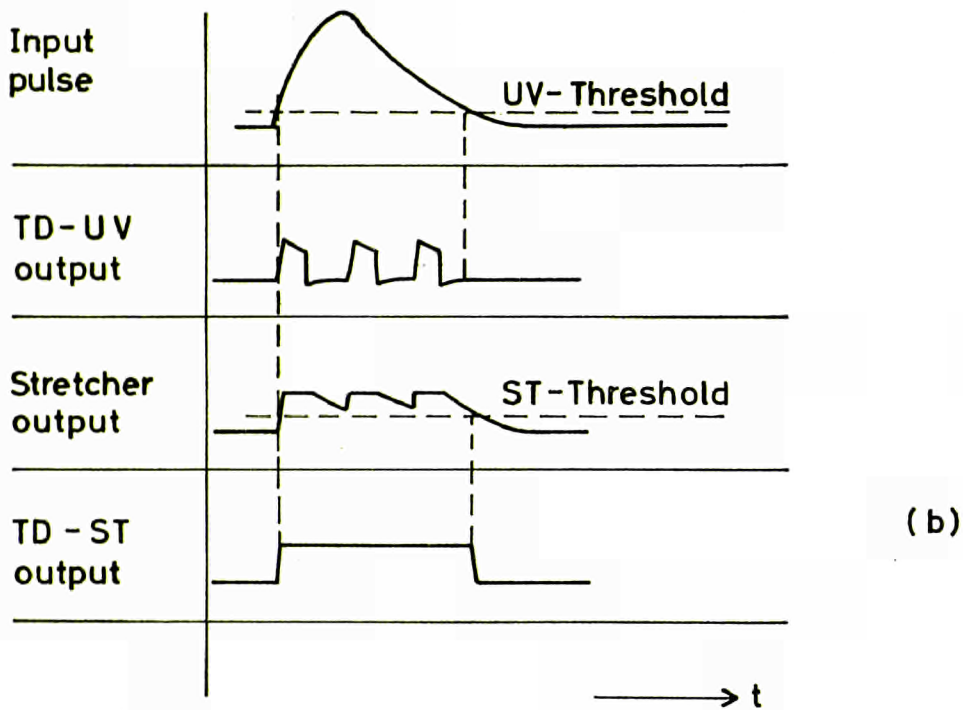
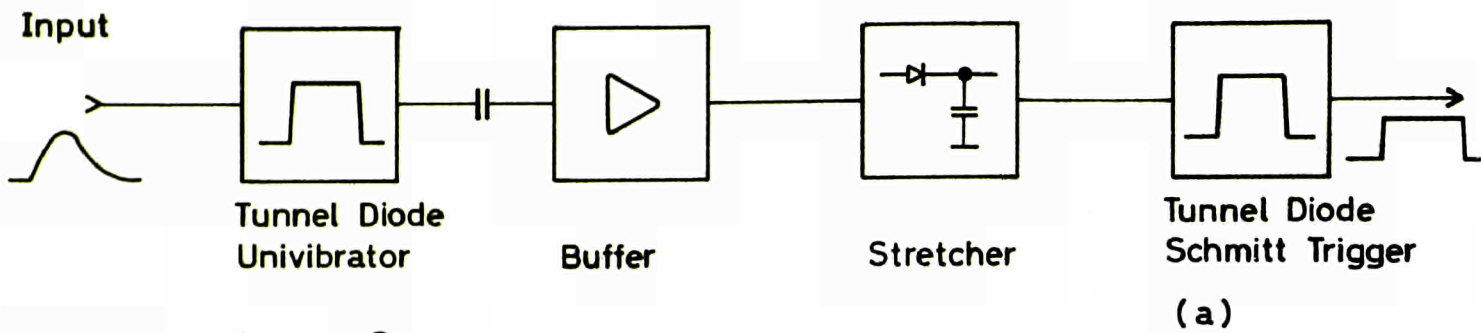


