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BEHAVIOUR OF THE THRESHOLD CIRCUIT AT THE INPUT OF ANALYSIS SYSTEMS FOR SCINTILLATION PULSES*

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In nuclear physics experiments, errors of timing measurements result from the contribution of disturbances, intrinsic at the electronic counting system. The counting system is affected by the statistical variations of the input pulse shape. We have studied for a tunnel diode basic monostable circuit the threshold behaviour and delay jitter vs input rise time. Therefore we give an operative definition of the threshold and calculate its variation for exponential and ramp input shaped pulses. The results are critically tested with experimental circuits. We find finally the counting losses to be ascribed to the jitter of the input pulses rise time. The results obtained may be straightly applied to all switching circuits in a more general fashion.

1. Introduction

The errors of timing measurements in nuclear physics experiments result from the contribution of several factors of disturbance, that we may refer to as:

1. intrinsic disturbance of the detector,
2. intrinsic disturbance from the P.M. (or in general from the transducer),
3. intrinsic disturbance from the electronic counting system (electric filter).

The purpose of our work is to analyse the disturbances caused by the third point.

The distortions of the information due to pile-up effects have been exhaustively studied in recent works[1–3]). Moreover, up to now, the maximum repetition rate of the events to be analysed is not higher than 100 MHz. We wish to take into consideration the disturbances due to the statistical†† variations of the input pulse shape feeding the electronic analysing system, affecting timing information and loss of counting.

With regard to the analysing systems input circuits, we find a general use of the tunnel diode, that is to-day the device with the highest figure of merit.

To characterize the input pulse shape we have first taken into account the rise-time. Then we have studied the threshold behaviour and the output pulses delay jitter for a tunnel diode basic monostable circuit, with respect to the input pulse rise time.

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†† We must now distinguish two types of statistical variations of the rise-time. *First* we can refer to the variations of the rise-time for pulses of the same amplitude due to the jitter of the P.M. *Second* and more important are the amplitude statistical variations of the pulses from the P.M. that lead to a wide range of pulse slope at a definite threshold. Many and many works have been done to reduce the effects of this statistical variation on timing[4–7]).

As an easy application we have derived the counting losses to be ascribed to a variation of the input pulses rise time. The results may be applied in the more general fashion to all switching circuits. Following the ideas published in our previous letter[8]), we give here the results that must be considered as definitive and complete.

2. General considerations

We refer to the circuit whose schematic and equivalent scheme is shown in fig. 1. The resolving equations of the circuit, normalised to the characteristics values of the tunnel diode, shown in fig. 2 are

$$\mathrm{d}v/\mathrm{d}T = j_{\mathrm{in}} + j_0 + j_{\mathrm{L}} - f(v),$$
$$\mathrm{d}j_{\mathrm{L}}/\mathrm{d}T = (E - nj_{\mathrm{L}} - v)/K,$$

where $j = f(v)$ is the static characteristic (v, j) of the tunnel diode fitted with two parabolic functions joined at the point $[1.5, f(1.5)]$,

$$K = L/(R_{\mathrm{p}}^2 C); \qquad \mathrm{d}T = \mathrm{d}t/(R_{\mathrm{p}}C).$$

If the system may be considered free of noise, fig. 2 shows that the static threshold for a tunnel diode biased

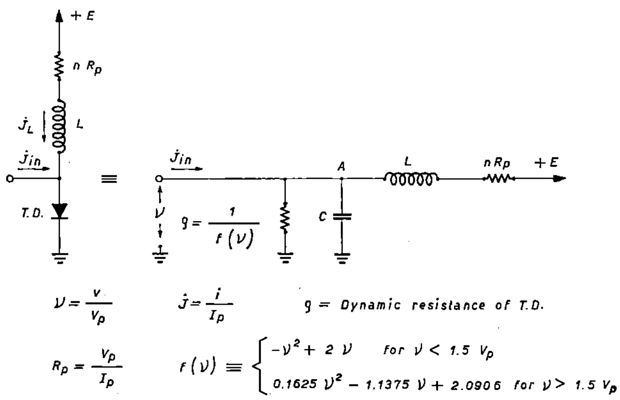

Fig. 1. Tunnel diode monostable scheme and its equivalent circuit.

