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EXTENDED RANGE TRANSISTORIZED PRECISION RATEMETER

by V. MANDL

FEBRUARY 1962

JOINT NUCLEAR RESEARCH CENTER
ISPRA ESTABLISHMENT (Italy)
Electronic department

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Brussels, February 1962 - pages 10 + fig. 6.

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The instrument has an input range from 10 to 10000 pps and is characterized by a better stability and linearity. The modifications introduced into the circuit are discussed and the measurements made are reported.

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EXTENDED RANGE TRANSISTORIZED PRECISION RATEMETER

SUMMARY

An improved linear ratemeter based on a saturated core blocking oscillator is described. The instrument has an input range from 10 to 10000 pps and is characterized by a better stability and linearity. The modifications introduced into the circuit are discussed and the measurements made are reported.

1 - INTRODUCTION

The principle of operation of this ratemeter has been described in a previous paper[1]. The present instrument has a more extended input pulse range and all the circuits have been redesigned for a better stability and linearity. The ratemeter is provided with an input amplifier that allows it to operate directly from thin window Geiger and proportional counters as well as from photomultipliers. The input amplifier is followed by a scale-of-eight and its regularizing action is exploited to decrease the counting losses of random pulses. The shaper is a saturated-core blocking oscillator driving a constant current generator which feeds an RC integration circuit. The time constants are of 2.5 ; 5 and 10 sec and have been chosen in order to reduce errors due to statistical fluctuations. These values of time constants are limited by physical dimensions of capacitors and by output power requirements, but when necessary other capacitors can be added as shunts.

2 - GENERAL SPECIFICATIONS

Full scale ranges : 10 ; 30 ; 100 ; 300 ; 1000 ; 3000 and 10000 pps.
Time constants : 2.5 ; 5 and 10 sec all independent of scale ranges.
Resolving time of amplifier and scale-of-eight : 1 μsec.
Resolving time of saturated-core blocking oscillator : See part 7 : Tests and Measurements, and Fig. 2.
Maximum ambient temperature allowed for correct performance : + 55°C.
The instrument and all external meters connected to it are protected against overload on all ranges.

3 - INPUT SPECIFICATIONS

The two inputs "To AMPL" and "DIRECT" accept negative polarity signals only. They are both protected against overvoltages and signals up to an amplitude of 50 V can be connected.

The input marked "To AMPL" has a sensibility of 5 pCoulomb which are equivalent to 3×10^7 electronic charges.

The threshold level for a pulse of 1.5×10^{-7} sec duration supplied by a generator with 100 Ohms internal resistance is 100 mV. This sensibility can be improved by reducing the feedback factor.

Signals with amplitudes greater than 3 volts overload the amplifier and could produce spurious counts therefore "DIRECT" input must be used. Its minimum sensibility is of 2.5 Volts.

4 - OUTPUT SPECIFICATIONS

A rough indication of input pulse rate is given on an built-in direct-reading meter (precision class 2.5). and an output voltage from 0 to 10 mV across a 10 Ohms resistor is available to drive a recorder. The polarity of the output voltage is positive to ground.

5 - POWER SUPPLIES

The instrument is designed to be supplied from the stabilized power supply unit Model AL10; however when necessary it may work also with non regulated voltages. In those conditions there will be a maximum error in the output of $\pm$ 2 % for voltage variations of $\pm$ 10 %. More detailed specifications on performances with non regulated voltages may be found in Part 7 : Tests and Measurements and in Fig. 4.

The voltages and the currents required are :

- 10 V	1 mA
+ 1.5 V	0
+ 10 V	5 mA
- 20 V	50 mA

6 - MODIFICATIONS OF THE CIRCUITS, THEIR DESCRIPTION AND DISCUSSION

The modifications introduced into this ratemeter had the purpose to extend the input range from 1000 to 10000 pps, to improve the stability and linearity and to eliminate the adjustment potentiometers in view of small series production.

6.1 EXTENSION OF THE INPUT CAPABILITY

In order to extend the input range the following three possible solutions were examined : to add a third blocking oscillator with a shorter pulse length ; to reduce the current of the constant current generator or to increase the scaling factor.