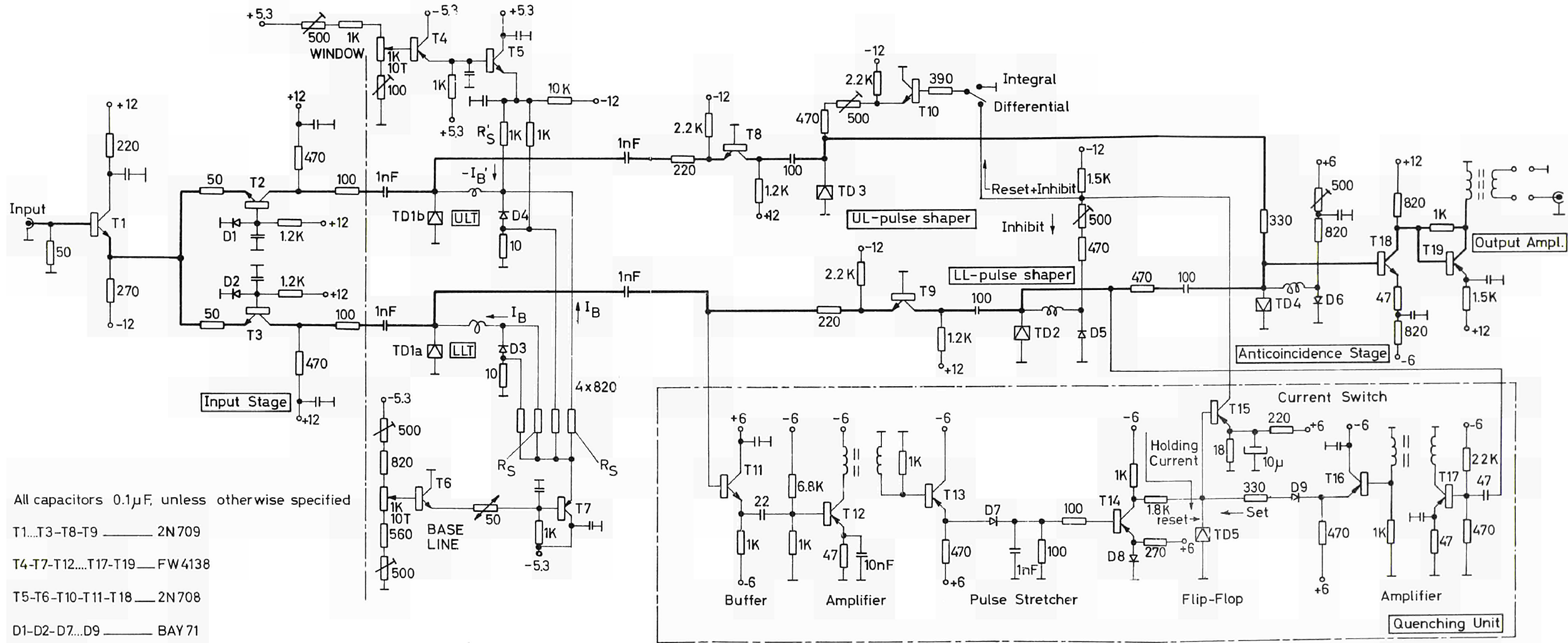
Fig.2

Principle of a Univibrator Threshold with Schmitt-Trigger Behaviour.