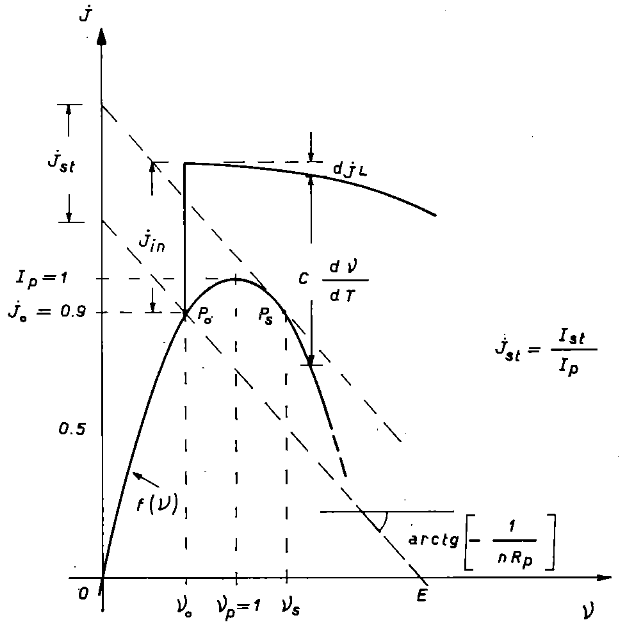

Fig. 2. Graphical characteristics of the tunnel diode monostable equivalent circuit.

with $j_0 = 0.9$ is the current value j_{st} intercepted, as known, on the j-axis by the load line nR_p and its parallel tangent to the static characteristic. For an input pulse rise time $\tau, [0 < \tau > \infty]$, the inductance present in the circuit inhibits the input current from flowing in the biasing resistance nR_p, lowering the value of the threshold. Its ideal lower limit is the value[8] $1 - j_0$, or $(I_p - I_0)/I_p$.

3. Threshold definition

The threshold of a tunnel diode (td) circuit depends on rise time of the triggering pulse and as a consequence on all the reactive parameters of the actual circuit.

We will evaluate the threshold behaviour as a function of the input pulse rise time ranging from 0 to ∞. To evaluate this behaviour we must refer to a td threshold definition that will be operative to allow an experimental measurement.

One usually defines the threshold for any switching circuit as the value of the lowest input pulse amplitude able to drive the circuit to the regenerative condition. For a td this is expressed analytically as

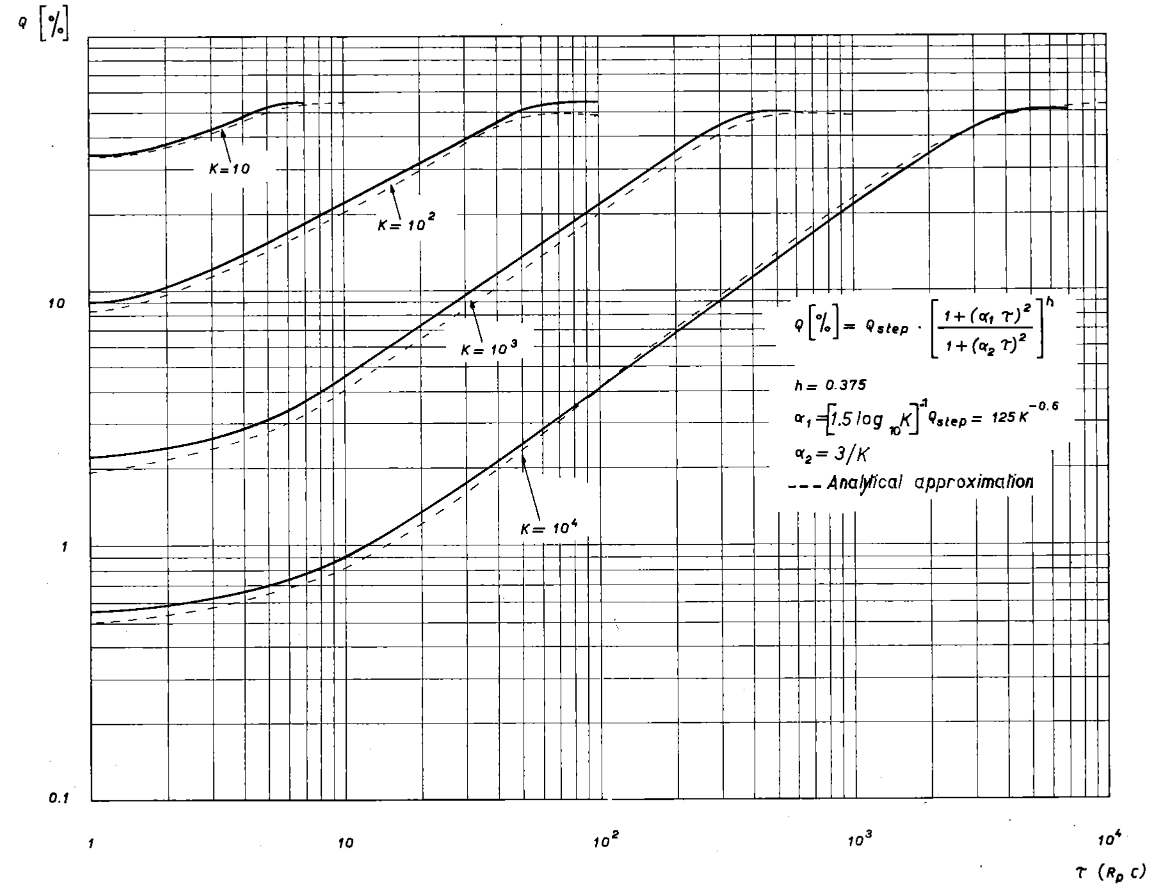

Fig. 3a. Threshold behaviour for exponential input vs time constant τ; bias current $J_0 = 0.0$; $n = 2.0$.

$$d(j_{in}+j_L)/dv = df(v)/dv.$$

As known, this condition states that, at the regenerative point, the tangents to the (v, j) characteristic of the td and to the dynamic characteristic of the circuit, are parallel.

