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A NANOSECOND SAMPLING OSCILLOSCOPE

by

H.I. Pizer and H. Verweij.

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SUMMARY

A sampling oscilloscope is described which can be used in conjunction with any slow oscilloscope. The rise time is shorter than 1 nsec. The sweep length can be continuously varied from 10^{-8} sec to 0 sec. The total range which can be scanned is 250 nsec. The scan-time can be varied in 8 steps from 1 sec to ≈ 7.5 msec. The maximum sensitivity is 50 mV/cm, with slow oscilloscope sensitivity of 50 mV/cm, and signals up to 8 V are displayed linearly, via the direct low impedance input. This input impedance has been chosen to be 125Ω, but other impedances are equally valid. A high impedance probe is available, giving a calibrated over-all attenuation of 2.7, 10, 100 or 1000. The maximum acceptable repetition rate of the input signal is 100 kc/s. The equivalent noise at the 125 Ω input is less than 10 mV.

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1. Introduction

The display of low-level, fast pulses is one of the problems which arise when working in the nanosecond field. The development of fast transistorized nucleonic circuits, for example, requires an oscilloscope with a sensitivity of about 100 mV/cm, a rise time < 1 nsec and preferably a high input impedance.

Commercial oscilloscopes, available at the time of initiation of the development of this instrument, were either too slow (had too small a bandwidth) or were not sufficiently sensitive to meet these requirements.

The well-known Tektronix 517A has a rise time of 7 ns and a sensitivity of 100 mV/cm. Going directly to the plates of its cathode ray tube gives a rise time of 1.5 ns and a sensitivity of 16 V/cm.

The new Tektronix 585 has a rise time of 3 ns and a sensitivity of 100 mV/cm. A drawback is its low brightness for low repetition rates.

The rise time or bandwidth of an oscilloscope is defined by the rise time of the amplifier and its cathode ray tube. In general we can say that the amplifier is the first limiting factor. In fast oscilloscopes, distributed amplifiers are commonly used and though distributed amplifiers have been published[1)] with rise times < 1 nsec, no oscilloscopes have yet been constructed with these amplifiers.

The rise time of the cathode ray tube depends on the rise time of the deflecting system and is determined by the transit time of an electron to pass between the plates. The shorter the transit time, the shorter the obtainable rise time. A shorter transit time can be achieved by higher accelerating potentials or by shorter deflection plates. Both methods decrease the deflection sensitivity.

Another rise time limiting factor is the parasitic inductance of the leads to the deflection plates and the capacity between these plates. In the so-formed filter, the voltage across the capacity is the effective deflection voltage.

The distance between the plates determines also the maximum display amplitude on the screen; reducing the distance reduces the maximum height. If photographic enlarging is used, the reduction of scan becomes less important and acceptable.

The best compromise between all the above mentioned parameters, is perhaps given up till now by the Tektronix T_{54}P and the Dumont 5 XP cathode ray tubes (used in the Tektronix 517 and 517A).

The introduction of the distributed deflection system by J.R. Pierce[2)] was a real step forward. He cut the one long deflection plate into short ones, connecting them together with small inductances. In this way he made a distributed deflection system. The speed of the electrons in the beam must be the same as that of the electrical signal via the lumped delay network. In this way the electrons are deflected a number of times by the same signal. The total sensitivity is roughly equal to that given by one plate having the length of the sum of the individual plates.

Pierce's basic ideas were further developed - metal zig-zag strips, coaxial conductors and helical arrangements have been used for the deflection. Bandwidths up to 15.000 Mc/s[3)] have been quoted using these principles.

A commercial available oscilloscope is in use at CERN, which has a cathode ray tube with a distributed deflection system. This tube was described by Germeshausen et al[4)]. The bandwidth is 2000 Mc/s and the sensitivity 5.8 V/cm/helix. The tube has two separate deflecting helices, when the signal is also applied to the second helix, via a special inverter transformer, the deflection sensitivity is doubled. The inverting transformer reduces the bandwidth slightly. The tube has a very fine spot (0.05 mm) so the effective sensitivity can be increased by photographic analysis.

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The sampling oscilloscope uses a different approach to the problem of the display of low-level fast signals. It measures instantaneous amplitudes of successive identical pulses. These samples are amplified, stretched and displayed as a dot on a slow oscilloscope. The measurement is made with a narrow spike, triggered by the signal to be observed, and the movement of this spike along the pulse is governed by the horizontal sweep of the oscilloscope. In this way a true picture of the pulse can be made (see Fig. 1). The number of dots forming the image is

$$N = Tf ,$$

where

T = duration of horizontal sweep

f = frequency of displayed signal.

The principle was first described by Jansen[5] who developed a sampling oscilloscope with a bandwidth of 50 Mc/s. Later, McQueen[6] extended the bandwidth to 300 Mc/s.

During the development of the described oscilloscope, Sugarman[7] published a sampling scope for statistically varying pulses. A completely transistorized sampling scope has been indicated by Chaplin[8], the rise time is 1 ns. Several firms, like Tektronix, Hewlett and Packard, Lumatron, have recently marketed sampling oscilloscopes. The general principles are described in ref.9, a historical review in ref.10 and an application to R.F. techniques in ref.11.

* * *

2. Principle of Operation

The block diagram (Fig. 2) indicates the various parts making up the complete sampling scope. A trigger signal, obtained by tapping a fraction of the signal under observation, is connected to the trigger input. This trigger signal (Fig. 3a) fires the fast sweep generator consisting of the "amp", "fast trigger" and "bootstrap", which delivers a fast ramp (Fig. 3b) to the "variable delay". To this variable delay is also connected, via the "horizontal shift", a slow ramp (Fig. 3c) from the free running "slow time base generator".

The variable delay circuit gives an output when the instantaneous amplitude of the fast sweep becomes higher than that of the slow sweep. From this output the sampling spike is formed (Figs. 3d and e). The fast ramp is triggered by the signal, so has a fixed time relation to it. The slow ramp is free running and is used also for the horizontal deflection of the slow scope.

Figs. 3d, e and f will make it clear that when the spot moves from left to right on the screen of the slow scope the spike will sample the signal under observation from left to right. In this way an expanded image is obtained of the fast signal. The output of the variable delay is shaped into a narrow sampling spike by the spike generator, consisting of a "multivibrator", a "blocking oscillator" and a "sharpener". The sampling spike measures the instantaneous value of the signal under observation in the "mixer" and the mixer will give a slow output signal containing this information. The mixer output is amplified linearly, stretched into a pulse of constant width, and fed to the vertical amplifier of the slow scope.

The unblank generator is triggered by a pulse from the spike generator to unblank the beam of the slow scope. This "delay multivibrator" times the instant of unblanking during the stretching time. The "unblanking gate" gates the unblanking trigger pulse by means of a pulse from the slow time base generator, so that the beam only unblanks during the sweep time. After the beam has been unblanked, the stretcher is reset by the "release multivibrator", this resetting circuit is released before the stretching takes place by a trigger from the spike generator.

A qualitative description of the various parts is given below, a more detailed analysis of some topics will be found in the appendix.

* * *

3. Mixer, Amplifier and Stretcher

a) Mixer general

The limitations to the speed of response of the oscilloscope are the response of the mixer (see appendix 1a, b) and the width of the sampling pulse (appendix 1c).

In an ideal mixer the rise time cannot be faster than the active duration of the sampling pulse. This duration is that time which drives the mixer into conduction. In general, this is the top of an approximately Gaussian shaped pulse, the smaller the amount we use, the shorter the active part will be, and also the smaller the dynamic range of the mixer. A short rise time is obtained at the expense of the input voltage range.

The input voltage could be attenuated before the mixer and the gain after the mixer increased to compensate for this attenuation. This will result in an augmentation of the noise level as an unwanted additional effect.

An infinitely short sampling pulse will give a response depending only on the mixer. Two possibilities were considered when developing the mixing circuit. The use of a fast semi-conductor diode and a vacuum tube pentode as the mixing element. The diode will give fastest response and operate satisfactorily with sampling pulse amplitudes down to 100 mV. A pentode mixer gives a slower response, due to its greater electrical size and requires a minimum sampling pulse amplitude of ≈ 1 V.

The noise level of the diode mixer is greater than that of the pentode mixer, due to the inherent noisiness of semi-conductor devices. Microwave tubes have been tried but no good results were obtained.

A pentode mixer was adopted, because of its superior dynamic range and noise level (V_1 = 6AK5/5654). This type of tube was chosen for the good response of its input network (see appendix 1a and b) and suitable IaVg curve. A short grid base tube like a D3a or E180F, limits the range of the input voltage, grid current also occurs too early in these tubes.

b) Circuit description of mixer

The mixer tube (V_1) (see Fig. 4) is held in cut-off by a negative bias (- 25V), the sampling spike brings the tube into conduction to the centre of its anode current working range, ≈ 8 mA.

When there is a positive signal at the instant of sampling, the pulse will be superimposed on a more positive bias and result in a higher peak current. Similarly a negative signal gives a lower peak current (see Fig. 5).

Assuming the tube characteristic to be linear and the sampling pulse square, the anode pulse will be linearly related to the instantaneous value of the input signal.

c) Amplifier, amplitude linearity

A non-linearity in the mixer occurs from the non-linear relationship between grid voltage and anode current, giving a higher output for a positive than for a negative going input signal.

Another non-linearity in the same direction appears as the actual shape of the sampling pulse is more Gaussian than square.

Compensation for these two effects has been obtained by suitable biasing of V_1 and V_2 (RV_1 and RV_{10}) so that the net result is essentially linear (see Fig. 6).

The falling edge of the anode pulse is fast and equal (in time) to the sampling pulse width. V_2 amplifies ($\approx$ 20x) and slows down the mixer output. The inductance L is applied to reduce the noise and hum level and make the stretcher output less rate dependent.

The gain of mixer and amplifier is 1x (adjusted with C_{13}). 1 V fast signal at the input is converted to 1 V slow signal at the stretcher input (see Fig. 6).

As will be seen later, the stretcher is linear over the range of the mixer. So the limitation to the amplitude of the input signal is given by the mixer and amplifier. Fig. 6 shows that up to 8 V positive and negative the over-all result is linear, saturation occurs at about 10 V.

