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FAST TIMING CIRCUITS PERFORMANCES WITH TUNNEL DIODES*

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The behaviour of tunnel diode timing circuits has been analyzed for two modes of operation: the Orman mode (the td biasing point is on the high voltage region of its V,I characteristic) and the monostable mode (the td is non linearly biased on the low voltage region). The circuit performance is characterized by a factor F, whose values vs the input dynamics, biasing currents and width of the input signals, have been evaluated solving numerically the system of non-linear differential equations of the two circuits.

A timing circuit, suggested by the theoretical analysis is proposed and the experimental results obtained have been quoted.

1. Introduction

Many tunnel diode (td) timing circuits have been reported during the last three years[1–5]. We have analyzed in this paper the behaviour of td timing circuits to find out the final performances attainable in these systems. We have considered in the following, the switching of the td at its peak point to detect the zero crossing of the analyzed pulse instead of considering the same operation utilizing the switch accross the valley point because the worse rise time of the output information.

Two modes of operation may be actuated: first, biasing the td nearest to the peak point [monostable mode[1,3,5,6]]; second, biasing the td on the high voltage state of its V, I characteristic [Orman mode[2,4]]. The main difference of the two modes of operation is that the second mode provides an input pulse selection owing to its hysteresis equal to the difference between the biasing and the valley current.

The analysis of the two modes of operation will be performed taking straight into account the three conditions for a good timing given in our previous letter[8]) that will be reported here. These are:

1. To lower as much as possible the zero crossing detector threshold.
2. To select the input pulse dynamics so that the minimum selected amplitude must be very much higher than the threshold of the zero-crossing detector.
3. To limit the input pulses after the zero in order to obtain the switching of the td during a time independent from the input pulse overdrive.

2. Analysis of the two modes of operation

In order to give a parameter F to characterize the timing performances of the two modes of operation above considered we start assuming that it must keep into account the following factors:

1. The ratio of the input to the output dynamics, δ.
2. The ratio of the input to the output pulses slewing times, ϑ.

If we assume that F be greater as much as δ and ϑ increased, that is as better are the performances of the circuits, we will obtain:

$$F(T) = (\Delta\tau_{\text{in}}/|\Delta\tau_{\text{out}}|)(D_{\text{in}}/D_{\text{out}}) = \delta\cdot\vartheta, \qquad (1)$$

where:

$\Delta\tau_{\text{in}}$ = the slewing time between the minimum ($j_{\text{in min}}$) and the maximum ($j_{\text{in max}}$) amplitude of the input pulses (normalized to the td peak current) computed on the rise-time at the amplitude equal to the fwhm of the minimum input pulse.

$|\Delta\tau_{\text{out}}|$ = the absolute value of the slewing time for the output pulses computed as before.

D_{in} = $j_{\text{in max}}/j_{\text{in min}}$.

D_{out} = $j_{\text{out max}}/j_{\text{out min}} = 1$ that means we have taken always into account the limiting action.

T = the width of the input signal normalized to the R_pC time constant of the td, where R_p is the ratio between the peak voltage and the current and C is the capacitance of the td measured at the valley point.

To evaluate F we have numerically integrated the differential equations[7]) of the two following circuits; monostable with non linear biasing (monostable mode of operation); bistable with the biasing point on the high voltage state of the td V, I characteristic (Orman mode of operation). The input signals we have been dealt with, is a single period sinusoidal waveshaped one.