From fig. 2 can be seen that the intercepted segment on a straight line parallel to the j-axis by the two tangents, represents the value of the instantaneous current in the capacitance to be associated to the td ($C\,dv/dT$). As straight theoretical derivation, in order to satisfy the given definition, the current $C dv/dT$ would be zero, when the input signal amplitude is the threshold value. Unfortunately this condition cannot help us because the analytical solution of the problem is impossible and the numerical one leads to an infinite delay. Moreover such delay has no physical meaning as the noise, always present, puts a lowest limit to the current in the capacitance which can not be zero.

If we think the noise associated with a certain frequency band, i.e. the noise be not equivalent to a zero frequency signal, the input signal amplitude does not remain constant as it is required for the tunnel diode to switch in an infinite time.

Let us now give an operative definition of the td circuit threshold:

"The td circuit threshold is the amplitude of the minimum input signal which gives the maximum output signal delay".

According to that definition we have measured experimentally, the threshold values for several types of td. The experimental results of both the threshold and correspondent maximum delays are reported on the theoretical curves. Comparing these results with those worked out by the computer we can state that in our experimental conditions the noise rms (j_n) is about 0.002.

4. Input signals characterization

To calculate the threshold behaviour and the output pulse delay of the td monostable circuit, we have first fed an input signal with an exponential rise-time of the shape

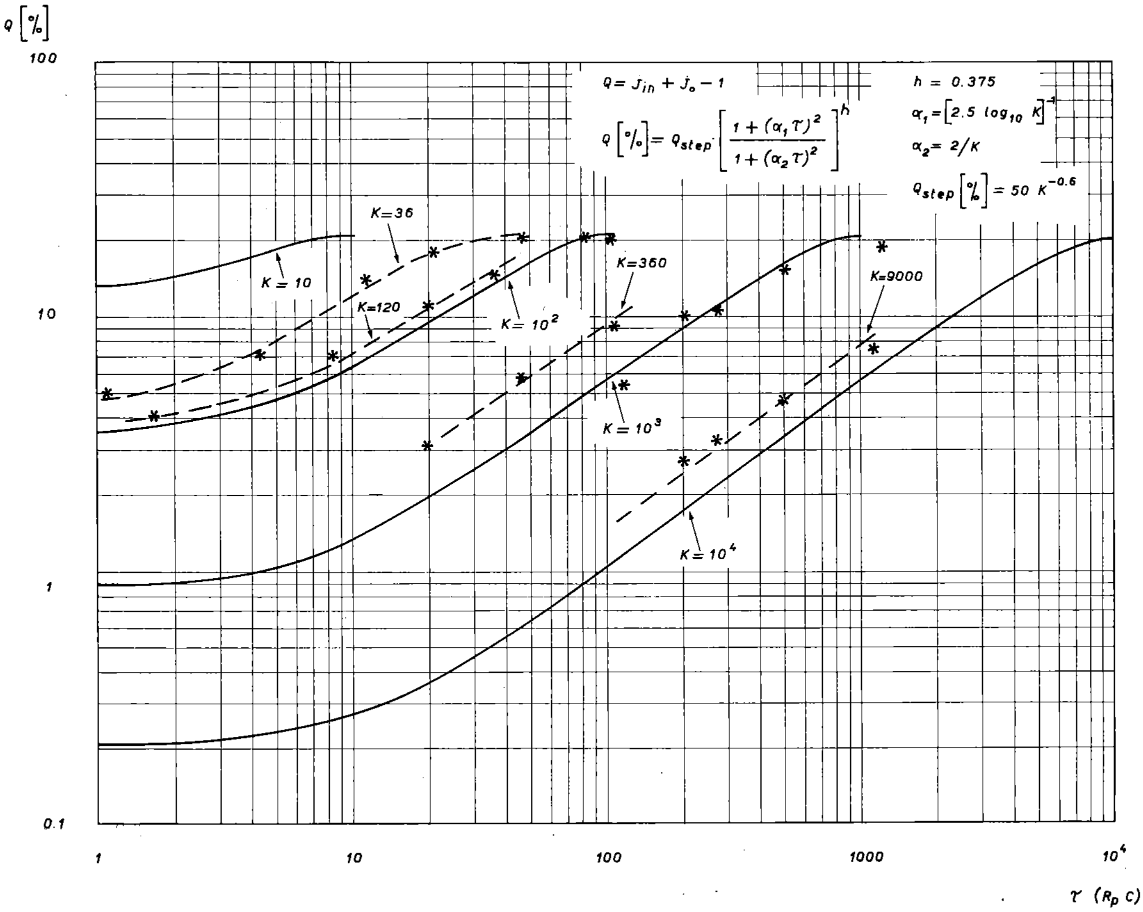

Fig. 3b. Threshold behaviour for exponential input vs time constant τ; bias current $J_0 = 0.9$; $n = 2.0$.