When there is no input signal, the output of the samplifier is 12 - 15 V being the zero level at the stretcher output.

d) Input impedance, probe

The direct input impedance is 125 Ω. Via the high impedance probe, Tektronix type P170CF, the input impedance is 12 MΩ is parallel with 5pF, when going direct to the probe, and 1pF via the capacitive attenuation heads.

The range of the probe is limited by the cathode follower in the probe. The maximum direct input signal is 2.4 V positive and 1.2 V negative and the over-all attenuation is then 2.7 times (2.7 V fast pulse in, gives 1 V stretched pulse out).

The three capacitive attenuator heads, which can be screwed onto the probe, give a calibrated attenuation of 10, 100 and 1000. The power for the probe is supplied by cathode follower V_{13}^{B}.

e) Stretcher

The stretcher consists of a differential amplifier (V_3 and V_4), an integrator V_5^{A} and C_{19}, the storage condenser. When the input signal at V_3 goes positive, the anode of V_4 will go positive by an amplified amount. V_{5_A} charges C_{19}. The voltage on C_{19} is fed back, via V_5^{B} and D_{11-22} to the grid of V_4. The positive going signal on this grid will reduce the positive signal on the anode until balance is obtained.

This feedback is accomplished in a very short time, so that in actual practice the voltage on C_{19} follows the input voltage to its peak value.

When, after having gone positive, the input signal goes negative, the grid of V_4 is held at the reached peak level and so the anode of V_4 and the grid of V_5^{A} will go negative, as all current through R_{18} is transferred to V_4. V_5^{A} will be cut off and the voltage at C_{19} is held, until after unblanking, the condenser is discharged by the release tube V_6 to the steady level of the grid of V_3, where it is clamped by the feedback action.

In the quiescent state the output DC level of the stretcher is at 12 - 15 V. Triggering the scope with no input signal, so that only a sampling spike arrives at the mixer, brings the stretcher output level to 0 V (adjustable with "baseline" on front panel). The information about the input signal will be superimposed on this level.

For optimum linearity of the stretcher, the difference between grid volts V_3 and output level has to be adjusted to zero, at 0 V level with RV_9, Fig. 7 shows the performance of the stretcher.

The droop of the stretched signal is $< 0.3\%$ in 8.5 μs.

4. Fast Sweep Generator

A buffer amplifier V_7, a sensitive trigger circuit V_8 and V_9 and a bootstrap V_{10}, V_{11} and V_{12}, form the fast sweep generator.

Positive and negative trigger signals can be used by the application of an inverting transformer at the input. The trigger threshold is $\approx$ 10 mV (for 20 ns pulse). For trigger signals > 25 mV the triggering delay is practically constant.

The tubes V_8 and V_9 are both conducting 15 mA, so working in the region of high g_m, the loop gain is kept low by a biased off diode D_2.

When a negative trigger signal arrives at the grid of V_8, bringing D_2 sufficiently far into conduction, so that the loop gain becomes higher than one, the circuit fires. V_8 will be cut off and the full 30 mA cathode current will be switched to V_9. The anode of V_8 will ring positive and then negative with a time constant depending on L_2, the parasitic capacity at anode V_8 - grid V_9 circuit and C_{31}. When the signal goes negative V_9 will open again and the oscillation will be overdamped by D_1 and R_{41}, so that after the decay the steady state is reached again.

The output pulse at the anode of V_9 is shaped to the right width by L_3 and the parasitic capacity. The width of this negative pulse determines the fast sweep length (250 ns) and so the maximum working range of the scope.

By using a biased off semi-conductor diode to hold the trigger circuit stable, an increase in sensitivity of about one hundred times over that of the biased-off-tube versions is obtained.

The negative pulse from the trigger circuit cuts off the standing current in V_{11} ($\approx$ 25 mA). The anode of V_{11}, the grid of V_{12} and, via the cathode follower action of V_{12}, the cathode of V_{10} will rise, so that V_{10} is cut off.

C_{37} is charged with a constant current from C_{36}, giving a linear sawtooth out, on the cathode of V_{12}.

After about 250 ns the grid voltage of V_{11} will cross the cut-off value and the sawtooth ends, as V_{11} will reset the voltage on C_{37} to the steady value.

The fast sweep amplitude is adjusted by C_{37}.

* * *

5. Slow Sweep Generator

The free running slow sweep generator consists of a Miller integrator with the tubes V_{24}, V_{21}^{A}, V_{22} and V_{23} and a bistable multivibrator V_{20}.

During the reset period (T_1), V_{20}^{A} is on, V_{20}^{B} is off, V_{22}^{B} is on and clamps the first grid of V_{24} to a small negative voltage (- 2.5 V). V_{24} is on having a very low anode voltage (≈ 5 V). V_{21}^{A} is off as its cathode is clamped by V_{22}^{A} to - 2.5 V and its grid via V_{23}, DC coupling, at ≈ - 55 V.

The grid voltage of V_{20}^{B} decays from a negative value relative to its cathode. At some instant it crosses the cut-off point, and the circuit will switch to a state where V_{20}^{A} is off and V_{20}^{B} is on.

The anodes of V_{20}^{B} and V_{22} will go to - 12 V, cutting off the current in V_{22}.

The first grid of V_{24} will be free to move negatively, the anode goes quickly positive (≈ 45 V) and catches up the cathode level of V_{21}^{A}, where the feedback loop is closed and the Miller action and so the sweep commences.

A linear sawtooth is obtained, the rate of rise mainly determined by C63/C70 and R_{91}, $V_o \approx V_b(1 - \frac{t}{RC})$.

A part of the sweep is fed back to the grid of V_{20}^{A}. At a certain time this grid voltage reaches the point where V_{20}^{A} starts conducting (cathode is at - 60 V), V_{20}^{A} will be switched on and V_{20}^{B} off. This is the end of the slow sweep.

The anodes of V_{20}^{B} and V_{22} will go positive and V_{22}^{B} will clamp the first grid of V_{24} to - 2.5 V, the anode of V_{24} will go negative cutting off V_{21}^{A}.

C_{63}/C_{70} will discharge via $RV_5//RV_6//RV_7$, V_{22}^{B} and R_{85} until V_{22}^{A} catches the cathode of V_{21}^{A} again.

The feedback system from Miller integrator to multivibrator guarantees a constant output amplitude for all slow sweep speeds.

By switching capacity values the duration of the sweep is varied and in this way the number of dots. For a slow sweep time T_2 and a signal frequency f, the number of dots will be $T_2 f$. The minimum sweep time is ≈ 7 ms and the maximum ≈ 2 sec.

The slow sweep output for the horizontal deflection of the slow oscilloscope, is taken from the cathode of V_{21}^{A}.

With RV_5 the grid level of V_{20}^{A} is adjusted to a value lower than - 60 V, adjusting the moment of flyback, so the sweep time and the slow sweep output.

* * *

6. Variable Delay

The movement of the spike along the signal to be observed is arranged in the variable delay circuit.

The slow sweep from RV_7 is connected to the horizontal shift circuit, V_{21}^{B}, V_{25}, V_{26} and V_{27}. Here the sawtooth is clamped on a DC level, which can be varied, thus giving horizontal shift as will be explained later. Variations of sweep speed or sweep rate have no influence on this level. The output from RV_8 is fed to cathode follower V_{26} and from here to cathode of diode D_6, via R_{94}.

The fast sweep, from the fast sweep generator, is DC restored (D_5) in the grid circuit of cathode follower $V_{13}{}^A$ and connected to the anode of D_6, via $V_{13}{}^A$.

When the anode of D_6 becomes more positive than its cathode, i.e. when the instantaneous value of the fast sweep becomes more positive than that of the slow sweep, D_6 conducts and will let the remainder of the fast sweep through. This triggers the spike generator at the instant of coming through (see Figs. 3b,c,d and e).

Fig. 8 gives more in detail the action of the sweep speed variation and shift.

Assume that DC levels of fast and slow sweeps are the same at the electrodes of diode D_6. The slow sweep will scan the period from 0 - t_1. At the screen will be displayed signals occurring during this period. The sweep speed of the display is given by $A/B \times \tau$. The minimum sweep speed is 100 ns (10 ns/cm). $A_{max} = 50$ V (set by RV_6), B = 125V(set by C_{37}) and τ = 250 ns.

Moving the slow sweep upwards, so giving it a positive bias relative to the fast sweep, means that we scan the period from t_2 to t_3, moving the picture to the left on the screen. The variation of this positive DC level is made by helipot RV_8 ("hor. shift" on front panel), giving the possibility of observing signals along the total length of the fast sweep, thus making the working range 250 ns.

If we diminish the amplitude of the slow sweep going to the variable delay, RV_7 (the "sweep speed" helipot on front panel), we reduce the scanned period of the fast sweep (while the display lengths has remained constant on the screen), thus reducing the effective sweep speed (see Fig. 8b) $t_1 = A_1/B \times \tau$.

There is no fixed time correlation between the free running slow sweep generator and the recurrence of the signal. Because of this, the successive images on the screen have their dots in a random position, and due to the persistance of the screen, the dots result in a smeared line.

* * *

7. Spike Generator

The spike generator consists of V_{14}, V_{15}, V_{16}, V_{17}, V_{18} and V_{19}. Here the relatively slow signal out of the variable delay circuit is converted into the narrow sampling pulse.

The output of the variable delay circuit drives an EFP60 (V_{14}) trigger circuit, with feedback from dynode to grid. The time constant $C_{43} \times R_{67}$ is short compared to the slow sweep rate of rise, and cuts out the slow sweep pedestal of the variable delay output.

V_{14} triggers a blocking oscillator, V_{16} and V_{15}. V_{15} provides a low impedance grid bias for V_{16}, so that a constant bias is obtained even when the rate of the input signal varies (grid current is $\approx$ 9 mA at 100 Kc/s).

The lower side of the grid winding is connected to the cathode, thus bootstrapping the grid voltage. In this way anode voltage limiting is obtained, giving a higher output voltage and a better rate of rise than grid current limiting. A 400 V pulse is formed having a rate of rise of 20 V/ns.

For the type of core chosen, the number of turns on the transformer is not critical, as the rise time and amplitude are mainly determined by the properties of the tube (V_{16}). Two trigger circuits in succession were needed to cut out all influence of the slow sweep on the sampling pulse amplitude.