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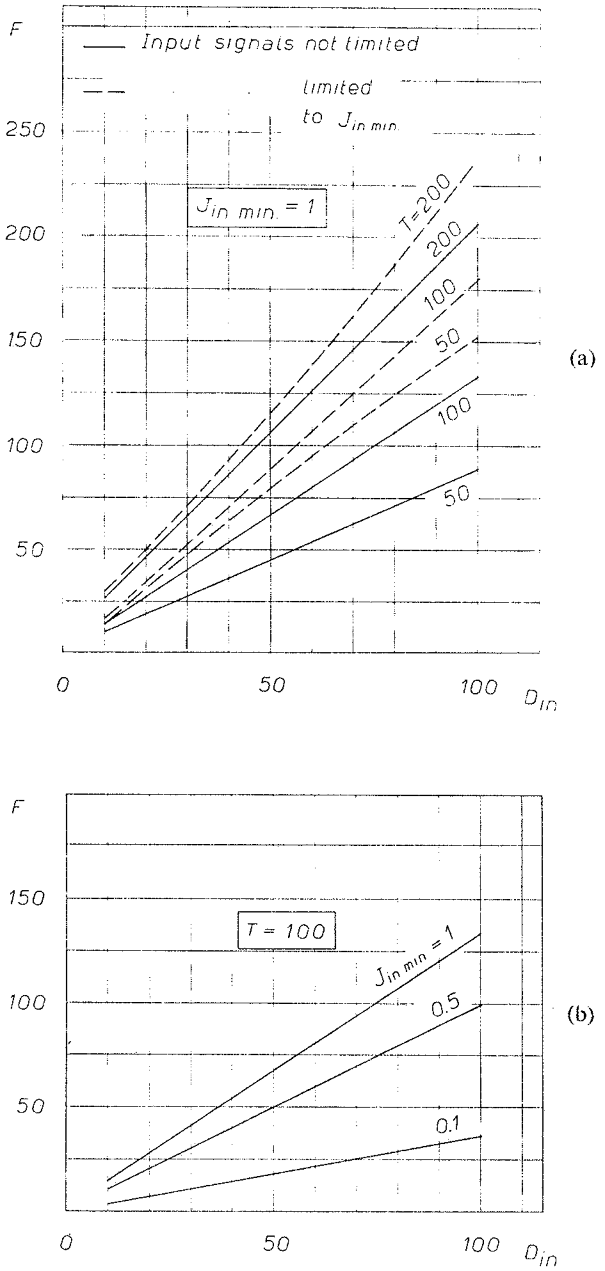

Fig. 1. Monostable mode of operation. (a) F vs input dynamics; (b) F vs input dynamics for several minimum input amplitudes

2.1. Monostable mode of operation

The threshold may be kept, in this case, very low, biasing the td very near to the peak point limiting only its value for dc level noise and multiple switching stability considerations[7]).

The input dynamics must be selected in a separate channel to perform the gating action at the input of the timing discriminator.

The limitation allows the timing output information to be easy extracted from the zero cross detector. This operation could be done before or after the zero crossing detector. One wishes generally to limit the input to improve the timing performances as will be shown in fig. 1a where F vs the input dynamics is reported. The dotted lines are referred to the limited input signals. In this case and in the following the limitation has been done before the zero crossing detector. In fig. 1a the limiting action occurs at the value of the minimum input amplitude equal to the peak current. From the linearity of the curves one deduces that for each T value ϑ is a constant.

In fig. 1b for a $T = 100$, F is reported for several minimum input amplitudes. From these, one can assume that the convenient minimum selected amplitude may vary from $j_{in\ min} = 0.5$ to $j_{in\ min} = 1$, because F increases for slowly varying $j_{in\ min}$ with the loss of many of the input analyzed pulses.

In fig. 2, F vs minimum input amplitude for an input dynamics = 100 is shown. We can see better from these that by increasing $j_{in\ min}$, F is slowly increased.

The F parameter, in the case of not limited input pulses, increases with T, that is the performances of the circuit are improved utilizing a faster td. For limited