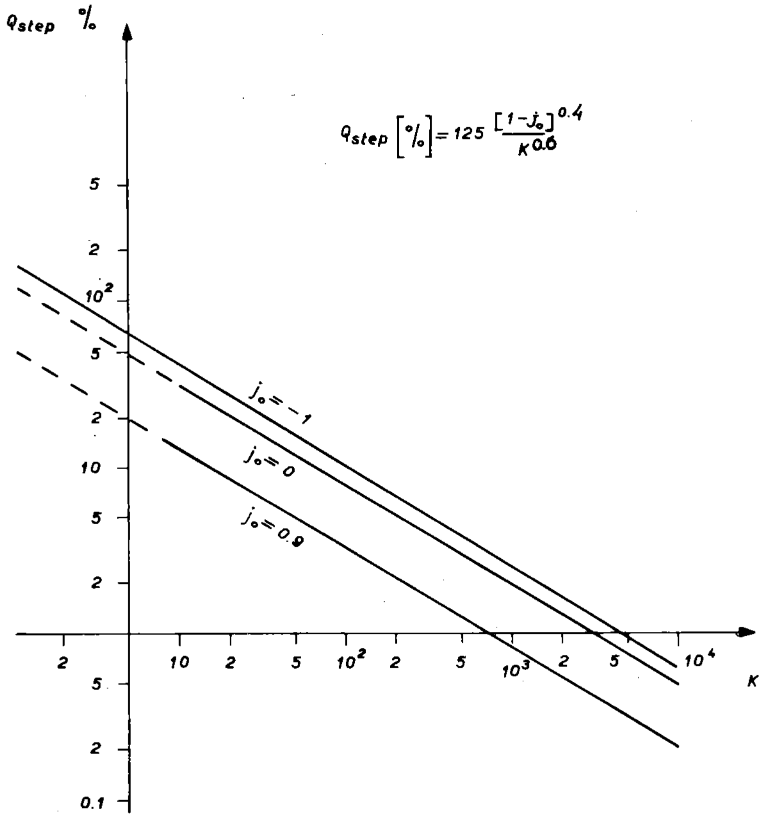

Fig. 4. Threshold behaviour to step input vs K.

$$j_{\text{in}}(t) = j_{\text{max}}[1-\exp(t/\tau)],$$

where τ varies from R_pC to $10^4 R_pC$.

Now, we are able to find a precise value of the threshold and the corresponding maximum delay with a fixed noise level, as said before. One expects that, for a fixed τ, (a fixed value of the threshold) and several input signal amplitudes, only the delay should vary. But what actually happens is that for increasing amplitude also the threshold increases. To explain this, we must suppose the td monostable is also sensitive to the slope of the input signal which we assume to be

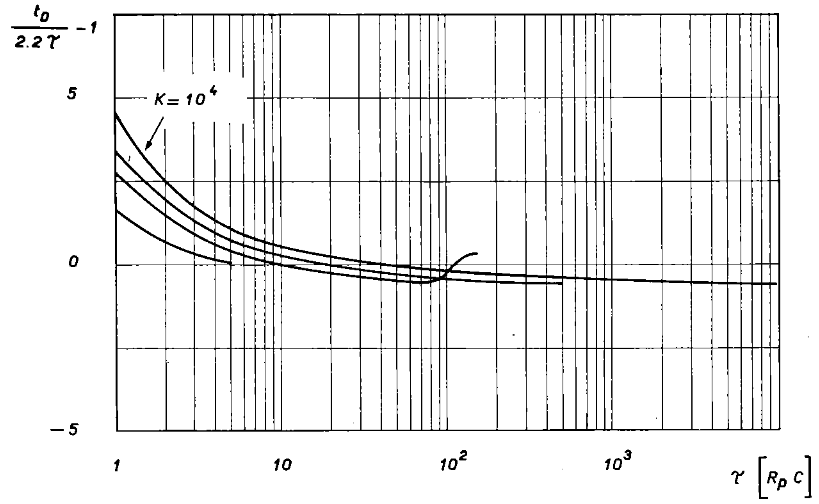

Fig. 5a. Intrinsic delay vs τ for $J_0 = 0.9$; $n = 2$; $J_n = 0.01$.

