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SENSITIVE, 100 MHz PULSE DISCRIMINATOR AND SHAPING CIRCUIT

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A discriminator and pulse shaper is described with the following characteristics: 1 mA minimum threshold ranging up to 30 mA, maximum input repetition rate of 100 Megapulses/s for threshold variation within 5%; delay 4 ns at 1% overdrive, time slewing (for input pulse risetime 0.5 ns) is 2 ns for 80% and 4 ns for factor of 100 overdrive. At minimum threshold (0.5 mA) the circuit can be overdriven by at least a factor of 10, more for higher threshold settings. This has been obtained by input limitation and complete isolation of the output tunnel shaper during all the input pulse width.

1. Introduction

In modern experiments of nuclear physics the photomultiplier high-voltage bias is often lowered to reduce time jitter and variation of the signal to noise ratio[1]).

Under these conditions fast and sensitive discriminators with low time-slewing are needed. They are often used also as pulse shapers[2,3]); that is, they must run overdriven by factors of ten. Threshold must stay constant when the input frequency is increased. Generally, in fact, one requires to understand the results of the experiment, on the basis of the preexperiment checking procedure with light pulsers to activate the photomultiplier[4]). The usual requirement is that from 0 to 100 MHz threshold stability must be kept within 5%. A short delay is also required for instance in order to increase the efficiency in triggering sparkchambers.

In many circuits threshold setting is obtained by varying the tunnel biasing current. The value of the peak current of the tunnel diode I_p is determined by