a) Block Diagram

b) Timing Diagram





All capacitors 0.1μF, unless otherwise specified

T1...T3-T8-T9 \_\_\_\_\_ 2N709

T4-T7-T12...T17-T19 \_\_\_\_\_ FW4138

T5-T6-T10-T11-T18 \_\_\_\_\_ 2N708

D1-D2-D7...D9 \_\_\_\_\_ BAY71

D3...D6 \_\_\_\_\_ BD4

TD1a,b \_\_\_\_\_ TDP3

TD2...TD5 \_\_\_\_\_ 1N3852

Fig. 4

The Realized Unit

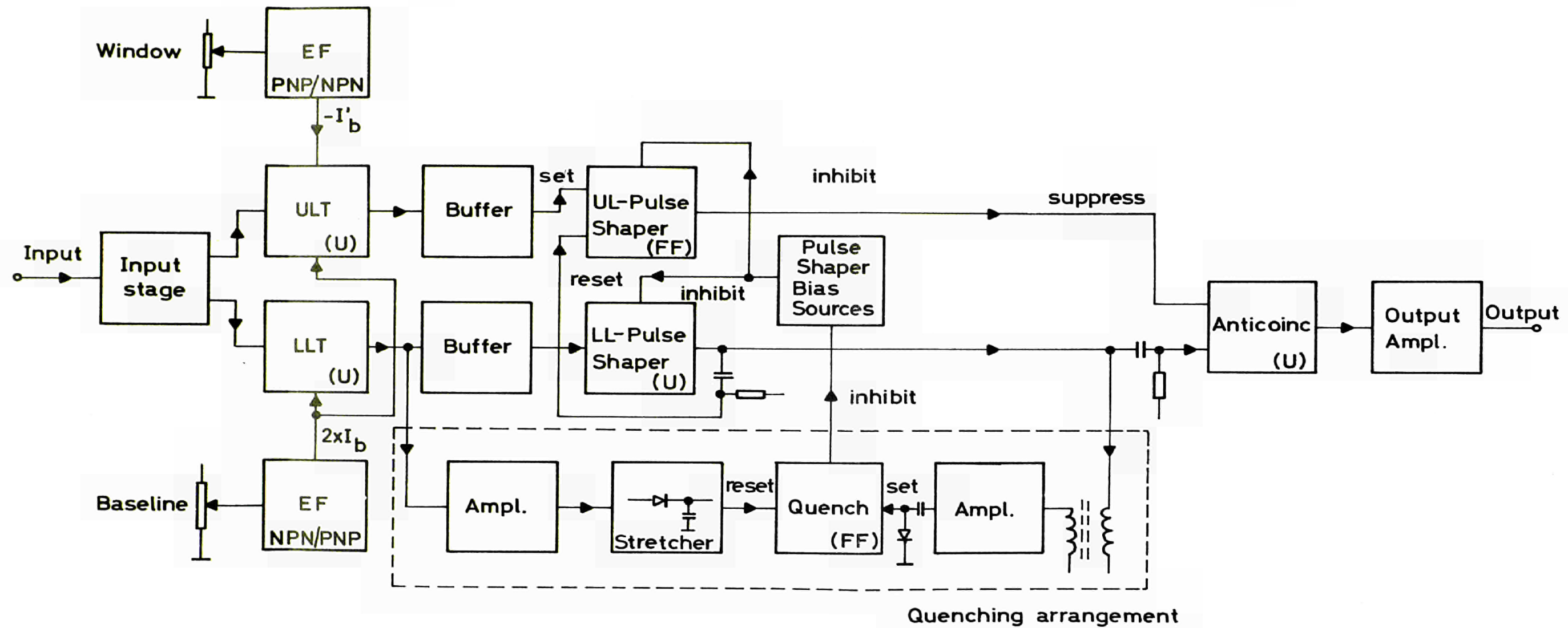


Fig. 3

Block Diagram of the Realized Unit

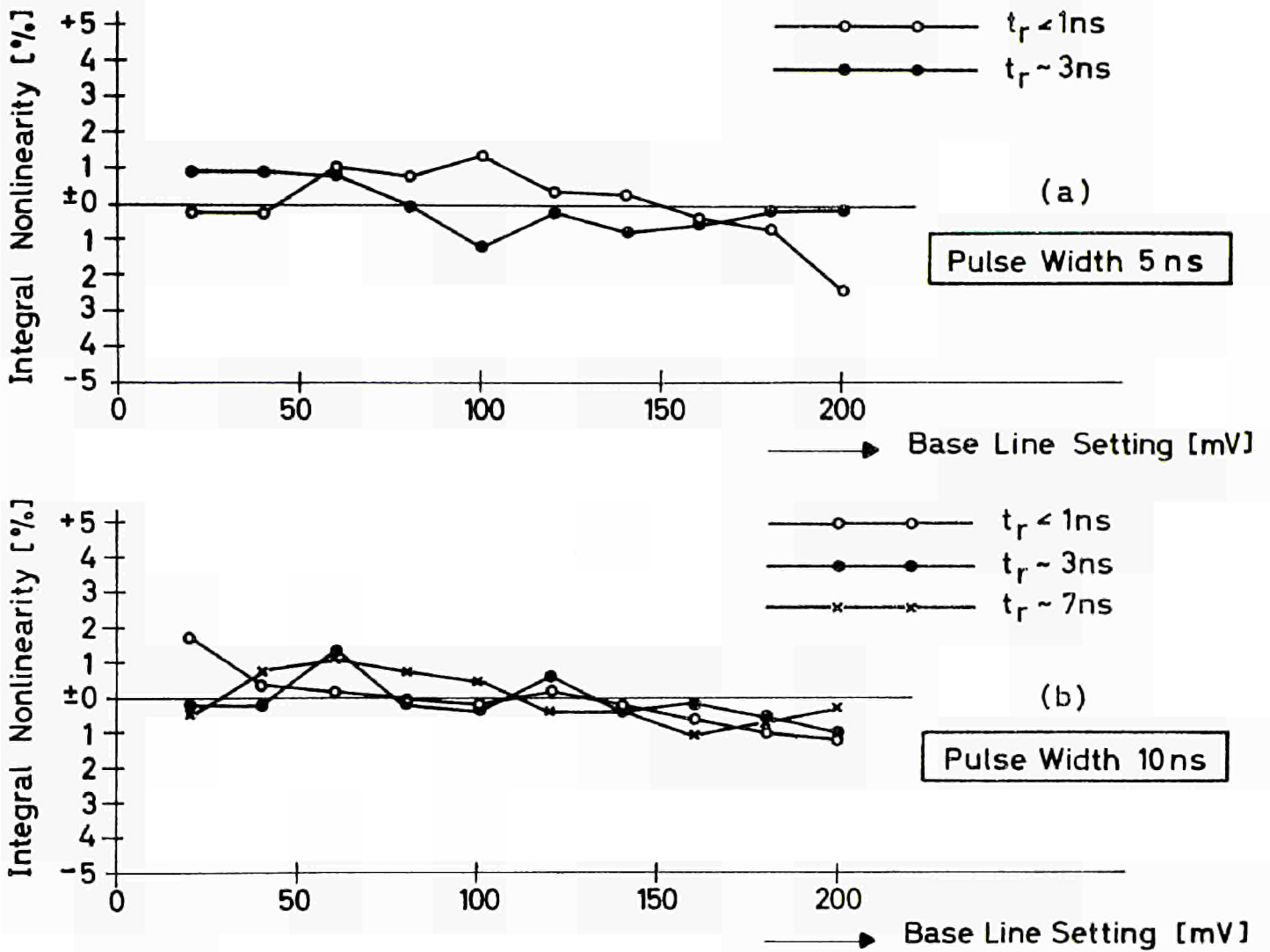


Fig.5

Integral Linearity of the Lower Threshold Level vs. Base Line Setting.

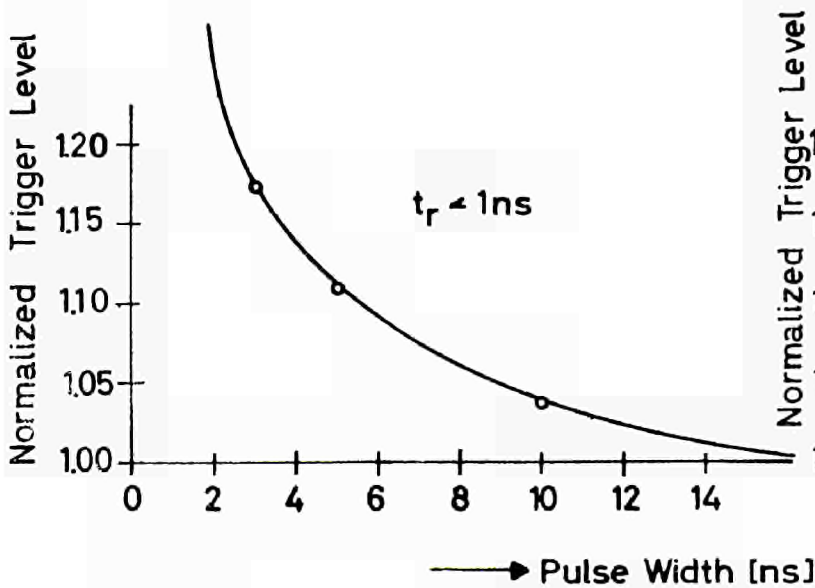


Fig. 6

Base Line Level vs. Pulse Width.