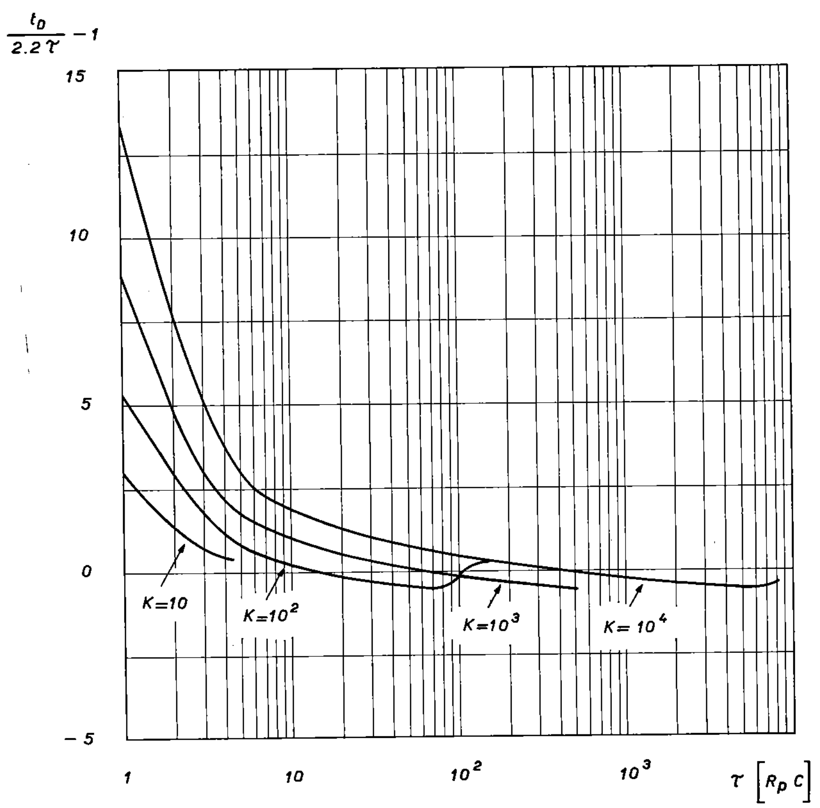

Fig. 5b. Intrinsic delay vs τ for $J_0 = 0.9$; $n = 2$; $J_n = 0.001$.

equal to the zero point slope j_{max}/τ. To study this effect we have assumed an input signal ramp

$$j_{in} = \alpha T,$$

letting vary the slope α from $10^{-4} \div 1 I_p/(R_p C)$.

5. Results of the calculations

The threshold behaviour for exponential input signals vs τ and for biasing current $j_0 = 0.9$ and for $j_0 = 0.0$ are reported in fig. 3a, b. On the ordinate is reported the % value of the overdrive

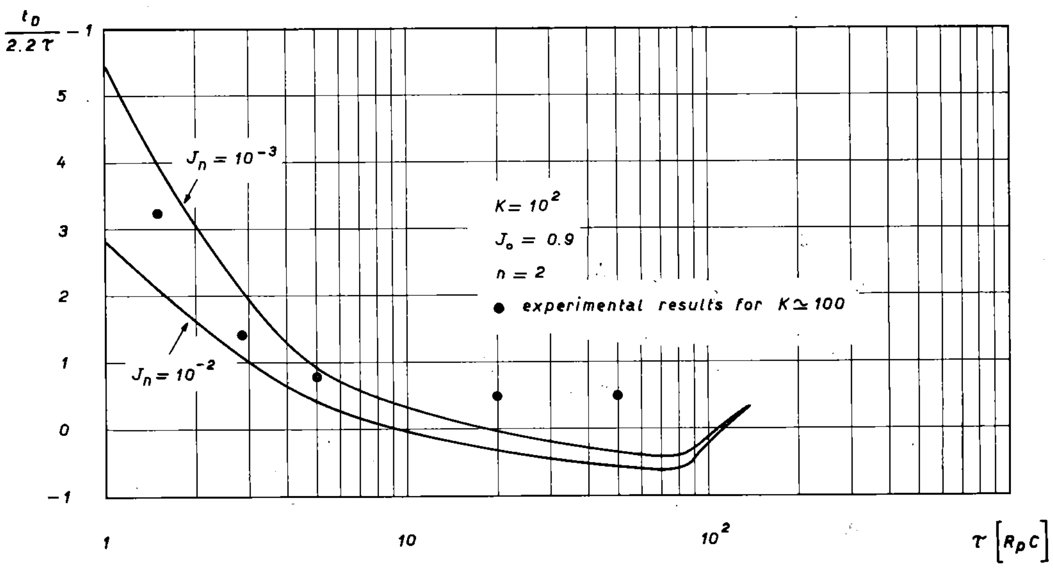

Fig. 6. Intrinsic delay vs τ for $J_n = 10^{-2}$ and $J_n = 10^{-3}$.