The output of the blocking oscillator drives the sharper V_{17}, V_{18} and V_{19}. V_{17} and V_{18} are biased off by -150 V and start heavily conducting when the blocking oscillator output has its highest rate of rise, the peak anode current is $\approx$ 2A.

The anodes of V_{17} and V_{18} and the cathode of V_{19} will come down at a rate mainly depending on the anode currents and the parasitic capacities and inductances present at anode V_{17} and V_{18} and cathode V_{19}.

V_{19} is biased off with 150 V and this ensures that the tube starts conducting when the cathode voltage has its maximum rate of fall. Roughly said, the anode currents of V_{17} and V_{18} are now transferred to V_{19}, resulting in a fast run down of its anode voltage. This voltage is differentiated with C_{53}, R_{81} and the cable to the mixer, yielding in this way the spike. R_{81} absorbs reflections returning from the mixer.

An analysis of the spike shaping network shows that when bringing into account all parasitic effects like inductance of connecting wires, tube pins and the various parasitic capacities (see e.g. appendix 1), the minimum rise time obtainable is $\approx$ 2 ns, so this is well in accordance with practice.

Only the upper 5V of the sampling pulse open the mixer V_1, in the quiescent state, the width at this level is < 1 ns.

* * *

8. Timing Circuits

The timing circuits are triggered by a pulse from the blocking oscillator V_{16}. They provide an unblanking signal for the slow scope and a release signal for the stretcher.

A delay multivibrator V_{28} is triggered from V_{16}. The positive going trailing edge of this pulse fires, via the unblanking gate, the unblanking multivibrator. So the width of this pulse determines the instant of unblanking (see Figs. 3g and h). The unblanking gate is opened by a negative pulse from the slow sweep generator, so that the beam only unblanks during the slow sweep. The unblanking multivibrator gives a 1 μsec, 40 V negative pulse which in the case of Tektronix scopes, when connected to the ext. cathode pin, gives bright unblanking of the trace.

The blocking oscillator V_{16} also triggers the release multivibrator which cuts off the release tube V_6 before the signal from the mixer comes to V_3. After unblanking the release pulse ends and V_6 brings the output level back to the steady state value.

* * *

9. Operation and Performance

Much of the nanosecond development in the Electronics Group is done with the aid of the described instrument.

Several units have been in use nearly continuously during the previous two years and the operation was found to be satisfactory.

The rise time of a typical test set-up, a mercury wetted contact relay pulser, a 100 ns delay cable RG 63/U and the sampling scope gives a rise time of 1.1 ns (Fig. 9b). The rise time becomes 1 ns (Fig. 9d) when the delay cable is replaced by a low loss cable H.M.7.Al. This 1 ns is effectively the result of the sampling scope and pulse generator, so we may conclude that the rise time of the scope is under 1 ns.

In the mixer the spike has to coincide with the signal. The triggering delay of the fast sweep generator, variable delay (in minimum shift position) and spike generator is ≈ 80 ns. Therefore the signal has to be delayed by this amount to be able to sample it. More convenient is to have the delay somewhat longer, then the picture comes more to the centre of the screen, 100 ns has been adopted. The need for the signal delay cable vanishes, if an early trigger signal is available. The rise time becomes ≈ 2 ns (see Fig. 9e) when the signal is transmitted via the high impedance probe. Care must be taken to keep the ground wire of the probe short.

The noise level is < 10 mV as can be seen from Fig. 10b.

The trigger jitter is too small to be measured, so this is not a limitation for further reduction of the rise time. Measurements on a zero-crossing circuit, where time shifts of 10^{-10} sec were of interest, have been executed with the instrument.

The brilliance of the picture, obtained at a frequency of 100 c/s (Mercury relay pulser), is such that it can be observed in daylight without a hood.

As already discussed, the limitation of the rise time is in the spike generator and the mixer. Improvement of the scope response is foreseen by improving these parts. The remaining circuitry allows a rise time < 10^{-10} sec.

* * *

10. Acknowledgement

We would like to thank Mr. H. Alleyn for his assistance and contribution to the development of this project.

* * *

APPENDIX

1. Rise time limitations

The two determining factors for the rise time are the response of the mixer and the width of the sampling pulse.

The current in the tube will be given by the voltage across C_{cg}, $Ia = g_m V_{cg}$, so we have to examine this voltage.

During the absence of the sampling pulse the substitute diagram can be drawn as Fig. 11. The arrival of a spike is a disturbance in the network, as the tube starts conducting.

The substitute diagram for this period is given in Fig. 12. We neglect transit time effects compared to the stronger effect of the parasitic inductances and capacities. So during the spike the signal voltage on C_{cg} will follow a different time function, for the signal response, however, the voltage on C_{cg} has to be studied from Fig. 12.

An approximate analysis will be carried out for the response of the mixer to the input signal and to the sampling pulse, then the influence of the sampling pulse width (as present across C_{cg}) will be considered, the total performance depending on the combined effect of these factors.

a) Input signal response

Assuming that the inductance L is sufficiently high that the effect of the capacity C can be neglected, Fig. 11a can be simplified to 11b and 11c.

The voltage across C_t is of interest. The response to a unit step function input for R less than the critical damping resistance is:

$$V_c = V\left[1 - e^{-at}\left(\frac{a}{b}\sin bt + \cos bt\right)\right] ,$$

$$a = \frac{R}{2L} \qquad b = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}} \; .$$

A good compromise between rise time and overshoot is the under-damped situation where :

$$a = b = \frac{R}{2L} = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}} \; .$$

The overshoot is 4% then. The rise time from 0 - 100%

$$t_r = 2,3 \; CR. \quad - \quad (\text{sec})$$

and

$$R = \sqrt{\frac{2L}{C}} \quad - \quad (\text{ohm}) \; .$$

C_1, R_1 and R_2 were chosen to obtain this performance. C_1 was taken 10 pF.

$$L_t = 30 \text{ nH} \qquad C_t = 3 \text{ pF} \; .$$

The theoretical value for

$$R_t = \sqrt{\frac{2L}{C}} = \sqrt{\frac{3.10^{-8}}{3.10^{-12}}} = 100 \; \Omega$$

and

$$t_r = 2.3 \; C_t R_t = 2.3 \times 3 \; 10^{-12} \times 100 \approx 0.69 \text{ nsec} \; .$$

It was found in practice, when taking R_1 and R_2 so that $R \gtrsim 94 \; \Omega$, the best result was achieved.

b) Response for the sampling pulse

The diagram is given in Fig. 12a. Neglecting transit time effects, then the circuit can be modified to Fig. 12b, which at its turn can be reduced to the simple circuit of Fig. 12c.

The values of C_{cg}, C_f and R_f depend on the g_m and so on the instantaneous value of the spike. Using the nominal value of 5 mA/V we get some idea of the magnitude of the reflected elements

$$C_f = \frac{C_{cg}}{g_m Z_0} = \frac{5}{5.10^{-3} \cdot 50} = \frac{5}{0.25} = 20 \text{ pF} .$$

$$R_f = \frac{g_m L}{C_{cg}} = \frac{5.10^{-3} \cdot 15.10^{-9}}{5.10^{-12}} = 15\,\Omega .$$

The response of the network to the spike will be somewhat slower than for the signal as the damping is increased.

c) Rise time limitation depending upon sampling pulse duration

A treatment of this phenomena is given in ref. 9 pp 263.

* * *

REFERENCES

1) "Extended range distributed amplifier design" by John Eichholz et al., Rev.Sci.Instr. January 1959, 30, 1.

2) J.R. Pierce, Electronics 22, 97 (1949).

3) K. Owaki, S. Terahata, T. Hade and T. Nakamura, Proc. I.R.E. 38, 1172 (1950).

4) K.J. Germeshausen, S. Goldberg and D.F. McDonald, I.R.E. Trans. on electron devices, ED - 4, 152 (1957).

5) "An experimental stroboscopic oscilloscope for frequencies up to 50 Mc/s" by J.M.L. Janssen. Philips Technical Review 1950, 12 (No.2) 52 and 1950, 12 (No.3) 73.

6) "The monitoring of high-speed waveforms" by J.C. McQueen. Electronic Eng. October 1952.

7) "A sampling oscilloscope for statistically varying pulses" by R. Sugarman, Rev.Sci.Instr. vol. 28, p. 933, November 1957.

8) "A method for designing transistor avalanche circuits with application to a sensitive transistor oscilloscope" by G.B.B. Chaplin - presented at the 1958 Transistor and Solid-State Circuits Conference, Philadelphia, Pa.

9) "Millimicrosecond pulse techniques" by I.A.D. Lewis and F.H. Wells, Pergamon Press, 1959.

10) "Sampling oscillography" by R. Carlsson et al., 1959, I.R.E. Wescon Convention Record part 8.

11) "Fractional millimicrosecond electrical stroboscope" by W.M. Goodall et al., Proc. I.R.E. September 1960, pp 1591.