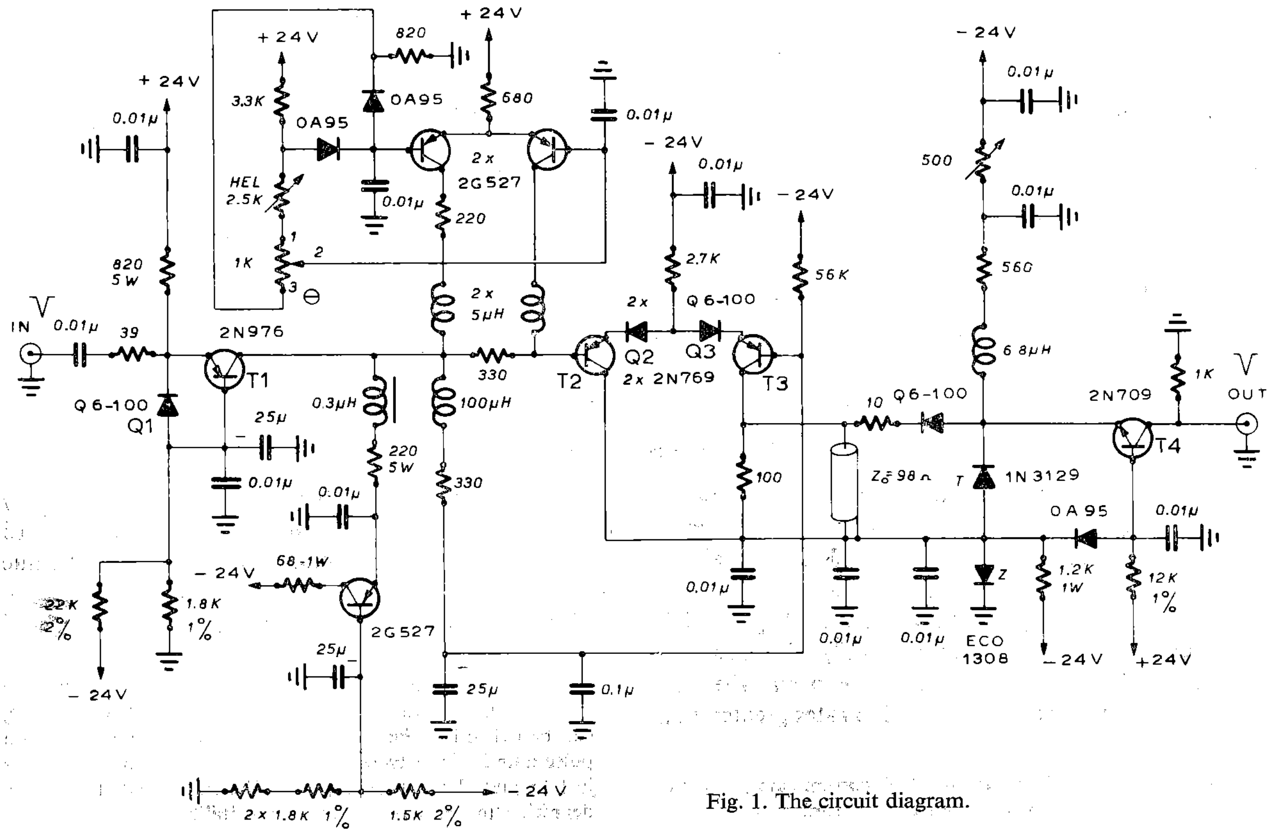


Fig. 1. The circuit diagram.

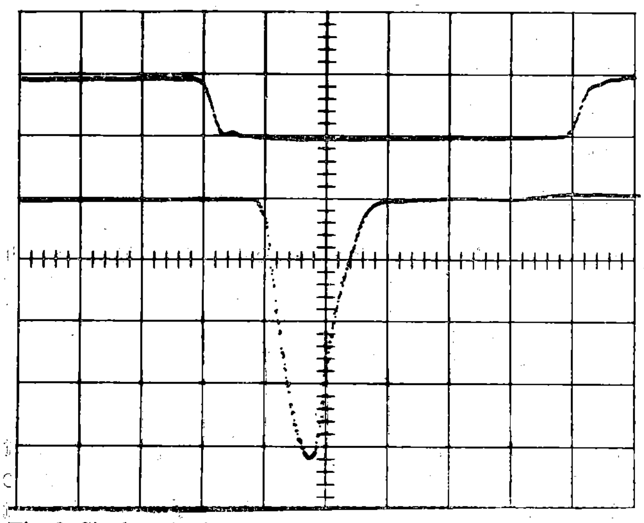


Fig. 2. Single pulse input and output waveforms. Upper curve: vert. 50 mV/div.; hor. 5 ns/div.; lower curve: vert. 0.2 V/div.; hor. 5 ns/div.

A 20 mA peak fast tunnel diode is able to operate at 100 MHz allowing a threshold range variation of factors 6 ÷ 7, from 2 mA to 12–14 mA with current gain variation within 25%.

In our circuit the threshold+ has been provided back-biasing the transistor that transfers over threshold, the trigger action to the tunnel output shaper; this remains isolated from the input during all the input pulse base-width by the limiting action of a long-tail-pair stage.

2. The circuit

The circuit can be thought of as formed by two different subcircuits (fig. 1). The first, formed by transistors T1 (input) and T2, performs two functions: limitation (T1 over the maximum value of threshold, 30 mA) and amplification (T1 with voltage and T2 with current gain). In the second one, the pulse is shaped by a shorted line, discriminated by the tunnel diode and fed to the output through the transistor T4. The diode