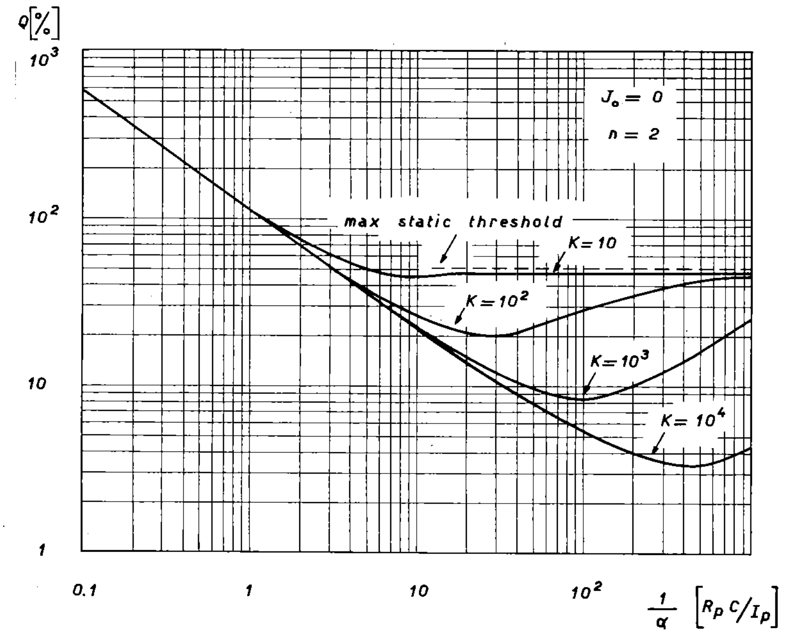

Fig. 7a. Threshold vs $1/\alpha$ for ramp input.

$$Q = j_T + j_0 - 1,$$

where j_T is the threshold value of the current. The curves shown there may be analytically fitted by the expression

$$Q = Q_{st}[\{1+(\alpha_1\tau)^2\}/\{1+(\alpha_2\tau)^2\}]^h. \quad (1)$$

Q_{st} is the overdrive of the step input signal. Its values vs K are reported in fig. 4 and may be well fitted with the expression:

$$Q_{st} = 125(1-j_0)^{0.4}/K^{0.6}.$$

The α_1, α_2, h, values are reported, for different j_0, in fig. 3a, b. The expression (1) may be obtained taking into consideration a phase-lead network for $\tau \ll \tau_0$ and a phaselag network for $\tau \gg \tau_0$. $\tau_0(K)$ is the time constant

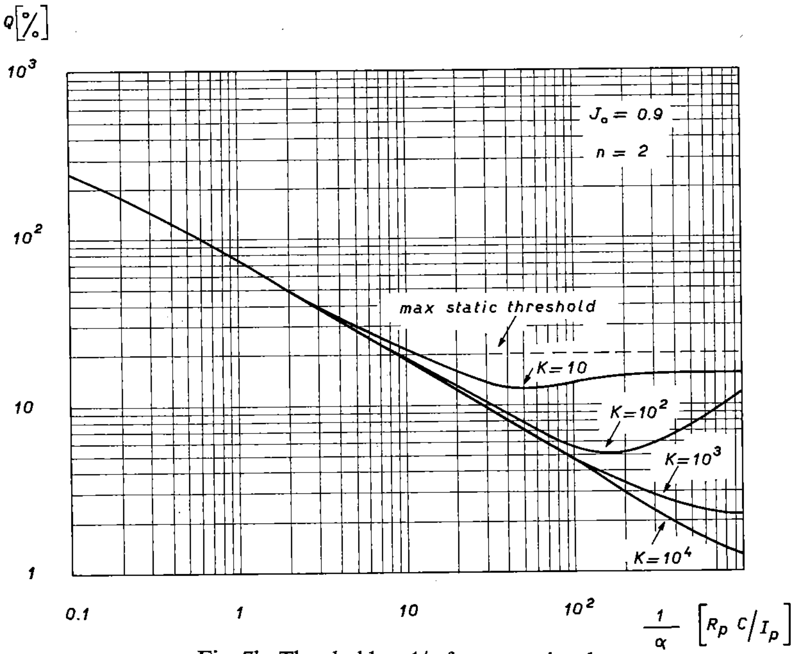

Fig. 7b. Threshold vs $1/\alpha$ for ramp signal.

of the inflection point of the curves in fig. 3, that is the abscissa of the maximum variation ($dQ/d\tau$) in the threshold behaviour. Unfortunately the analytical expression is not rational and therefore is impossible the synthesis of an equalizing linear network.

The intrinsic delay of the monostable circuit, that is the difference between the minimum width t_D and its rise-time 2.2 τ, normalized to the input rise-time, is shown in fig. 5a, b for two values of the input noise j_n. This normalized delay is zero for $\tau = \tau_0$. We can see that the delay increases rapidly with decreasing noise level.

In fig. 6 we report the values of the delay for a fixed K and for the two noise levels of fig. 5 and also the experimental values. We observe that for high values of τ the noise j_n is lower because the bandwidth is narrower and therefore the delay is greater than expected. We can conclude that in actual circuits j_n is not constant.