The simplest solution was to decrease the current which charges the integrating capacitors but it had the disadvantage of increasing the ratio between the minimum and the maximum charging current, which was necessary to reduce in order also to eliminate the adjustment potentiometers. This point will be still further discussed.

A third blocking oscillator with shorter pulses was not used because of the circuit complexity, so that only the scaling factor was increased from four to sixteen. Moreover the single blocking oscillator circuit of the previous model was replaced with two separate circuits of 100 and 1000 μsec pulse length each and the input amplifier was modified for 1 μsec resolving time.

The most important characteristics of these new circuits are reported in Table 1. For each input range are indicated the corresponding scaling factors, the duration and the magnitude of constant current which charges the capacitors.

The schematic of the complete instrument is given in Fig. 1.

Table 1

Input range pps	Scaling factor	Pulse length in μsec	Current in mA supplied to the integrating capacitors
10	1	1000	100
30	2	1000	66.6
100	4	1000	40
300	8	1000	26.6
1000	4	100	40
3000	8	100	26.6
10000	16	100	16

6.2 IMPROVEMENTS OF THE CIRCUIT PERFORMANCES AND ELIMINATION OF THE POTENTIOMETERS

An analysis of sources of errors in the output circuit was made as an attempt to achieve a better linearity and stability. Some of these errors were compensated in the previous instrument[1] by the adjustment potentiometers and before eliminating them it was necessary to examine the whole problem once more.

The output circuit is a voltage driven current generator in which only the emitter current is stabilized and it charges a capacitor in the collector circuit. The errors introduced are due to the following origins * :

a) forward common base current gain α

b) collector reverse current I_{CS}

c) forward base current I_b

d) base-emitter junction voltage V_{BE}

6.2.1

Only a very small spread of α may be tollerated in order to get a good linearity and an error-free indication because the collector current is not stabilized by the circuit, as said before. It is well known that variations in common emitter current gain h_{fe}** are produced by emitter current and ambient temperature changes, also very high spreads, up to 50 % are to be found among the normally supplied commercial transistor of the same type. For this last reason a selected transistor of meduim h_{fe}, type 2G527, was used with following values of h_{fe} which are specified by the manufacturer.

	minimum	typical	maximum
$V_{CE} = -1$ V ; $I_e = 20$ mA	72	91	121
$V_{CE} = -1$ V ; $I_e = 100$ mA	65	86	

* The discussion is limited to the current generator only because the saturated core blocking oscillator introduces only negligible errors already described in the previous paper.

** h_{fe} is here introduced because it is normally specified by the manufacturer while α is seldom indicated but of course it can be readely calculated from h_{fe}.

The ratio between the minimum and the maximum emitter current was kept low as may be seen from the Table 1 and no appreciable variations of h_{fe} vs. emitter current were introduced. Nothing was done to compensate or to reduce the influence of temperature on h_{fe}.

6.2.2

The collector reverse current I_{CS} is normally very small, not more than a few μAmps, and it flows through a base resistance of about 20 Ohms so that no appreciated errors are introduced.

6.2.3

The same 20 Ohms resistance is passed by the base current I_b but also in this case errors are negligible (less than 1 ‰) even when considering the maximum admissible variation of h_{fe}.

6.2.4

The influence of the base emitter junction voltage V_{BE} on the output precision is very strong because this voltage is added to the voltage applied in the base circuit and is a function of the emitter current and of the ambient temperature. It varies also among transistors of the same type.

With a positive supply voltage higher than 10 Volts it would be easy to design a circuit in which V_{BE} variation could be negligible as compared to the signal voltage applied in the base. Unfortunately, in our present transistor system[2] we don't have such a positive voltage and it was also impossible to use a negative bias in collector in order to increase the applied voltage in base because otherwise the output terminals would be floating. Nevertheless it was tried to design a better circuit without changing its basic mood of operation. The applied voltage in base was made as high as possible with the available positive supply, the absolute value of V_{BE} was kept low by choosing the type of transistor (2G527) and it spread was limited by the proper choice of the emitter current range. No attempt was done to reduce or compensate the temperature effects on V_{BE} which is of about - 1.8 mV/C.