* * *

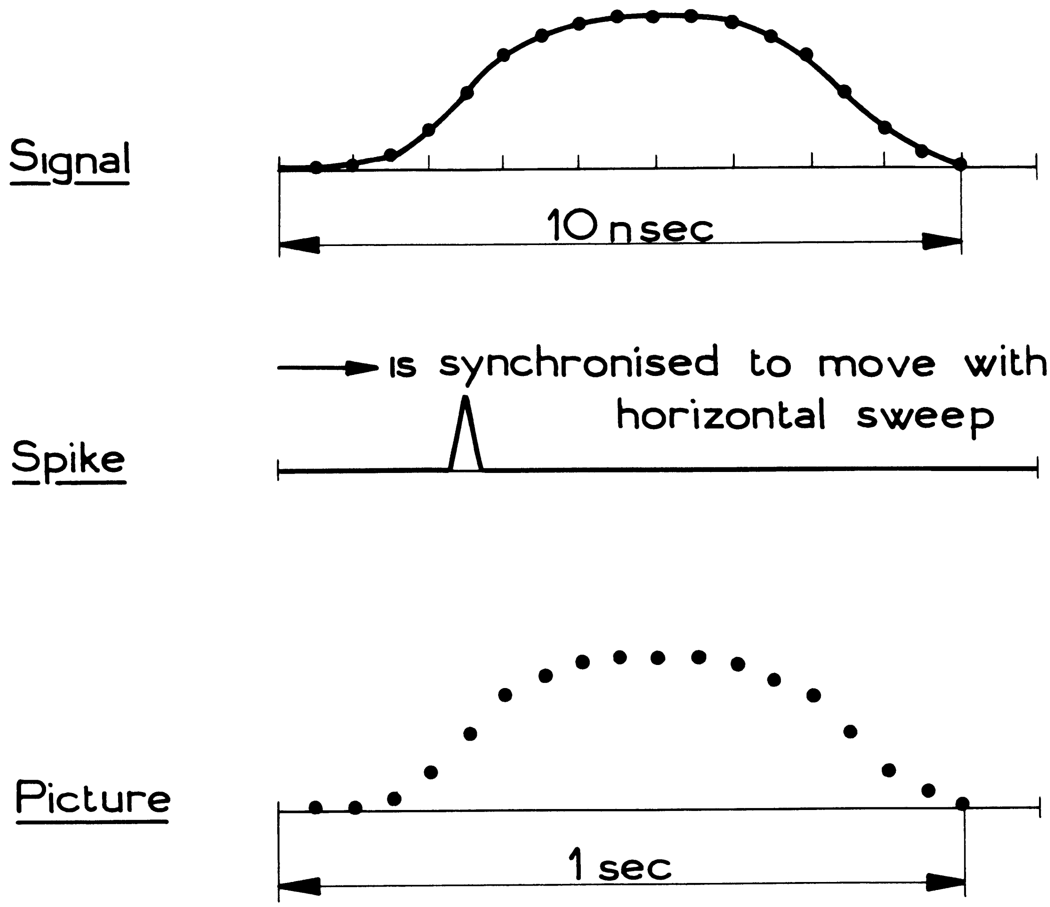


FIG 1 A narrow spike samples the signal

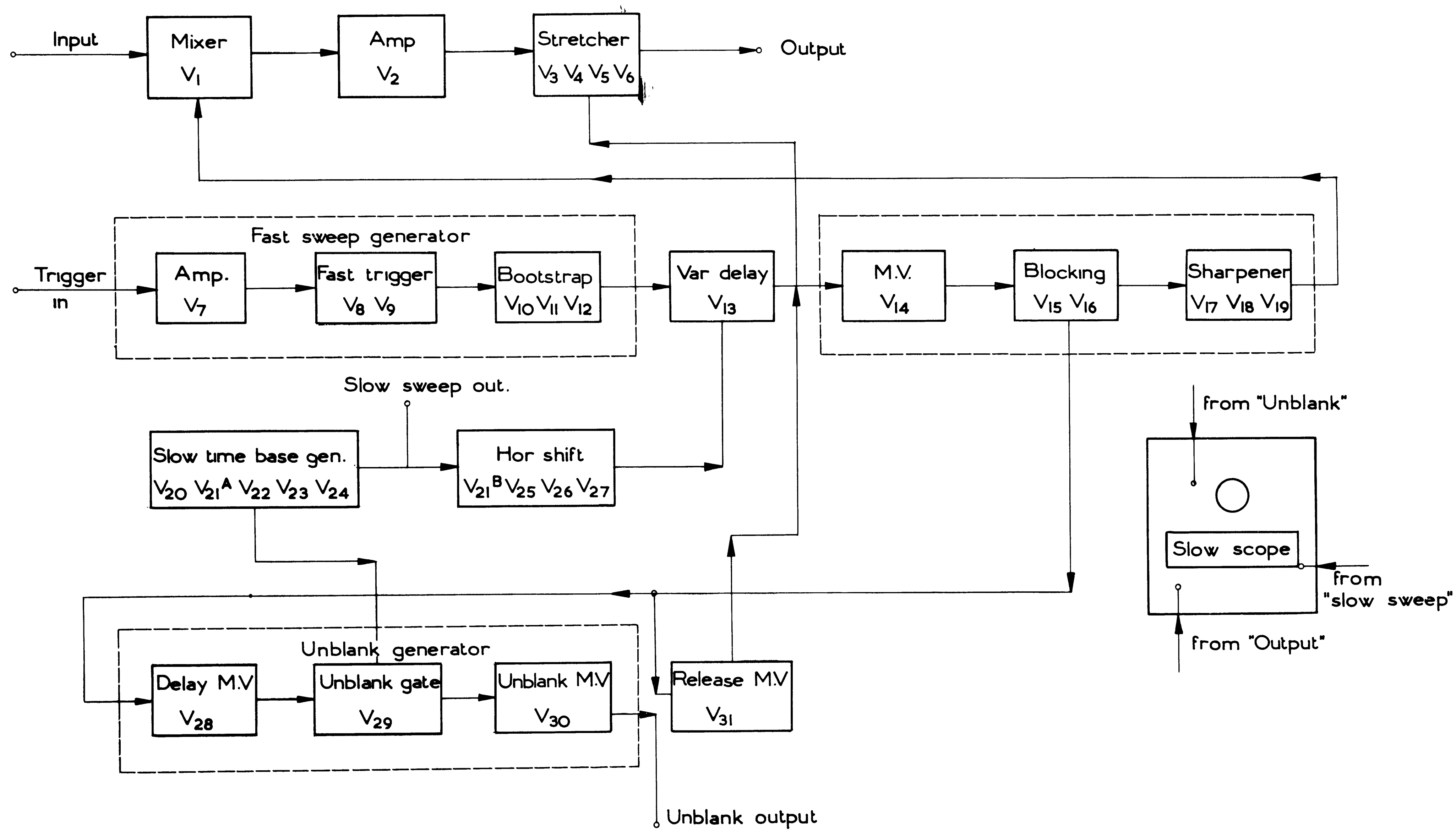


FIG. 2 BLOCK DIAGRAM

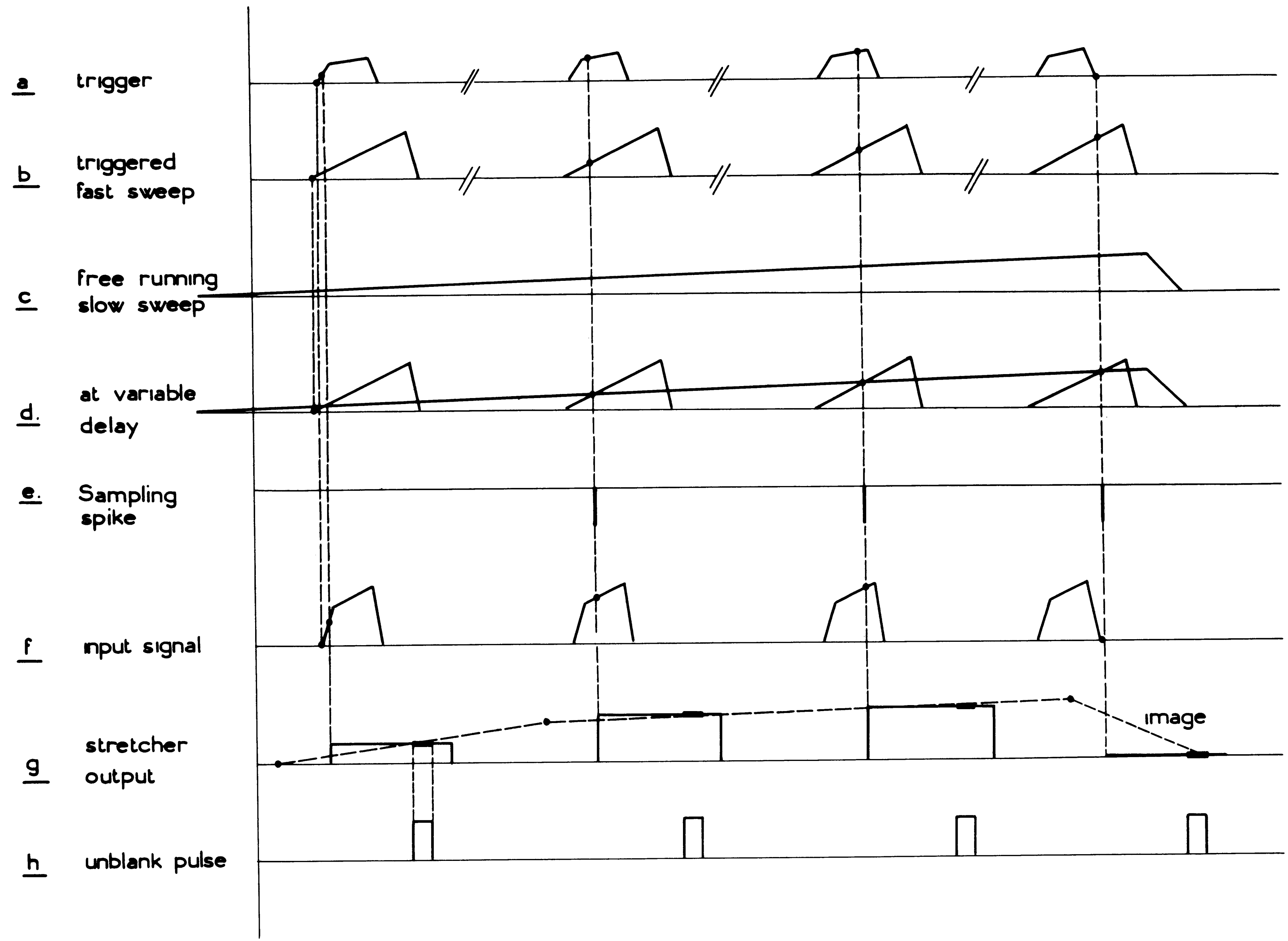


FIG. 3 Sequence of sampling

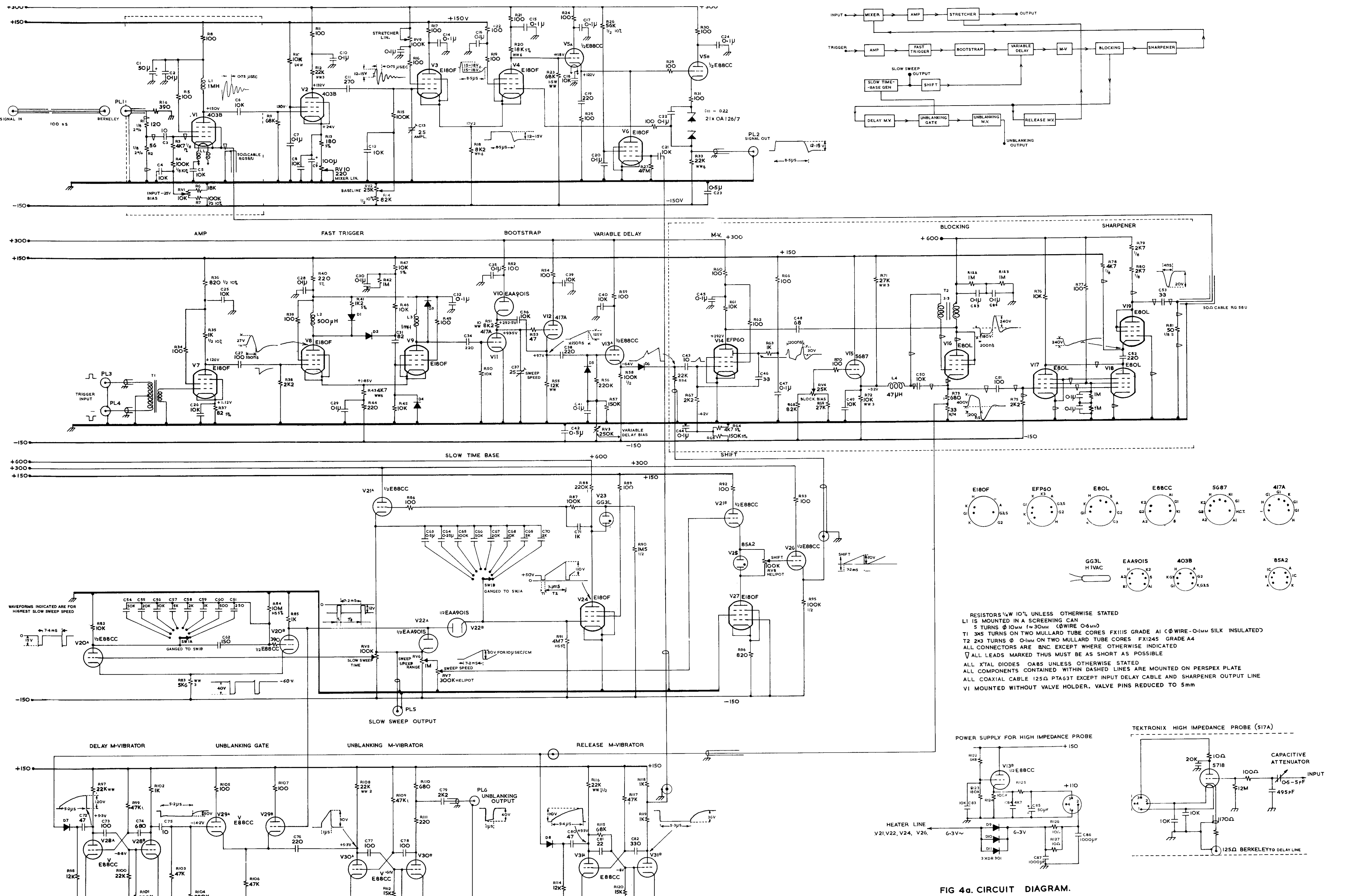
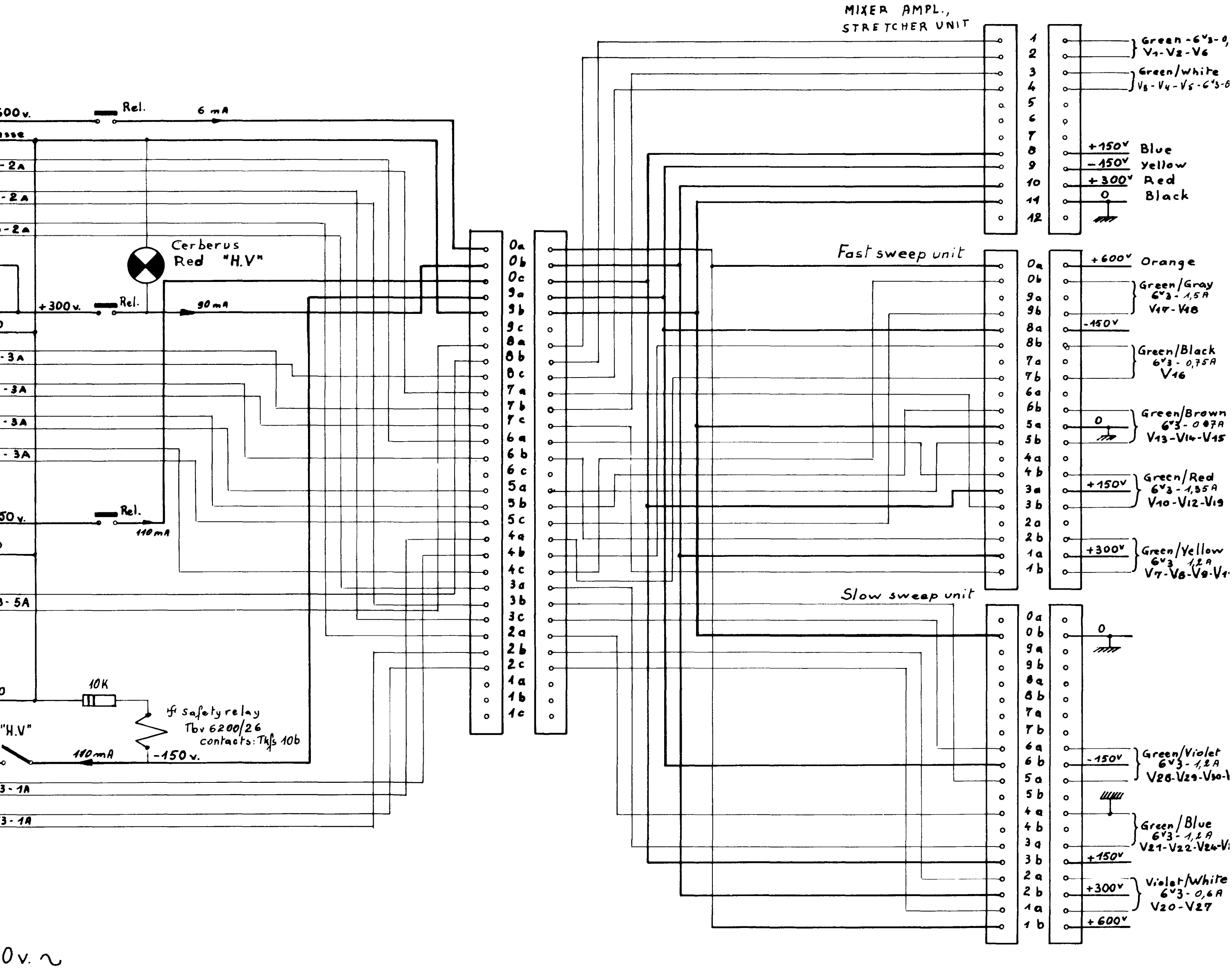