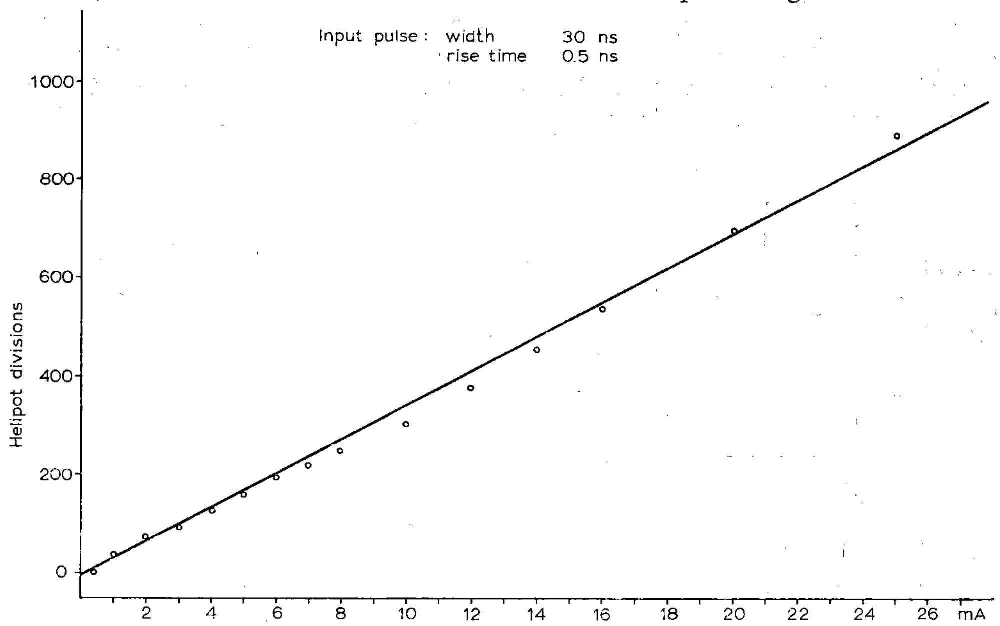


Fig. 3. Diagram of the threshold setting.

tolerance consideration (the "worst case" brings $i_{bias} = 0.9\ I_p$). Moreover one knows that the gain-bandwidth product W* of the tunnel is seriously reduced when the bias current is lowered at a fractional value of the peak current. Passing from $0.9\ I_p$ to $0.5\ I_p$, W is decreased by a factor of two[5]). The range of threshold variation is thus much reduced when the circuit must be operated at repetition rates greater than 50 MHz.

Q3 and the transistor T3 separate the two parts by remaining off during the input pulse width. Q3 and T3 are then active current limiters also at very small value of the input current.

To obtain good performance at very low threshold

* We assume as in the linear region, W = current gain × repetion rate, when the tunnel is operated as a discriminator.

+ Threshold has been referred to a 30 ns wide pulse with rise time of 1 ns. Threshold independent from input wave-forms, can be defined as the charge delivered during triggering by a pulse amplitude of twice the threshold setting and as wide as just to give the output (λ-pulse). We have used the μ-pulse definition to measure the circuit sensibility.

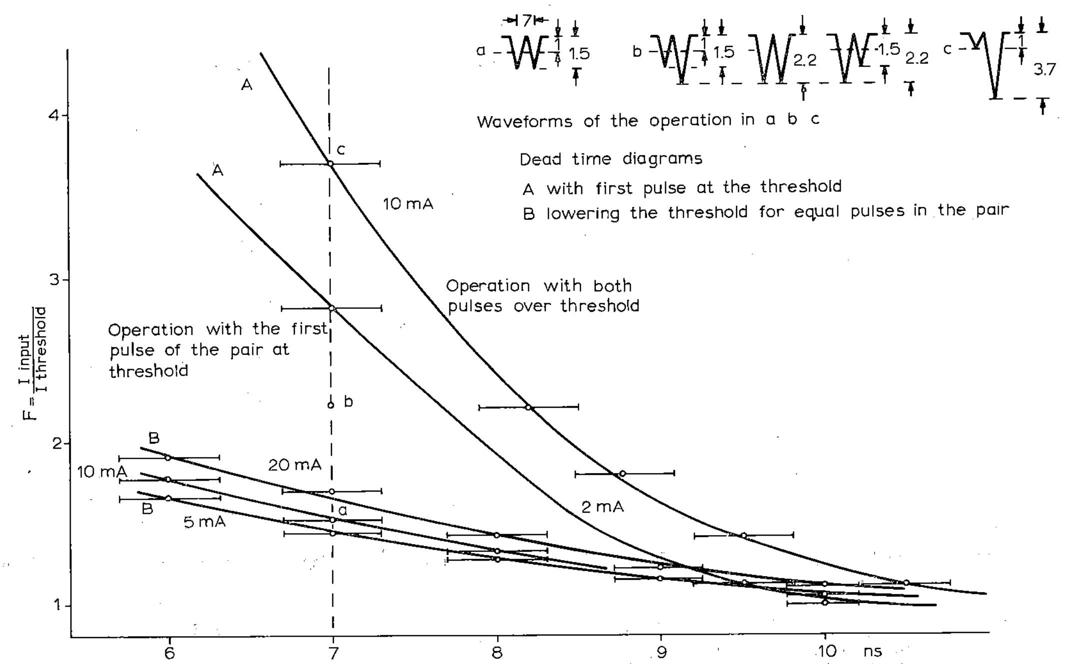


Fig. 4. Results of dead time measurements.