The result of these modifications were seen from a final test which was performed with ten different transistors 2G527 in the current generator circuit with the supply voltage and the ambient temperature kept constant. The deviation in the output voltage were of - 0.9 % + 0.6 % with a 100 mAmps current and of - 0.24 % + 0.56 % when the current was reduced to 40mAmps.

The overall performance of the instrument vs. temperature is indicated in Fig. 3.

7 - TESTS AND MEASUREMENTS

Tests have been performed for establishing :

a) the counting losses due to the settling time and to the dead times.
b) the overall stability of the instrument vs. temperature, voltage and time.
c) the linearity with even and random pulses.

7.1 COUNTING LOSSES FOR RANDOM PULSES

The dead time of the amplifier and of the scaling circuit is of 1 μsec, as said before, and that of the blocking oscillator is shown in Fig. 2. On all the scale ranges except the lower range of 10 pps the error due to counting losses is lower than 1 %. On the 10 pps range there are no scaling circuits included and the counting losses are due to whole dead time of the 1000 μsec blocking oscillator in addition to it settling time which can be estimated as 8 times the pulse length. In those conditions the maximum error is of 7 %.

These counting losses have been calculated according to calculations and diagrams given by A.W. Pryor, A.G. Klein[3] and J. Sandstad[4].

7.2 THE OUTPUT STABILITY VS. TEMPERATURE, VOLTAGE AND TIME

The output voltage stability vs. temperature for 10 ; 300 and 10000 pps scale ranges is indicated in Fig. 3. All the values are refered to + 25°C ambient temperature.

The output stability vs. supply voltage of + 10 V is indicated in Fig. 4. During this test the - 10 V supply voltage was kept constant. After it the stability vs. - 10 V supply voltage was checked and + 10 V supply voltage was kept constant. The error found was smaller than 1 ‰ for variations of ± 50 % on all ranges.

The warm-up period of the instrument is depending of the time constant selected and is not longer than 10 time constants. Also a medium term stability measurement has been performed during 8 hours with no appreciable errors.

7.3 THE LINEARITY

The linearity has been tested for even and random pulses. For even spaced pulses a nonlinearity has been found only at full scale of the highest range of 10000 pps. Its value is less than 1 %.

The linearity for random pulses has been measured increasing the time constant to 40 sec and the results are reported in Fig. 5 and 6. The points indicate the measured values and the vertical bars are the calculatea values of statistical deviation.