FIG 4a. CIRCUIT DIAGRAM.

SIS. R/2330



0 v. ~

+600V	always	Orange
+300V	"	Red
+150V	"	Blue
0		Black
-150V	"	Yellow

Safety-relay open circuits pos. high voltages

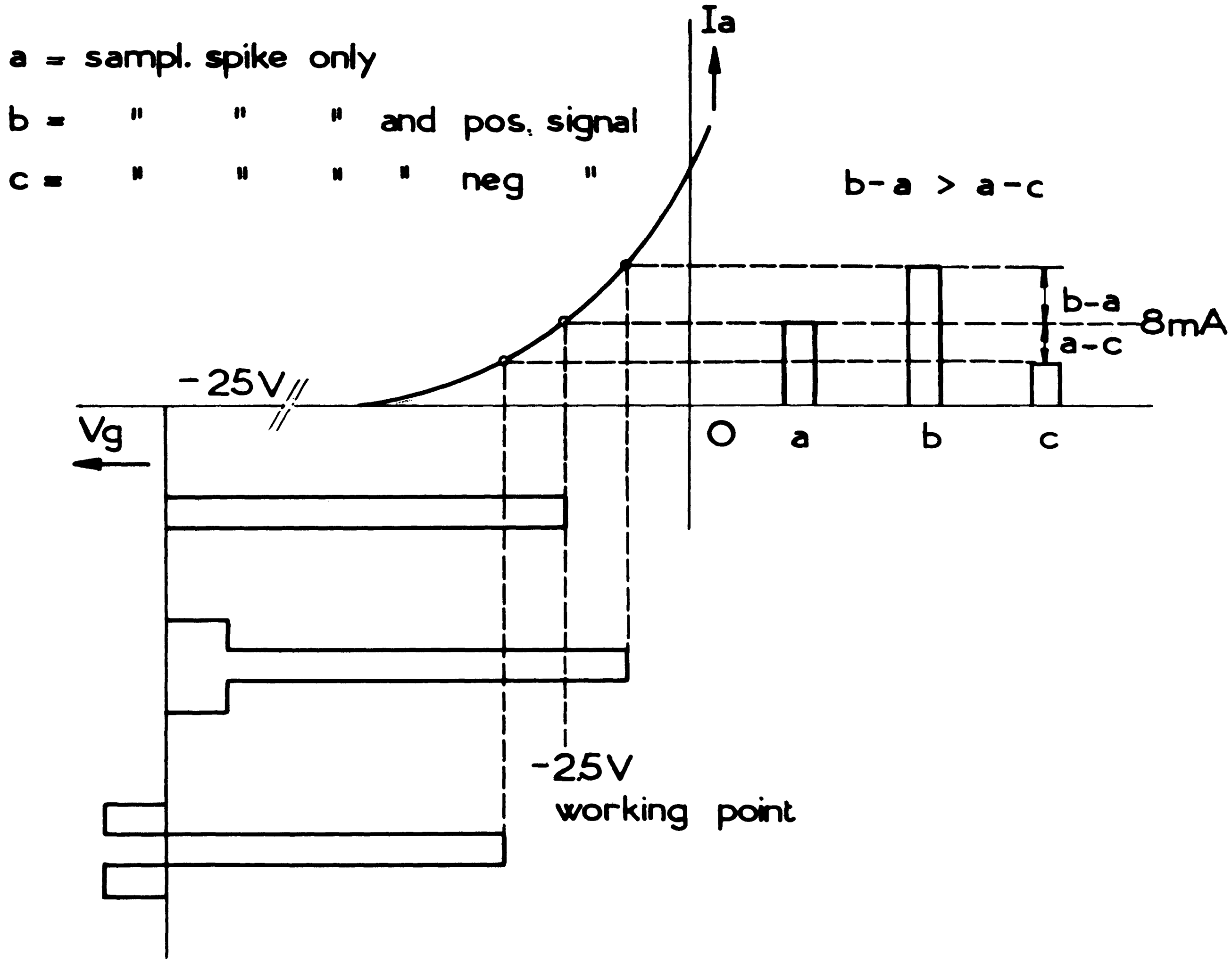

Ia
a = sampl. spike only
b = " " " and pos. signal
c = " " " " neg "
b-a > a-c
b-a
a-c
8mA
-25V
Vg
O
a
b
c
-25V
working point