The threshold behaviour for ramp input signals is reported in fig. 7a, b as a function of $1/\alpha$ where the unit of α is I_p/R_pC. In this case it is not meaningful to define an intrinsic delay at the threshold because it is always given by the ratio $j_T(\alpha)/\alpha$ where $j_T(\alpha)$ is the threshold value obtainable from the coordinate Q of fig. 7.

Then we report in fig. 8 $j_T(\alpha)$ vs the time $t/R_pC = J_T(\alpha)/\alpha$. The meaning of this diagram is to give the minimum amplitude to fire the circuit for signals reaching this amplitude in the time defined by the corresponding abscissa.

We will now describe the behaviour of the curves of fig. 8. For little values of t the threshold value j_T is high, owing to the fact that to reduce the time delay to t, one needs to overdrive the circuit. For time values higher than t_m (the abscissa of the j_T minimum), the behaviour of the threshold is evidently like to the input exponential rise-time signals.

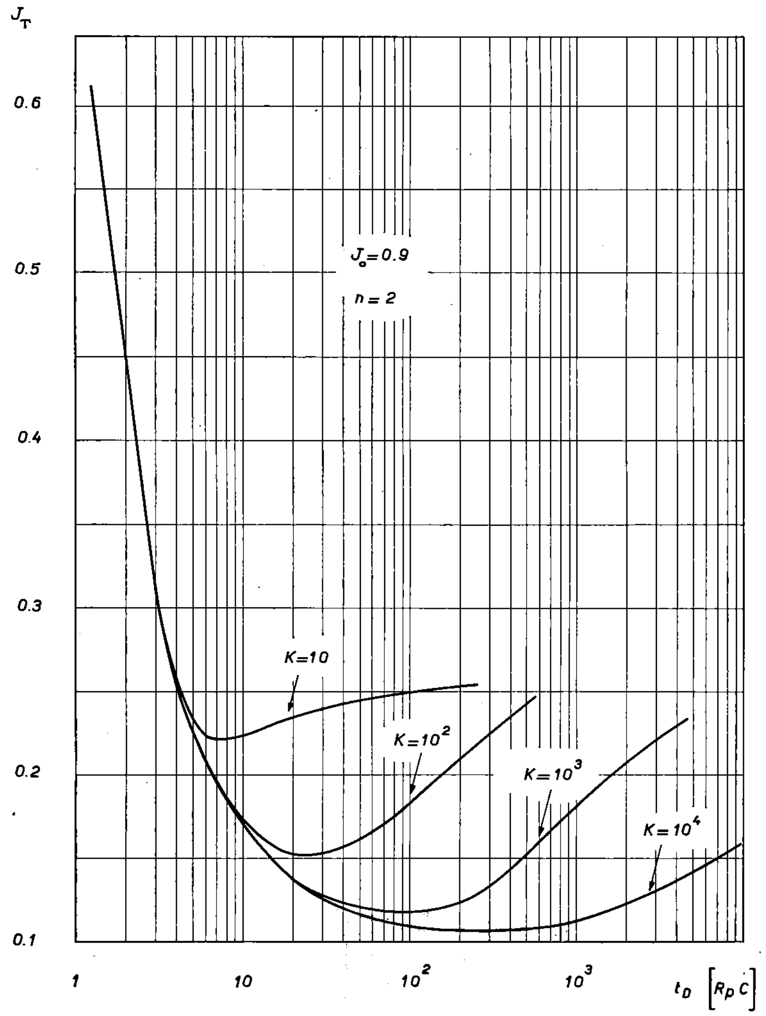

Fig. 8a. Threshold vs time delay for ramp input $J_0 = 0.9$.

6. Applications

As known, the rise-time jitter of the output pulse from a nuclear radiation detecting system is due to:

1. The scintillator geometry, referring to the impinging point of the particle,

2. The type and energy of an impinging particle[9]),

3. The temperature[10]) especially for gaseous and inorganic scintillators.

Then we will evaluate the distortion of an amplitude pulse distribution $N_1(A)$ caused by rise-time jitter whose distribution is $N_2(\tau)$ defined in the interval (τ_1, τ_2). If $N_2(A)$ is the input at a discriminator circuit with threshold behaviour like that in fig. 3, the distribution $N_{1d}(A)$ at the output may be calculated as follows.

The pulses whose amplitude is lower than the threshold corresponding to the minimum value of τ, (τ_1) are lost for counting. Those, whose amplitude is higher than the threshold corresponding to τ_2, are always present at the output.

For pulse amplitudes comprised between the threshold interval whose limits, A_1, A_2 correspond to τ_1 and τ_2, we want now associate the probability for the pulse of being discriminated.

Let us consider for a pulse amplitude A^* the corresponding τ^* which may be obtained explicitising the threshold expression (1) for τ.