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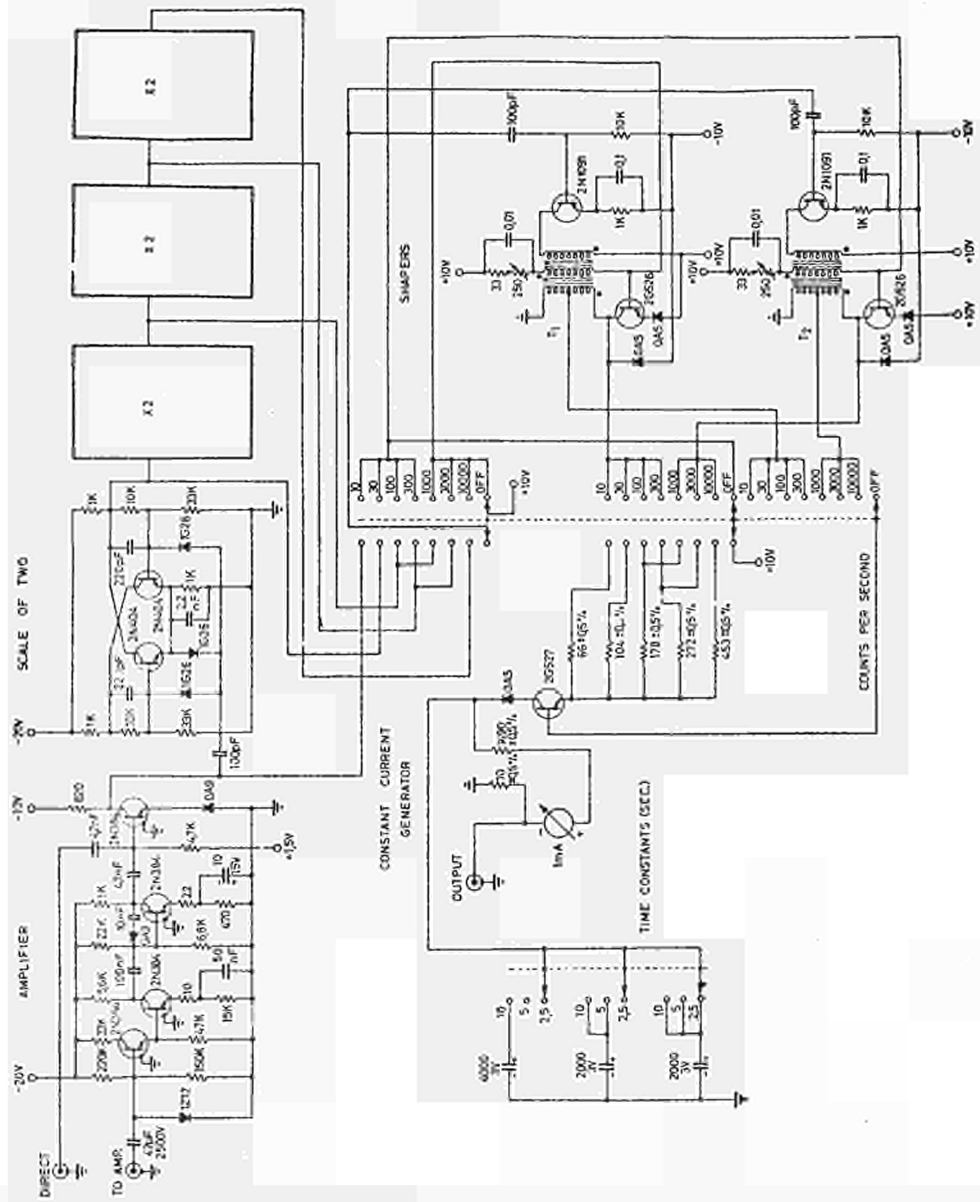

Fig. 1 - Schematic of the ratemeter.
All resistances are in Ohms, 1/2 W, ± 5 % unless otherwise specified, all capacitors are in microfarad unless otherwise specified.
Transformer T_1 : turns : 100/200/125/375 on 74 sheets Mu Metal M30 (Thickness 0.1 mm cross, mounted).
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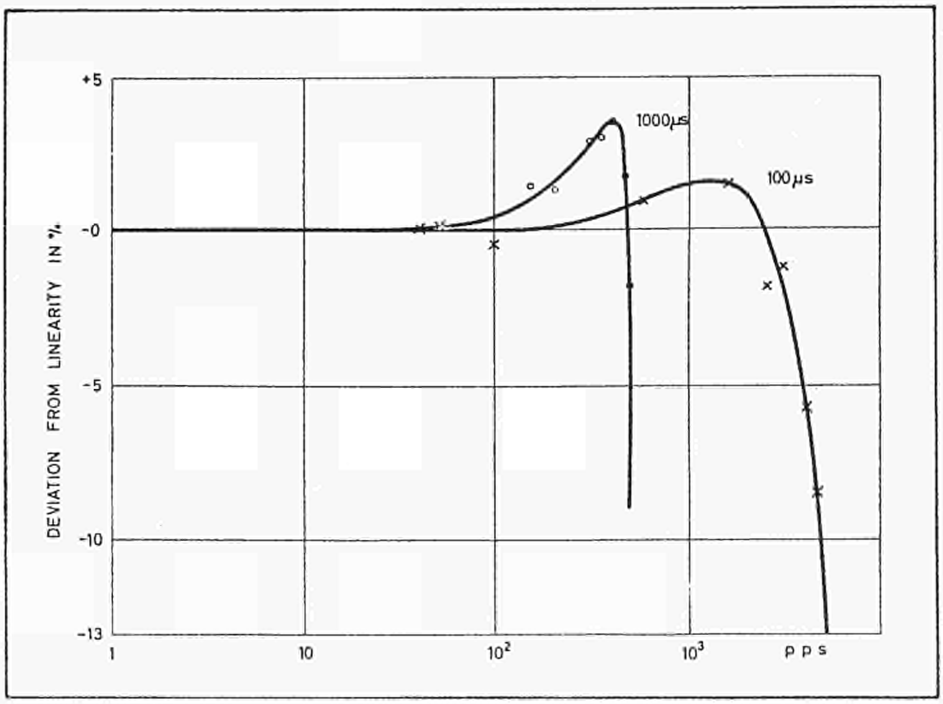