FIG. 5 [illegible]

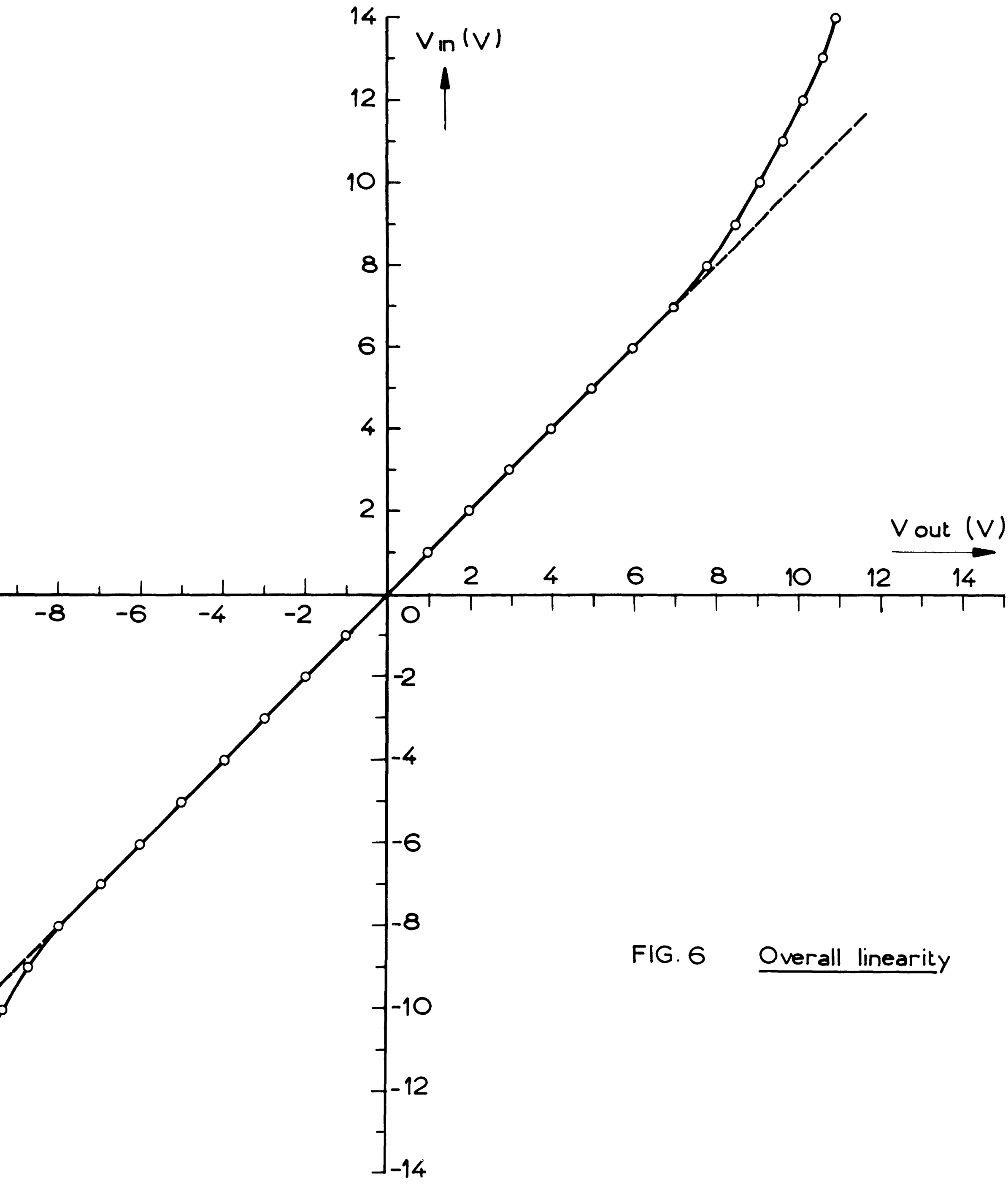


FIG. 6 Overall linearity

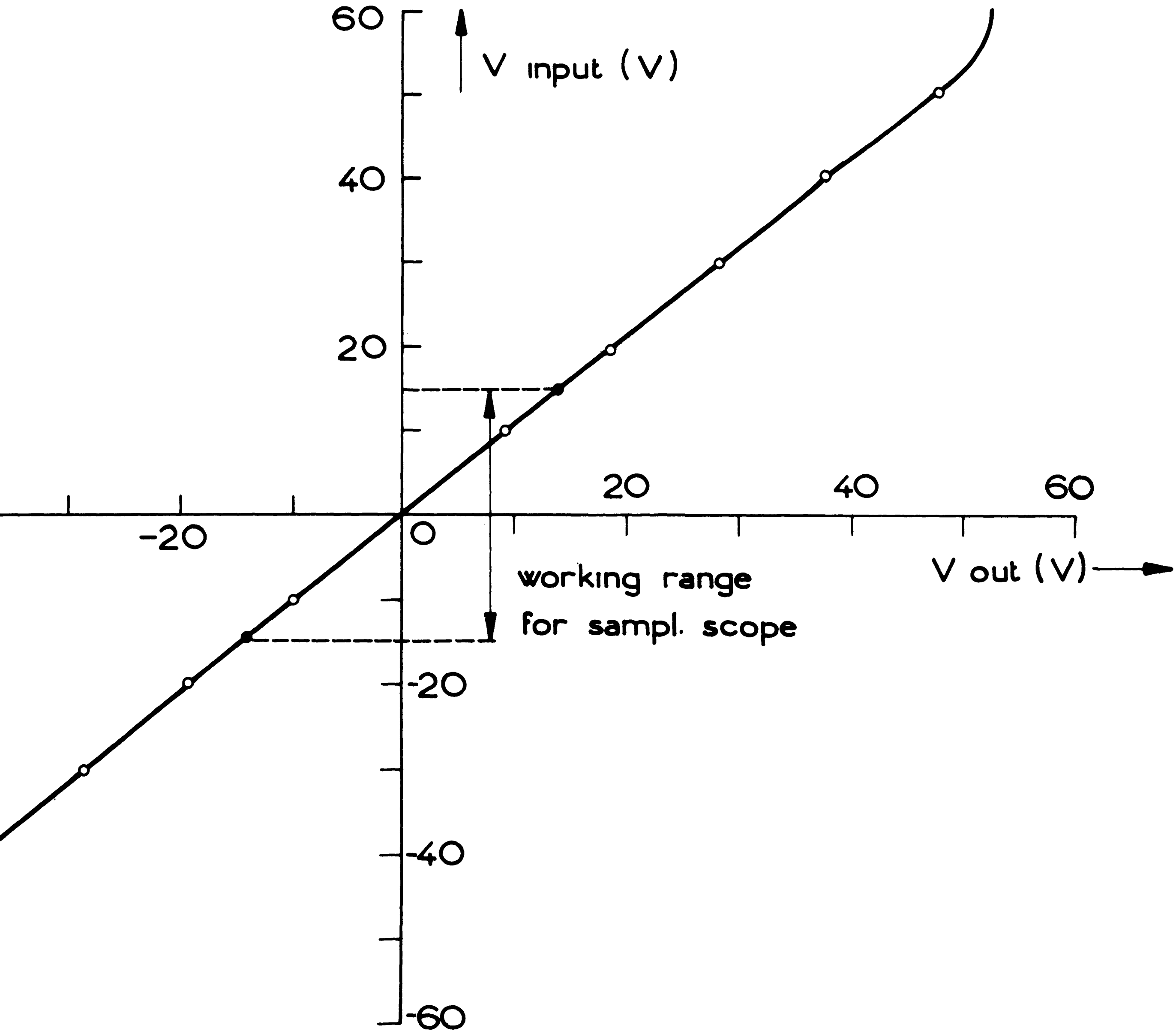


FIG. 7 Stretcher linearity

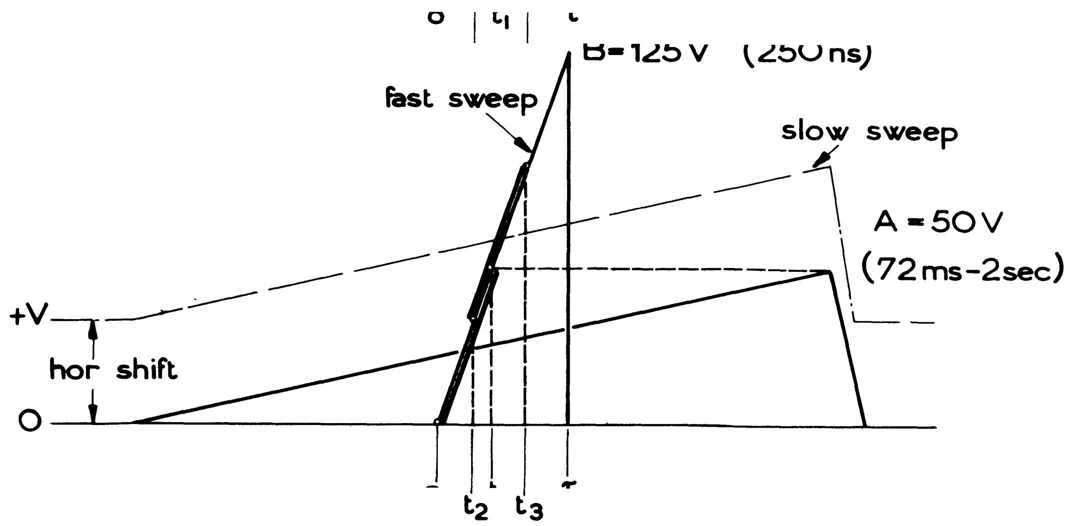
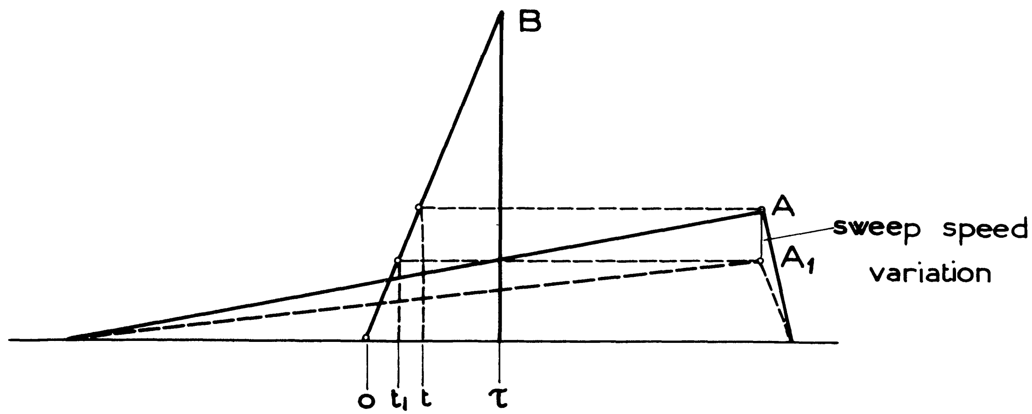
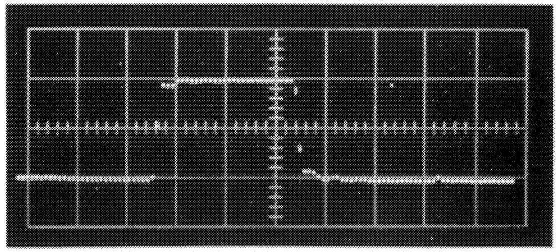


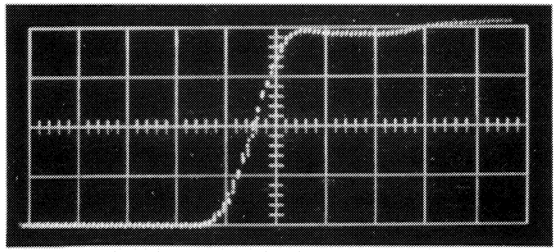
FIG 8a Horizontal shift



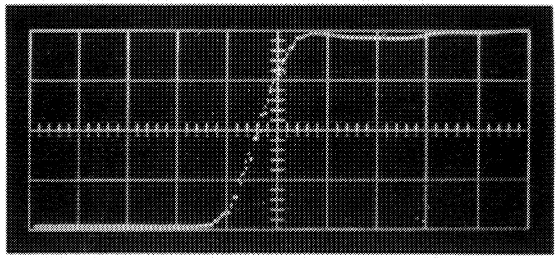
sweep speed $\frac{A}{B} \times \tau = t$



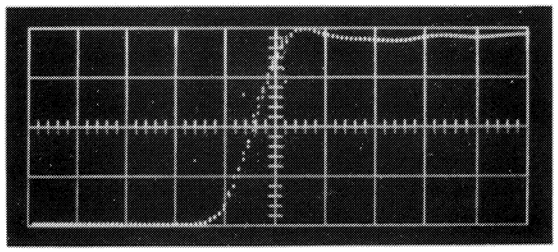
a.