settings, we need current gain between the input and the shaping circuit; we must in fact provide gain to recover loss of triggering current, due to the shaping line. The common base input transistor provides a voltage gain of about 4; the common collector transistor T2, that is normally off, is switched on by pulses over threshold, giving an average current gain of 5 (under 5 mA, I_c). The diode Q3, which has a very small recovery time (0.2 ns) and transistor T3 are biased with 5 mA current. They are off for input currents less than

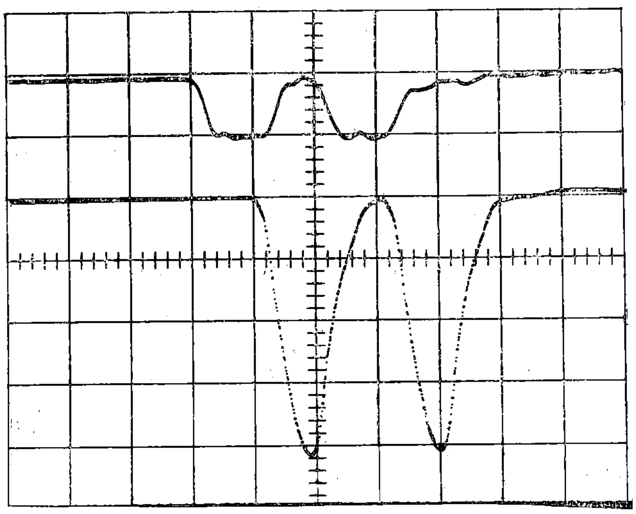


Fig. 5. Pair of pulses input and output waveforms. Upper curve: vert. 50 mV/div.; hor. 5 ns/div.; lower curve: vert. 0.2 V/div.; hor. 5 ns/div.

1 mA, performing their action also below the minimum threshold.

For minimum input pulse amplitudes the rise time on the forming line is 2 ns. The current pulse of the amplifier has 10% overshoot to reduce time slewing. The input transistor T1 is biased with 33 mA and is turned off by the input pulse, providing limitation for high current pulses. Input matching is assured by diode Q1.

The tunnel diode discriminates the pulses formed in width by the line[6]). The emitter to base diode of transistor T4 loads non linearly the tunnel[7,8]). The output wave form is independent from input pulses. This is a good advantage for the following logic.

Threshold setting is provided varying linearly the current of the long-tail pair transistor T5, T6. The voltage accross R cuts off more or less the transistor T2. Diode Q2 has a two-fold action: first, it protects from breakdown the base-emitter of T2 (–2 V); second, it provides a capacitance decoupling from the base of T2 to Q3*. Also T3 is cut off by the incoming pulses and the separating action of diode Q3 is thus improved.

* The capacitance of Q2 (2V reverse) is 2 pF. The junction capacitance of T2 (biased at 0 V) is 8 pF max. and the emitter to collector capacitance of T3 is less than 5 pF. With proper assembling (stray capacitance 1 pF) the total value of the coupling capacitance can be kept to less than 3 pF max. The time constant ($\sim$ 180 ps) is less than 1/10 of the amplifier rise time. The attenuation is then larger than -20 dB, that is $+20$ dB, is at least, the overdriving factor of the input.