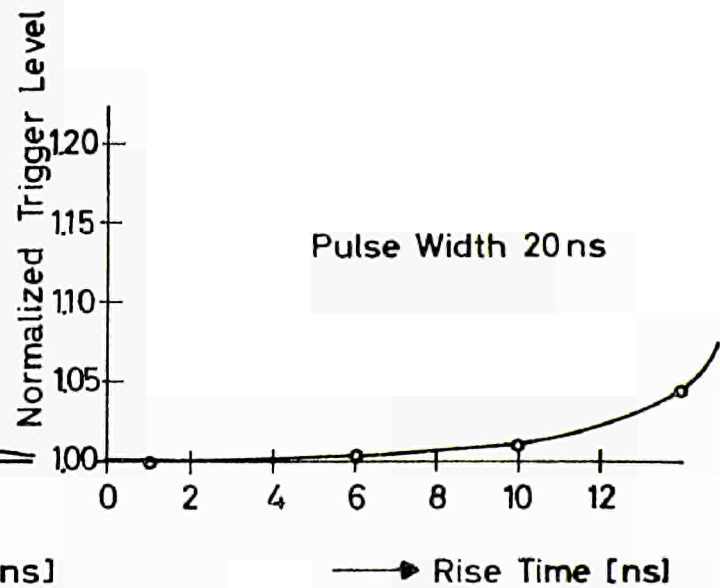


Fig. 7

Base Line Level vs. Pulse Rise Time.

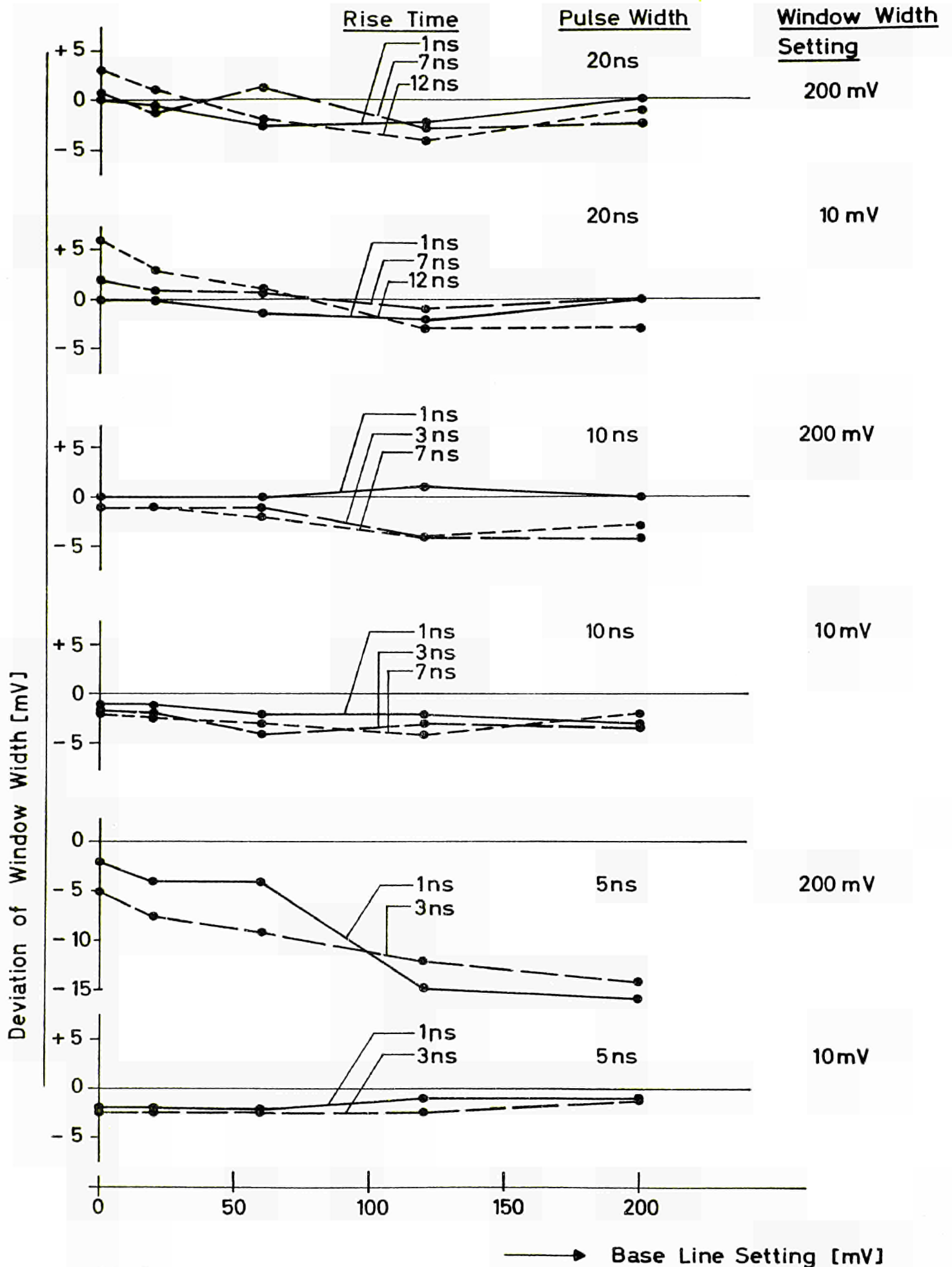


Fig.8

Window Width vs. Base Line Setting.