Fig. 2 - Deviation from linearity in the output circuit vs. input pulse rate for the blocking oscillators of 100 and 1000 µsec. The dead time and the settling time are obtained from these measurements.

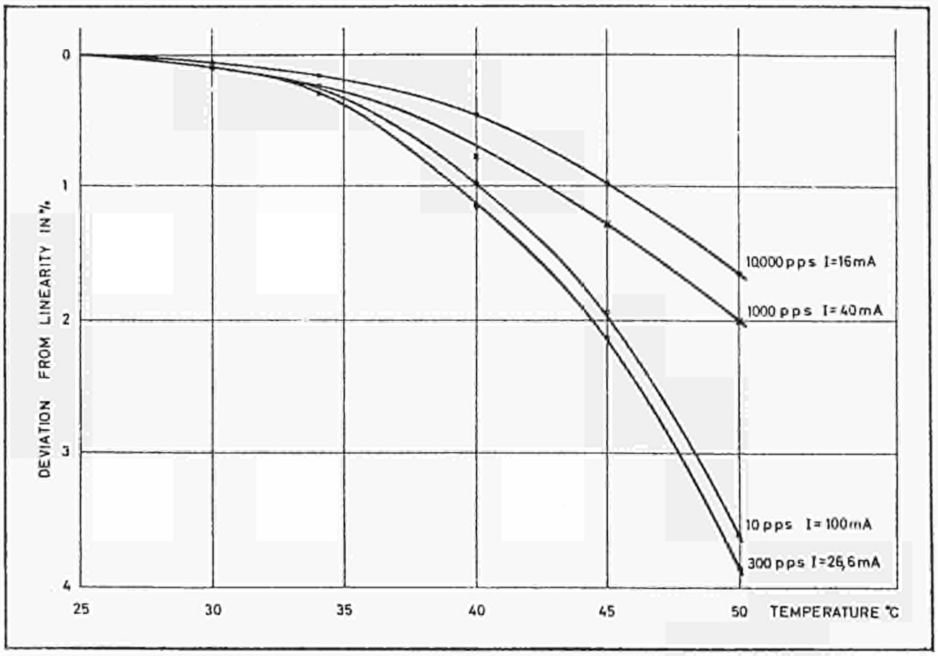

Fig. 3 - Deviation from linearity of the ratemeter vs. ambient temperature.