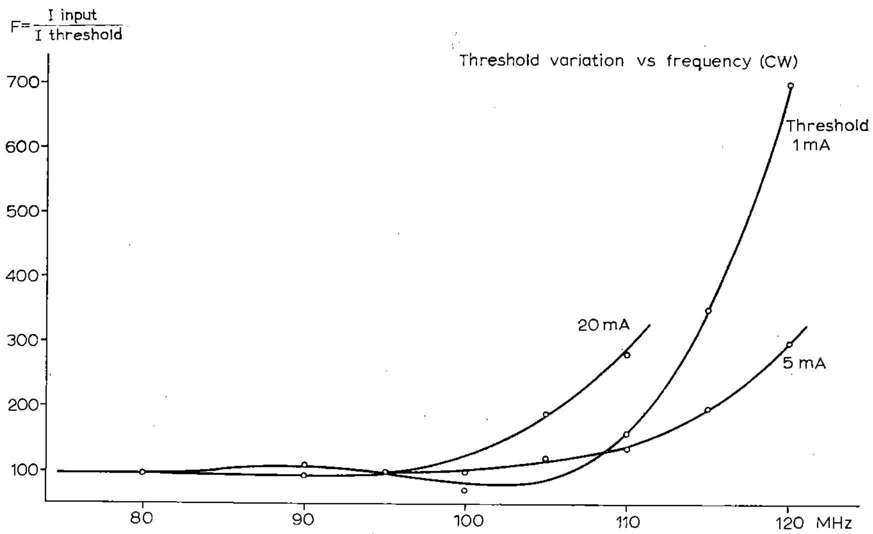


Fig. 6. Threshold variation as frequency for sinusoidal continuous wave at the input for 3 different values of threshold setting.

The long-tail pair formed by T2 and T3 assures a very good temperature stability of the threshold. In fact any dc level shifting at the collector of the input transistor is balanced off by the dc biasing of the base of T3: moreover the current steered into the line is little temperature dependent, that is the limiting action is assured between a wide temperature range.

3. Circuit performance

The characteristics of the circuit are shown in the table. The input and output waveforms at minimum threshold are shown in fig. 2. The diagram of the threshold setting is in fig. 3. It is linear within 10%.

The tunnel is biased at 19 mA (10% under peak). To avoid multiple starts, decoupling up to very high frequencies (500 MHz) of the tunnel from its biasing circuit* must be carefully provided[9]).

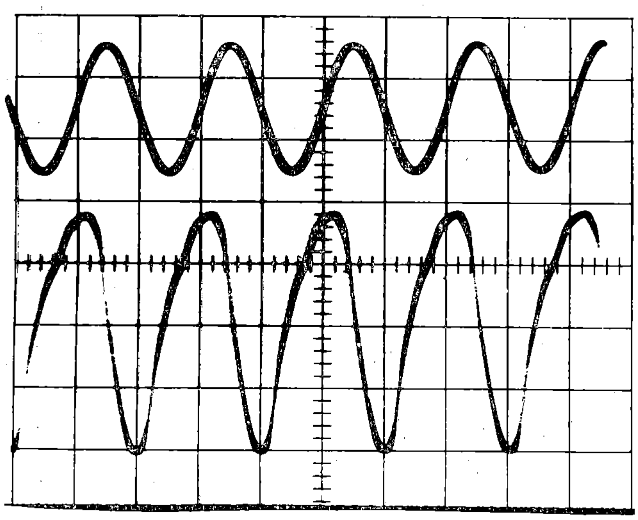


Fig. 7. Input and output waveforms for continuous wave at 100 MHz. Upper curve: vert. 50 mV/div.; hor. 5 ns/div.; lower curve: vert. 0.2 V/div.; hor. 5 ns/div.

TABLE

Characteristics		Notes
Sensitivity 1.3×10^{-12} C/mA (fig. 10)		for each mA of threshold setting
Threshold range (fig. 3)		
from	−1 mA	
to	−30 mA	
Dead time	10 ns	for threshold variation less than 5%
	8 ns	with overdriving of 100%
Output pulse	−16 mA	negative polarity
(fig. 2)	3 ns	fwhm, 6 ns at bottom
Delay	5 ns	with input pulse just at the threshold (1 mA)
	4 ns	with input overdrive 1%
Time slewing (figs. 8, 9)	4 ns	max. for factor of 100 overdriving with pulses 0.5 ns rise time
Frequency of operation 100 MHz (figs. 6, 7)		Max for threshold variation less than 5%
Linearity of threshold setting 10% (fig. 3)		
Overdriving factor > 10		experimentally always > 50

* That is oscillations sustained by the low conductance (negative) near the peak of the tunnel diode must be damped by parallel loading resistance of the circuit.