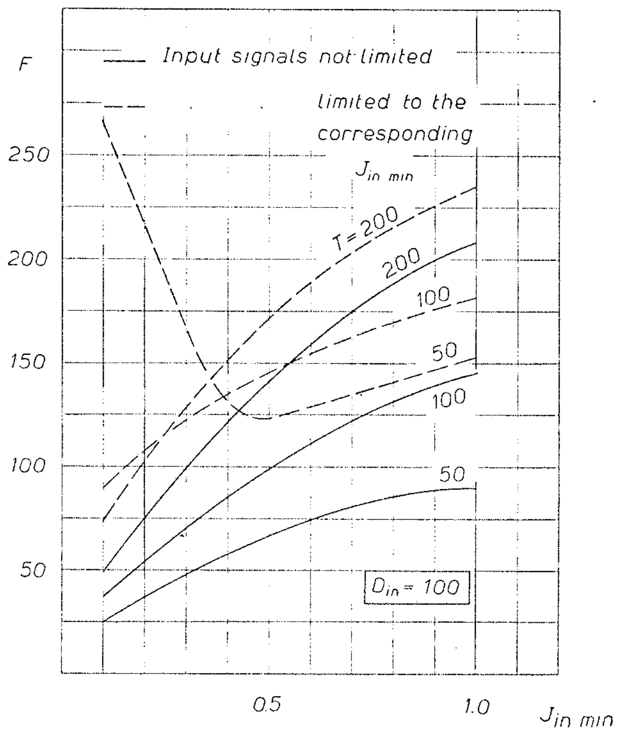

Fig. 2. Monostable mode of operation: F vs minimum input amplitude.

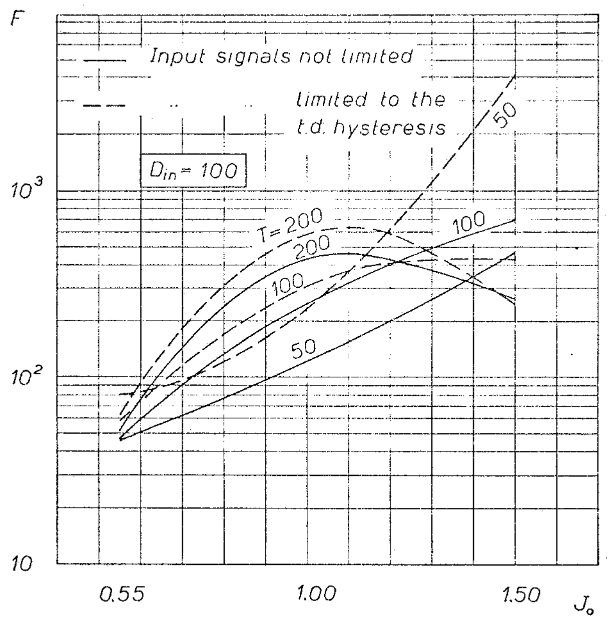

Fig. 3. F vs the biasing current j_0 for Orman mode of operation.

input pulses selected at minimum amplitude under $j_{in\ min} = 0.5$ we obtain an improvement in the circuit performances utilizing a slow td. In spite of this fact the actual circuitry does not utilize this region of selection for practical difficulties to limit at such low values.

2.2. Orman mode of operation

In this case the td selects the input dynamics with its hysteresis. For the values of T and the bias current j_0 we have considered, the hysteresis is reported in table 1.

To provide ideally the lowest threshold, the biasing point must to be set at the forward projected peak. The

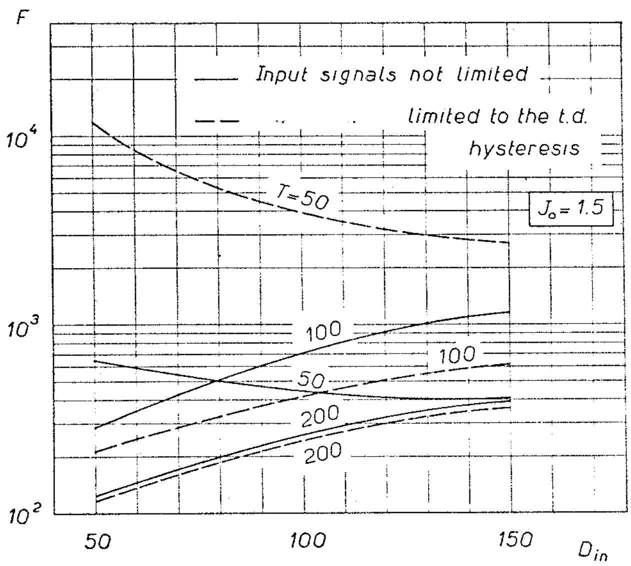

Fig. 4. F vs input dynamics for Orman mode of operation.