We define as probability:

$$p(A^*) = \int_{\tau_1}^{\tau^*} N_2(\tau)\cdot \mathrm{d}\tau / N,$$

where

$$N = \int_{\tau_1}^{\tau_2} N_2(\tau)\cdot \mathrm{d}\tau.$$

If we express generally the explicite function as

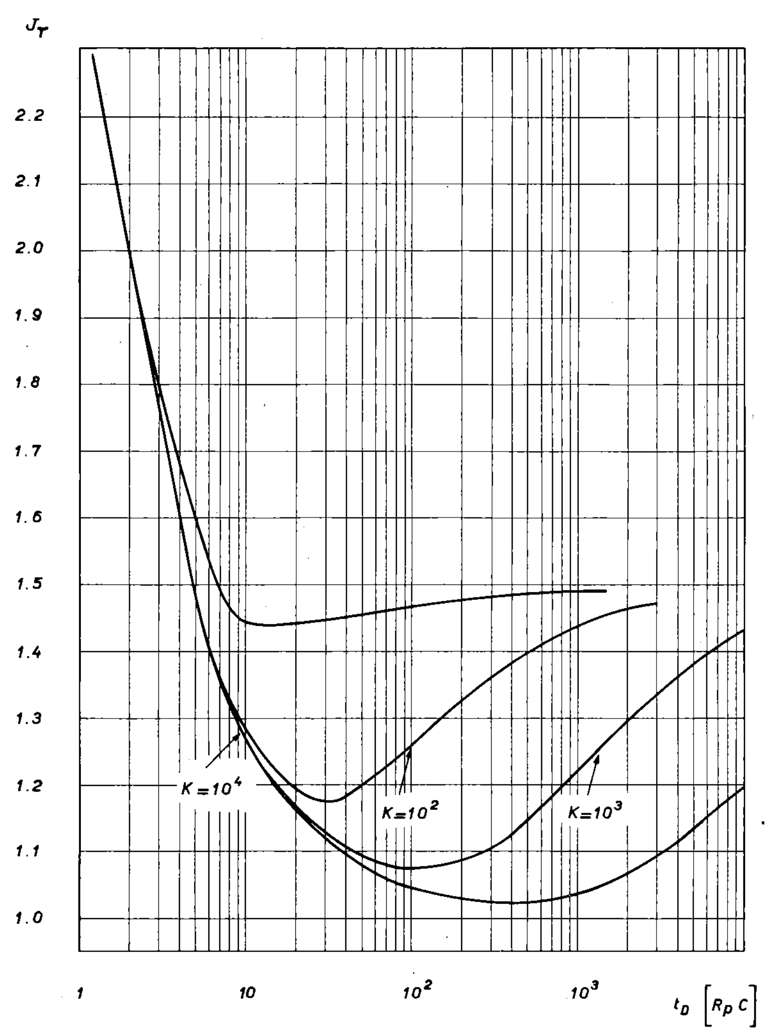

Fig. 8b. Threshold vs time for ramp input $J_0 = 0.0$.

$$\tau(A) = Q(A) + 1 - j_{\text{in}},$$

for a generic amplitude A we will obtain:

$$p(A) = \int_{\tau_1}^{\tau(A)} N_2(\tau) \cdot d\tau.$$

The counting losses due to rise-time jitter are:

$$L = N - \int_0^\infty N_1(A)\, d\tau = N - \int_0^\infty p^*(A) \cdot N_1(A) \cdot dA,$$

where $p^*(A)$ is

$$p^*(A) = 0 \quad \text{for} \quad 0 \leqq A \leqq A_1,$$
$$p^*(A) = p(A) \quad \text{for } A_1 < A < A_2,$$
$$p^*(A) = 1 \quad \text{for } A_2 < A < \infty.$$

If we assume $N_2(\tau)$ as a flat function defined between τ_1 and τ_2, $p(A)$ is proportional to the explicitized function $\tau(A)$.

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References

1) I. De Lotto, P. F. Manfredi and P. Principi, Energia Nucl. **11** (1964) 10,11.
2) B. Souček, Nucl. Instr. and Meth. **28** (1964) 306.
3) I. De Lotto and D. Dotti, Nucl. Instr. and Meth. **39** (1966) 281.
4) P. R. Orman, Nucl. Instr. and Meth. **21** (1963) 121.
5) A. E. Bjerke, G. A. Kerns and T. A. Nunamaker, Nucl. Instr. and Meth. **15** (1962) 249.
6) T. A. Basire, B. de Cosmac and J. Labbé, Electr. Nucl. (Paris, 1963) 325.
7) J. Garvey, Nucl. Instr. and Meth. **29** (1964) 137.
8) N. Abbattista, M. Coli and V. L. Plantamura, Nucl. Instr. and Meth. **37** (1965) 323.
9) J. B. Birks, *The theory and practice of scintillation counting* (Pergamon Press, 1964) 457, 632.
10) Ibid. 218, 460, 588.