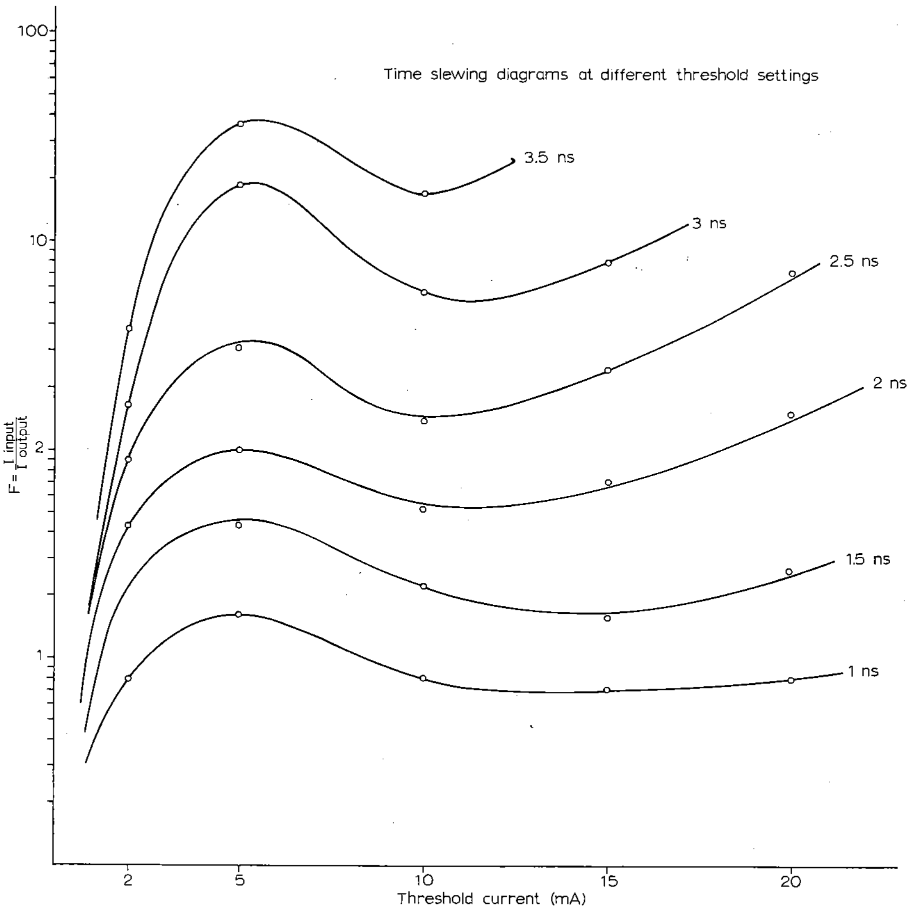


Fig. 8. Time slewing of the output pulse.

The dead-time of the shaper is 6 ns[6]) with 60% overdriving (shaping line* 1.8 ns length).

The transistor amplifier can run two pulses of 20 mA 3 ns wide at 10 ns separation with less than 3 dB of attenuation of the second pulse. Charging of transistor capacitance results in larger attenuation for nearer pulses.

Fig. 4 shows the results of dead time measurement. Diagrams refer to a pair of pulses 2 ns wide at fwhm with 1 ns rise time. The family labelled A has been obtained increasing the amplitude of the second pulse of the pair, the first one being at threshold. The family labelled B is the result obtained decreasing the threshold setting to produce the output of the second pulse, the pair of pulse remaining equal and constant in amplitude.