Table 1

Evaluated values of hysteresis for any j_0 and T.

T	j_0		
	0.55	1	1.5
50	0.75	1.3	1.75
100	0.6	1.1	1.6
200	0.55	1.1	1.55

switching past history of the td before reaching the peak affects the switching at the peak point with a delay that depends on the input pulse amplitude.

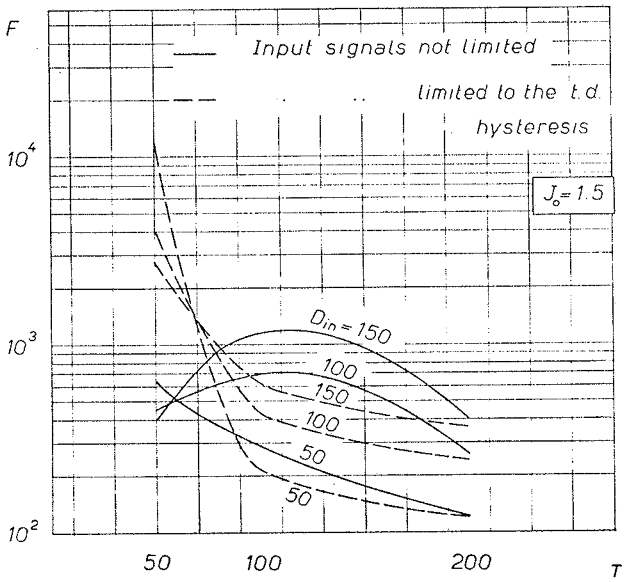

Fig. 5. F vs T for several values of dynamics for Orman mode of operation.

To minimize the slewing time at the output, one needs to find the optimum biasing point.

In fig. 3 F vs the biasing current j_0 for input dynamics of 100 is reported.

The circuit performances are improved increasing the biasing current as in the last diagram (fig. 2) of the mode of operation considered before, increasing the $j_{in\ min}$.

The limiting action in this case does not improve F for all the j_0 values. This fact is generally related to the history during the cycle of operation before the switching action at the peak.

F vs the input dynamics is reported for $j_0 = 1.5$ in fig. 4, where we can see again what we have just referred.

F vs T for several input dynamics and $j_0 = 1.5$ is reported in fig. 5, for $T = 100$ for not limited input