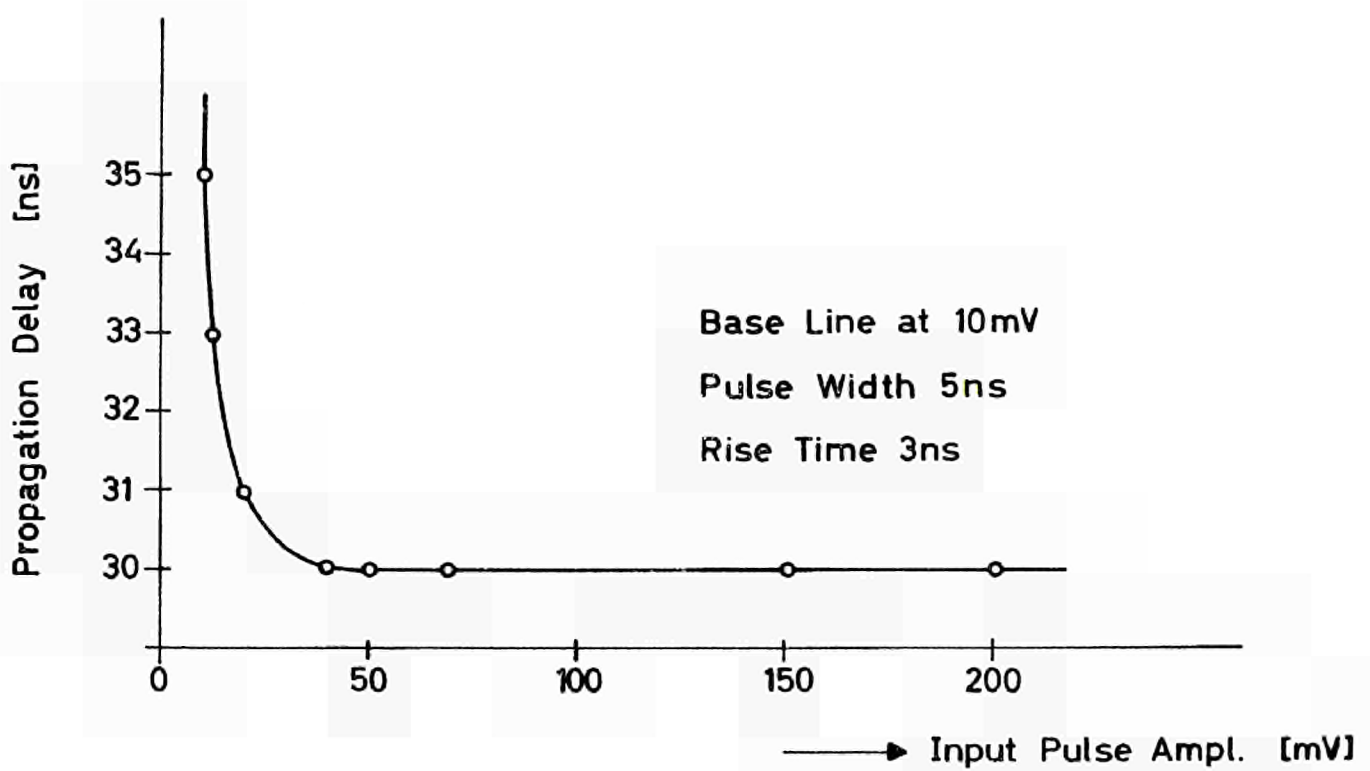


Fig. 9

Propagation Delay vs. Input Pulse Amplitude.





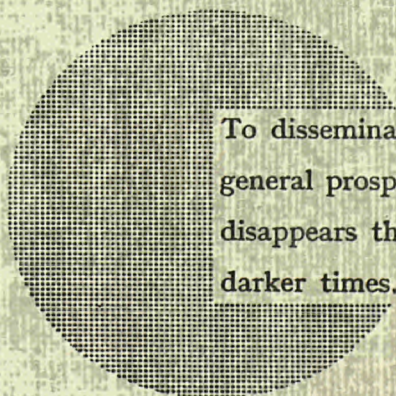
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Alfred Nobel



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