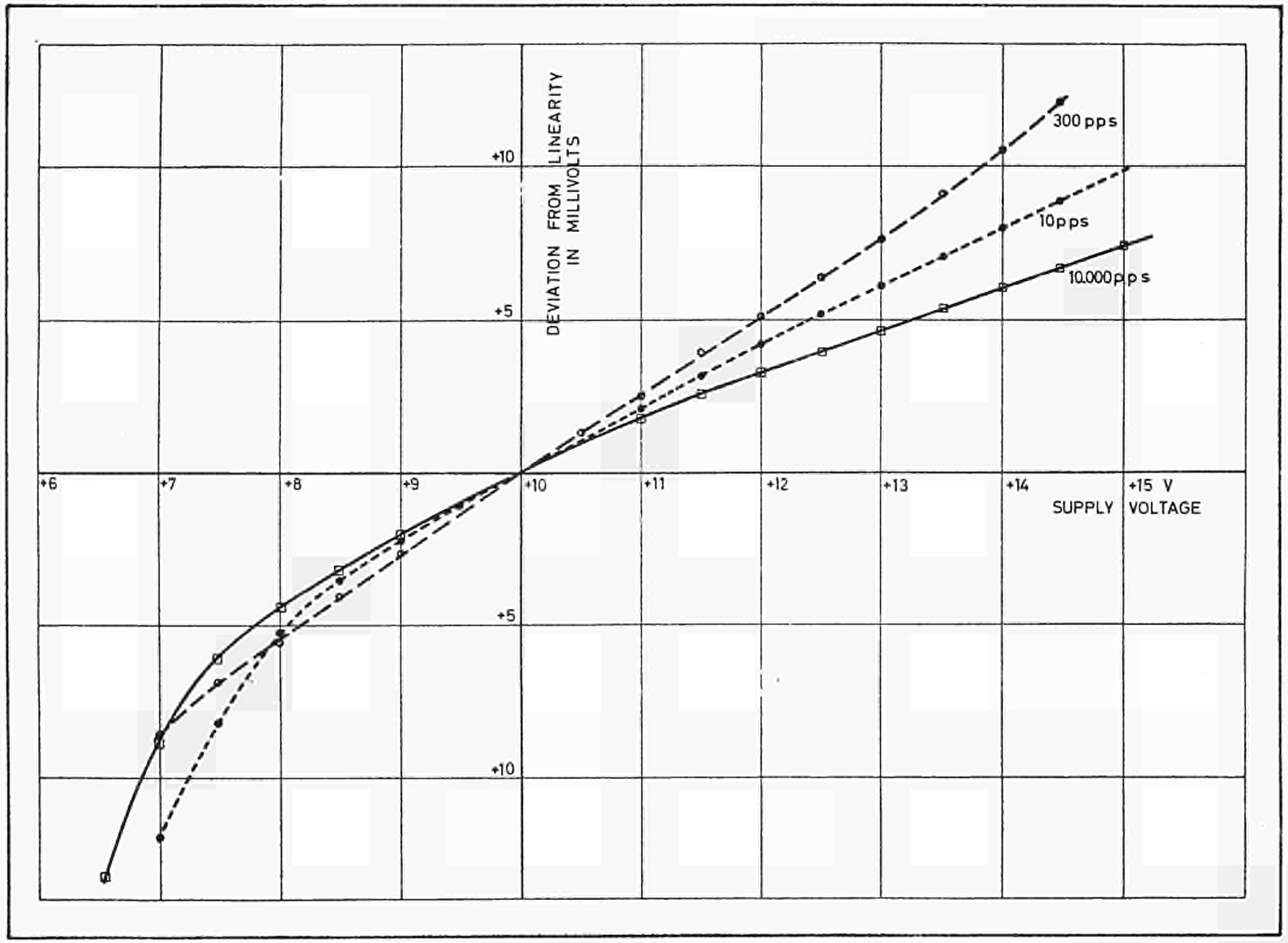

Fig. 4 - Deviation from linearity of the ratemeter vs. + 10 V supply voltage changes.