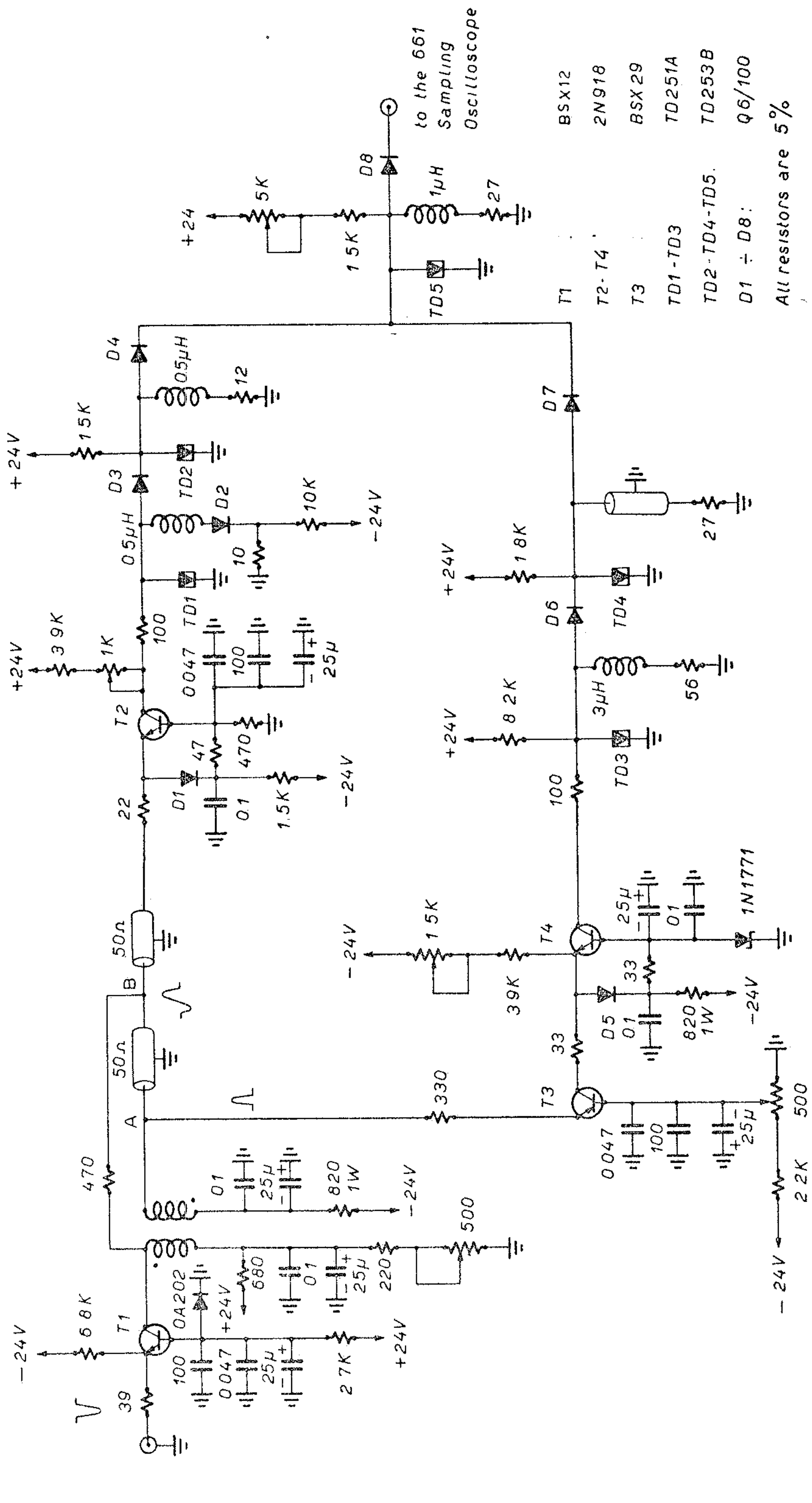

Fig. 6. Timing circuit diagram.

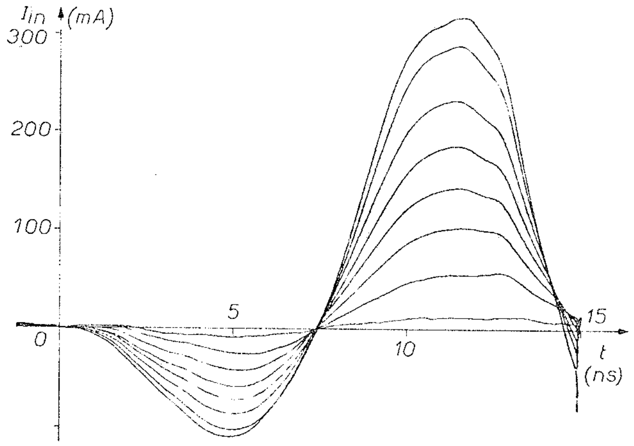

Fig. 7. Waveshape of the zero-crossed pulses at the input of the timing channel.

dynamics higher than 100, the curves show a maximum in the value of F.

3. The timing circuit

Following the logic scheme already proposed and with the aid of the theoretical results given before, we have developed an actual timing circuit whose final performances are in good agreement with the expected results.

We can generally observe that the Orman mode of operation (although more simple) performs the input signal selection through a threshold whose value is strictly tied to the maximum attainable value of F (the overall circuit performances). For that reason when more precise timing performances at very low value of $j_{in\ min}$ are requested one is obliged to adopt the circuitry of the monostable mode of operation of the td. Nevertheless the Orman mode of operation allows higher values of F be easy attainable in any case.

The specifications required four our circuit are: Bipolar input pulses with a period $T = 10 \div 15$ nsec; a selected minimum pulse amplitude of 3 mA; an input dynamics of 100.