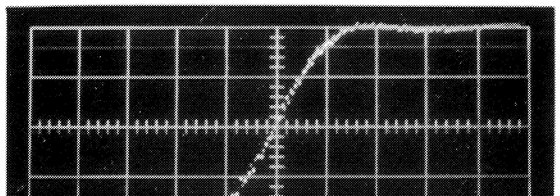
b.



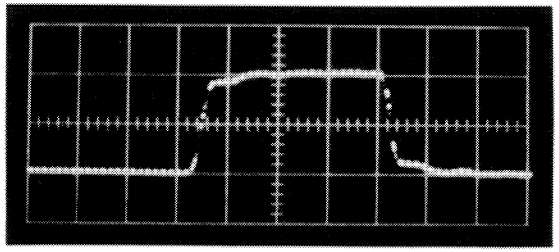
c.



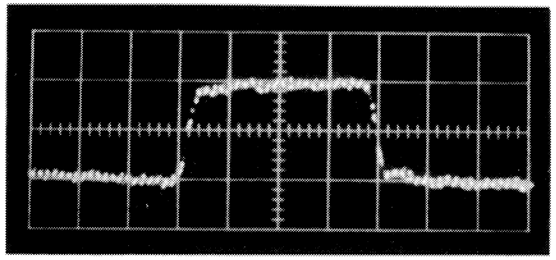
d.



e.



a.



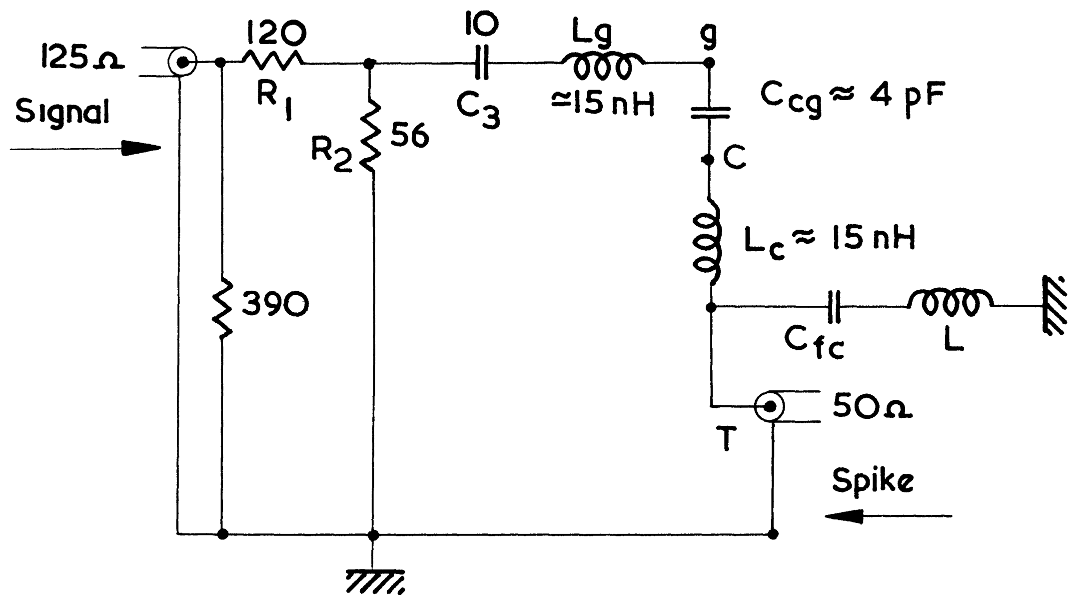
b.

Fig.10 Noise level of the oscilloscope.

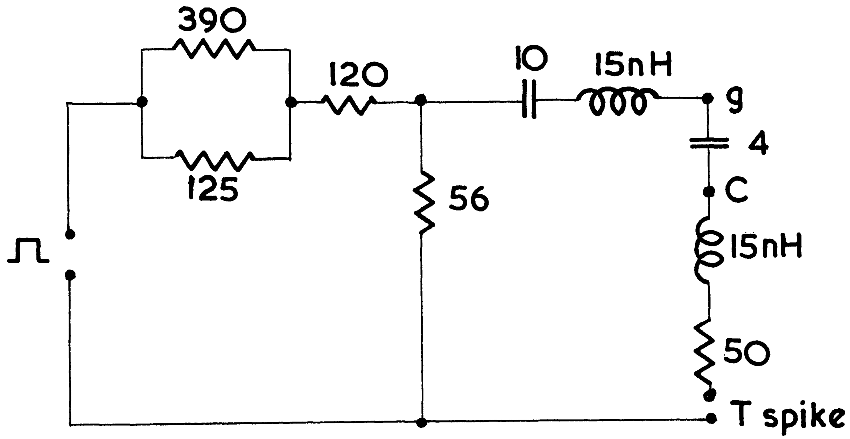
a. Vert. sens. 1 V/cm
Hor. speed 10 ns/cm

b. Vert. sens. 50mV/cm
Hor. speed 10 ns/cm

a

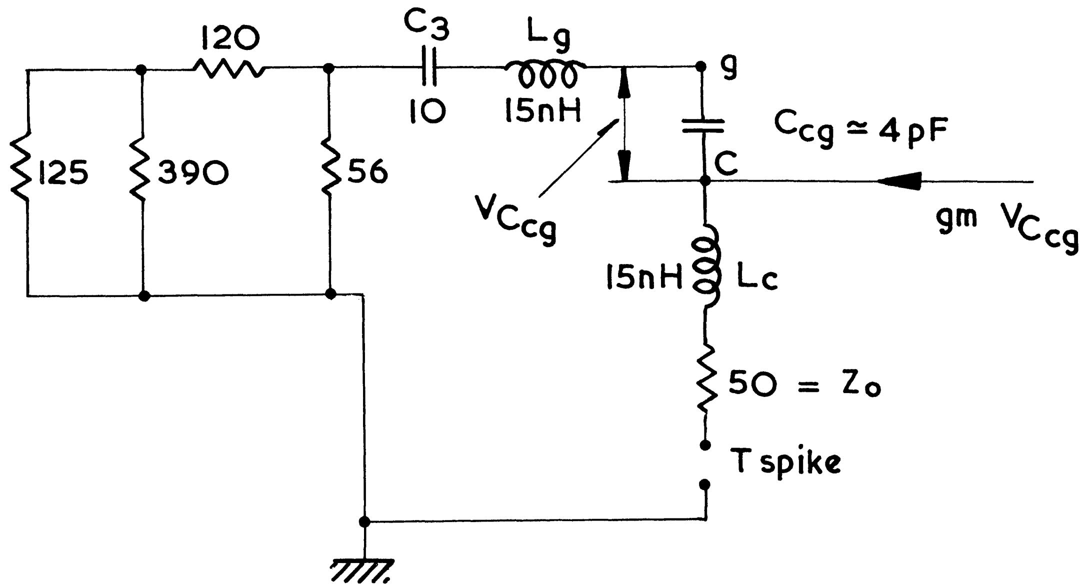

125 Ω
Signal
120
R1
56
R2
390
10
C3
Lg
≈15 nH
g
Ccg ≈ 4 pF
C
Lc ≈ 15 nH
Cfc
L
50 Ω
T
Spike

b.