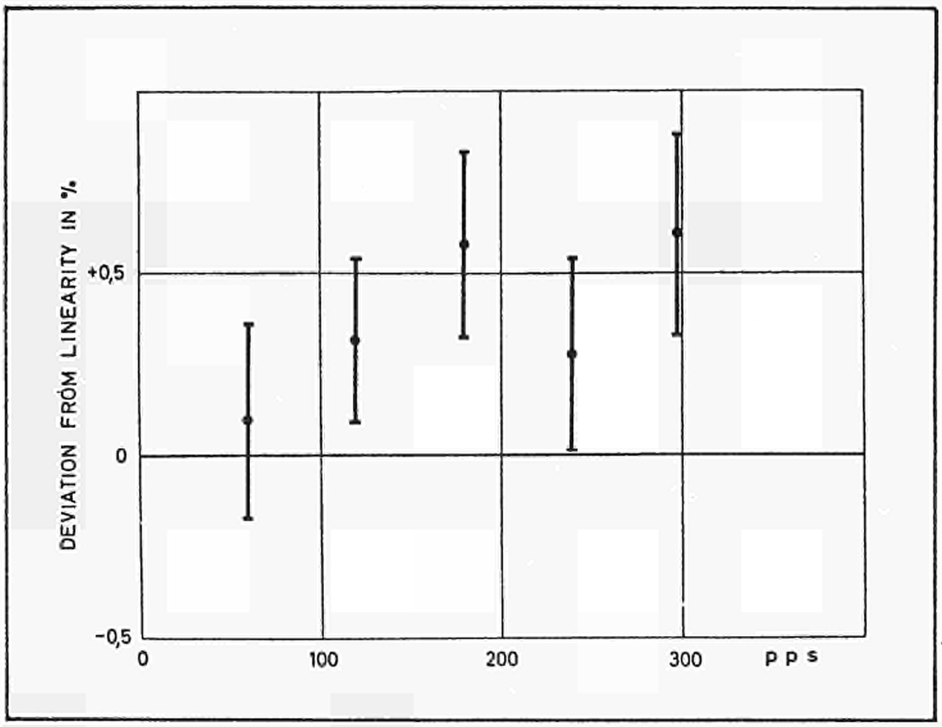

Fig. 5 - Deviation from linearity for random spaced pulses on 300 pps range.

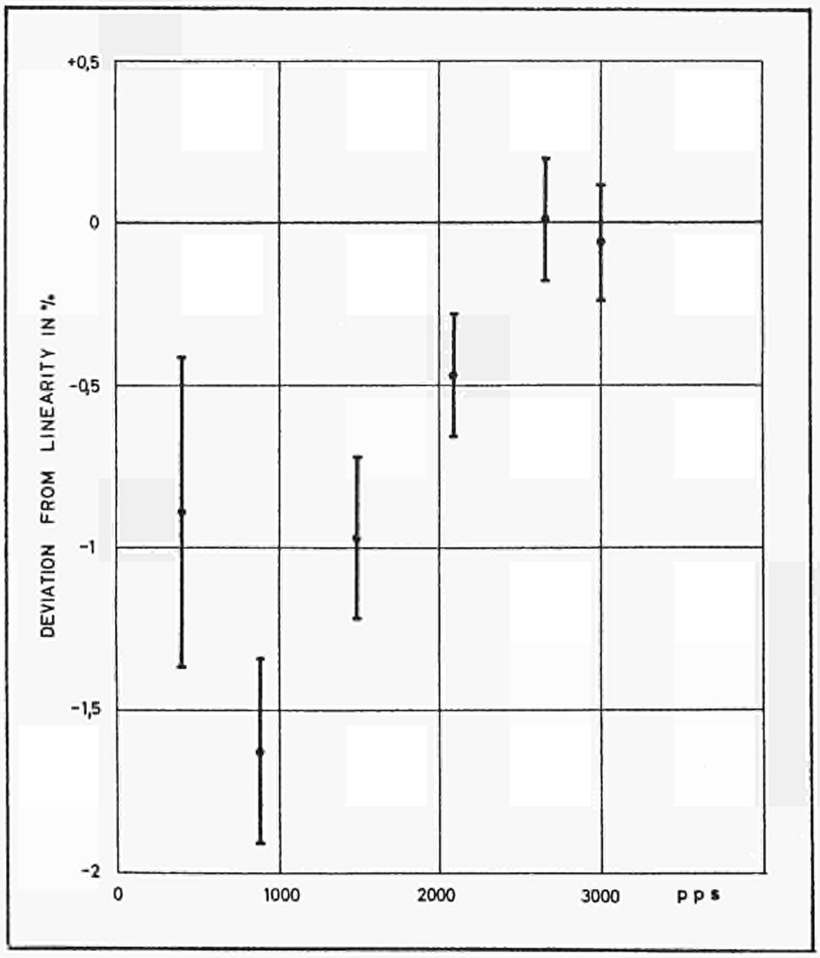

Fig. 6 - Deviation from linearity for random spaced pulses on 3000 pps range.