For this purpose we selected the TD 152 A with $R_p C = 70$ psec and $I_p = 2$ mA and we have the following normalized values for:

$$D_{in} = 100; \qquad T = 200; \qquad j_{in\ min} = 1,$$

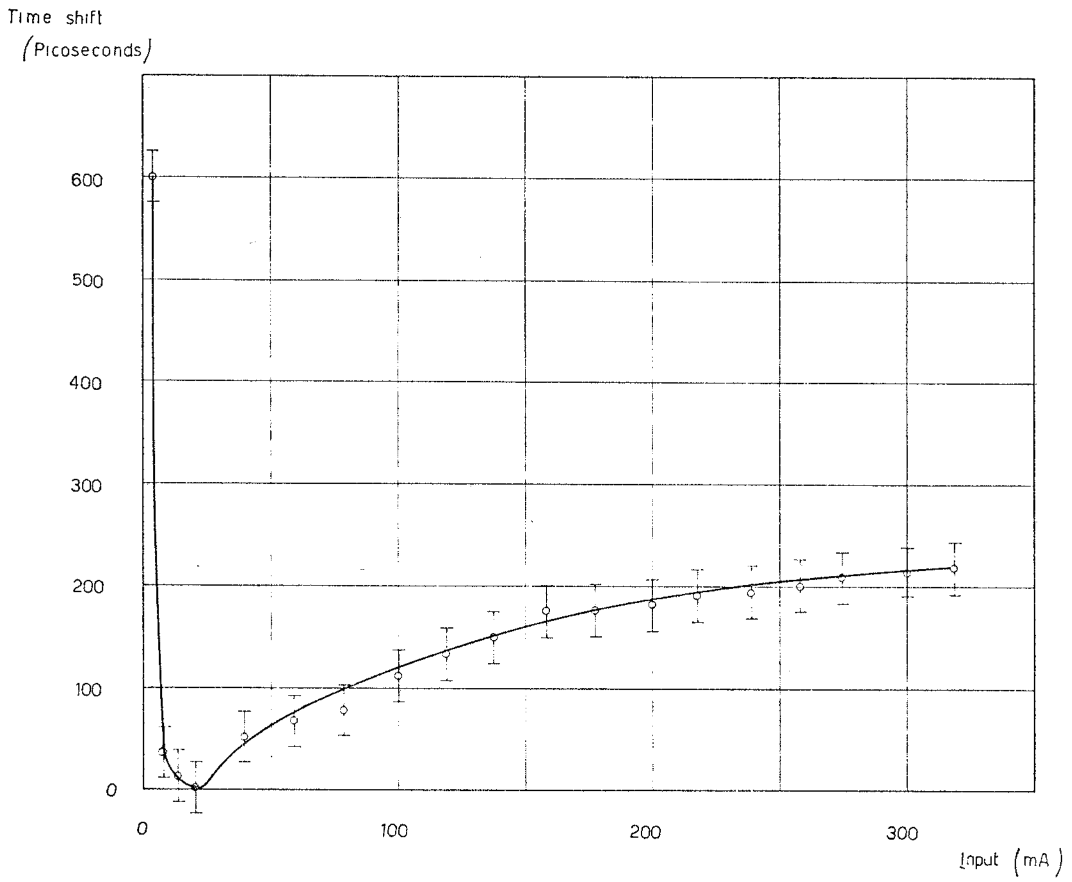

Fig. 8. Experimental time shift of the fwhm of the output pulse relative to the zero crossing of the input signal obtained with a pulse generator simulating the photomultiplier anode pulse.