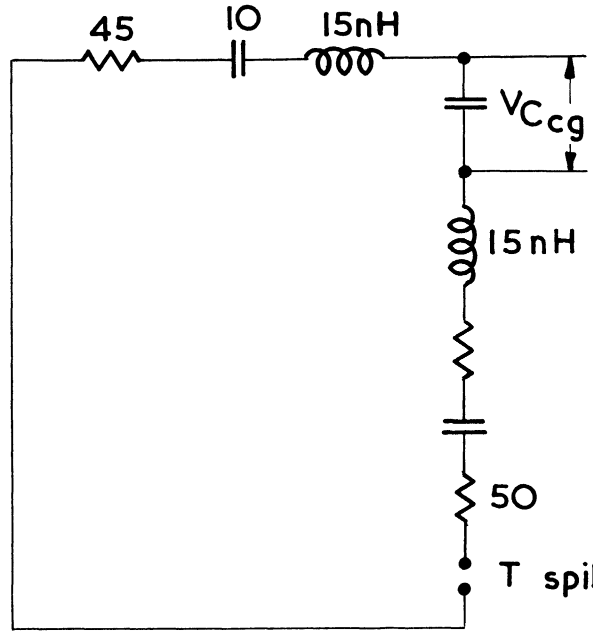

390
125
120
56
10
15nH
g
4
C
15nH
50
T spike

Vc

a.

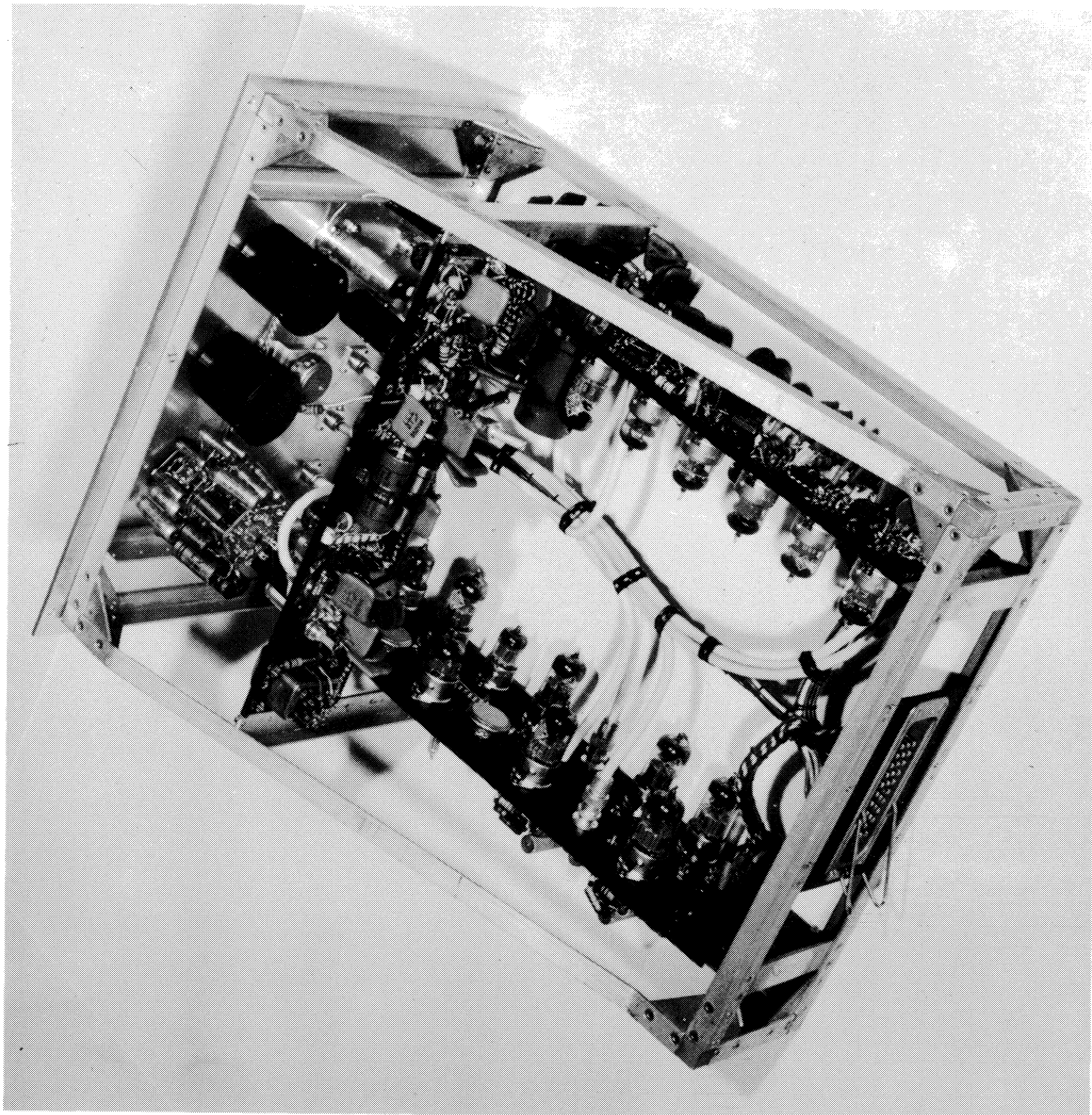


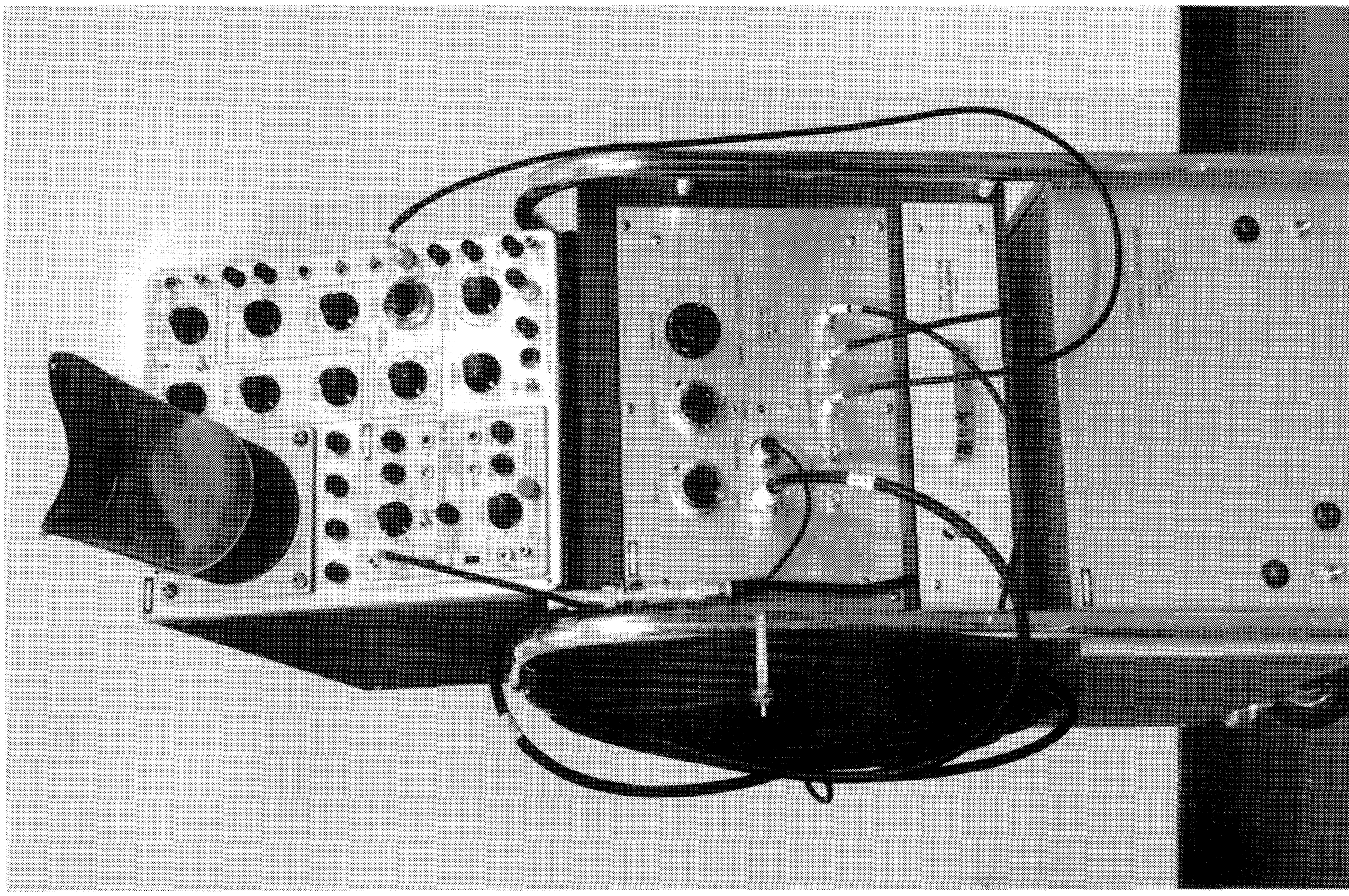
b



$$R_f = \frac{g_m L}{C_{cg}} \approx 15\Omega$$

$$C_f \quad \frac{C_{cg}}{g_m Z_o} \approx 20pF$$

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