The family A is the dead time diagram of the com-

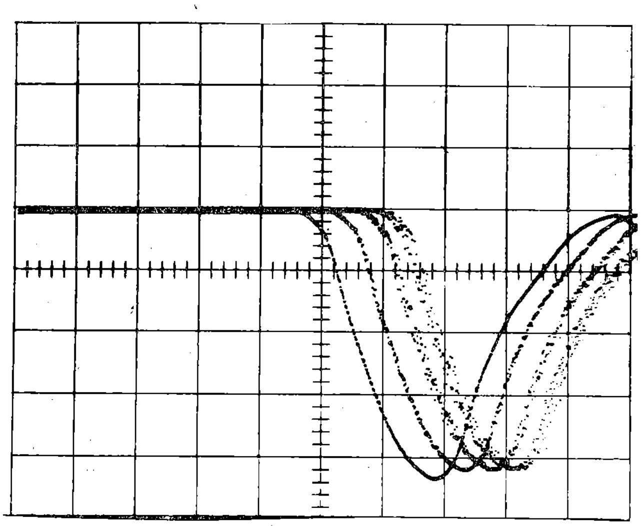
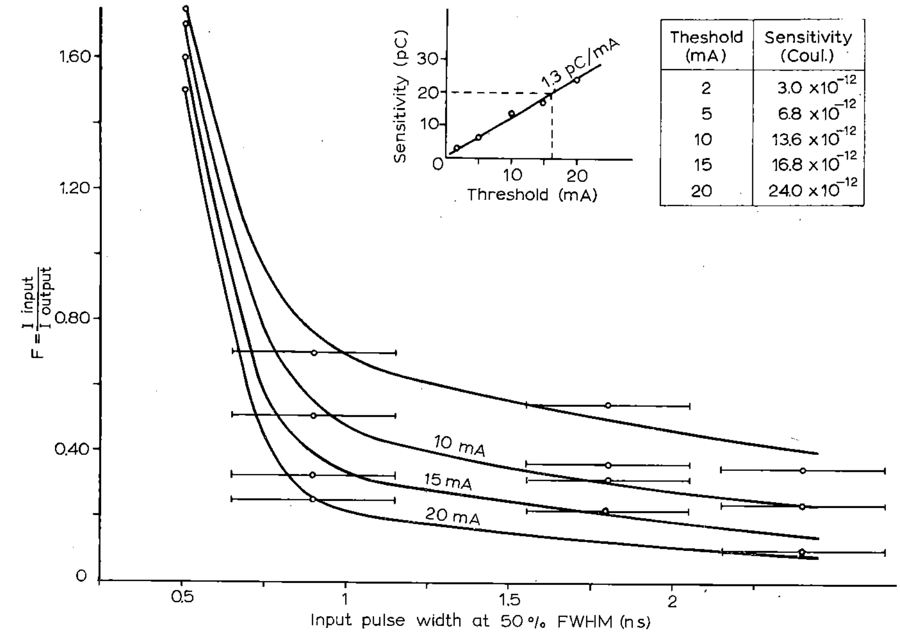


Fig. 9. Time slewing of the output pulse (input 1 ns risetime) corresponding to 0.4, 0.8, 3, 10 dB overdriving (threshold at 1 mA). Vert. 0.2 V/div.; hor. 2 ns/div.

* The line is of the microstrip type directly formed on the printed circuit.



Theshold (mA)	Sensitivity (Coul.)
2	3.0×10^{-12}
5	6.8×10^{-12}
10	13.6×10^{-12}
15	16.8×10^{-12}
20	24.0×10^{-12}

Fig. 10. Results of the measurement, with λ-pulses of the sensitivity of the circuit for several values of the threshold setting.

plete circuit: the family B is an indirect measurement of the output shaper dead time.

The points of the part of the plane between the A and B diagrams are values of overdriving for operation only with all two pulses over threshold. Points over the A diagrams corresponding to the threshold setting, are values of overdriving for operation with first pulse at threshold. (fig. 4b).

Fig. 5 shows input and output for two pulses 4 ns wide at 10 ns delay of the same amplitude (1 mA).

The threshold variation as a function of frequency for sinusoidal continuous wave at the input for 3 different values of threshold setting is shown in fig. 6. Waveforms at 100 MHz are in fig. 7. The threshold is constant up to 100 MHz; for little input currents the value of the threshold oscillates within 5%. This is due to a mismatching of the input. Some capacitive matching on the emitter resistor of T1 is also possible.

The time resolution of the following devices depend markedly on the delay variation of the circuit for overloading of the input. Time slewing of the output pulse is shown in fig. 8. The diagrams depend critically on the amplifier waveform. The input pulse rise time is 0.5 ns. With photomultipliers pulses, having 3 ns rise time, the time slewing contribution of the circuit is less than 10%. Time slewing is 3 ns for a factor of 10 of overload and 4 ns for a factor of about 100.

The time slewing produced by input amplitude variations of 0.4, 0.8, 3 and 10 dB is shown in fig. 9.

The sensitivity of the circuit for several values of threshold setting has been measured with λ-pulses[1]). The measure is the charge over threshold (in coulomb) that produces the output. Fig. 10 shows the results of the measurement. The sensitivity of the circuit is of some pC at minimum threshold.

Temperature stability of the threshold is better than 0.5%/°C in the range from 25°C to 65°C and the circuit does not need an initial warming-up period.

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