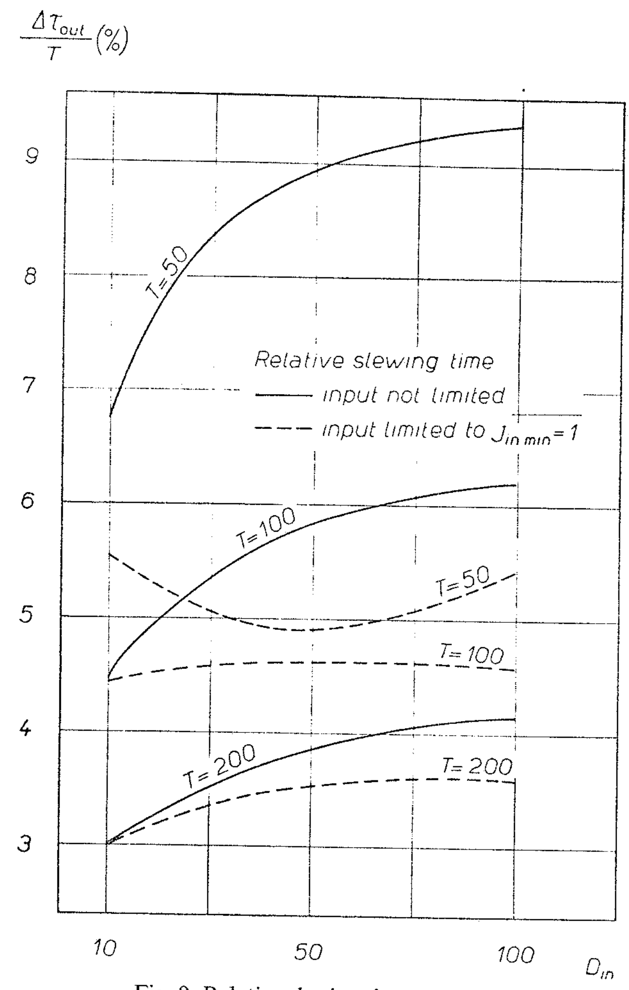

Fig. 9. Relative slewing time vs D_{in}.

which for a normalized input limited to 1 ($I_p = 2$ mA) gives the best value for F as can be seen in fig. 2.

3.1. Circuit description

We refer to the diagram of fig. 6. A negative pulse is applied to the transistor T_1. A little fraction of the input signal is derived from the point A to actuate the selection channel. The waveshape of the bipolar pulse at the point B for several amplitudes is shown in fig. 7. The ratio between the maximum negative and positive swings is less than one (about $\frac{1}{3}$). This waveshaping technique avoids the limitation on the negative going pulse in order not to shift the time of the zero cross unavoidable caused by recovery or storage effects. It is also possible in such a way to reduce the dynamics of currents through the transistor for the same input dynamics.

The delay cable after B assures the triggering of the output coincidence (TD5) monostable only from the very sensitive channel (the timing one).

The limiting circuit is formed by T_2 and D_1. To the non linearly baised td monostable of the timing channels we have applied the results worked out in section 1.1.

3.2. Experimental results

The slewing time $\Delta\tau_{out}$ vs the input pulse amplitude obtained with the circuit described above, has been shown in fig. 8. It has been measured referring to the zero-cross time of the input pulse to avoid the shift of the non ideal zero-crossing shaper.

In fig. 9 the behaviour of $\Delta\tau_{out}/T$ is shown, computed from the theoretical results, shown in fig. 1a, by the formula:

$$\Delta\tau_{out} = (D_{in}/F)\,(T/2\pi)\times$$
$$\times\{\arcsin(\tfrac{1}{2}j_{in\,min}) - \arcsin(\tfrac{1}{2}j_{in\,min}/D_{in})\},$$

derived from eq. (1) that can be used to convert all the other diagrams of F.

Our experimental results ($T \cong 200$; $R_pC \cong 70$ psec) agree satisfactorily with the theoretical results. The non monotonic behaviour of the slewing time characteristic, that results from fig. 8 and from[4,6]), is due to the limiting action on the input pulse.

3.3. Conclusion

The initial considerations about the realisation of a good timing circuit have been generally confirmed by the theoretical analysis except in particular cases that are of no great importance for actual circuits (fig. 2 for $T = 50$, referring to the limited input signal).

Furthermore, an experimental circuit, as that realised by us, which takes into account these considerations, should perform satisfactorily.

The theoretical results have not been exhaustively checked with experimental results because it would be necessary to extend the analysis to more broader ranges. This fact and the anomalies encountered for little dynamic ranges in the experimental slewing time curves obtained by us and reported by other authors need a more detailed analysis.

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