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# INTEGRATING WINDOW AMPLIFIER

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## Summary

A pulse-measuring technique, in which pulses are measured on the basis of area rather than amplitude, is employed in the design of a pulse window amplifier. This pulse-area-integration technique is used primarily to improve linearity, reduce resolution degradation resulting from rise-time jitter, and simplify amplifier drive requirements.

## Introduction

We have developed a window amplifier which senses pulse area, rather than pulse amplitude; such an amplifier provides excellent linearity, virtual immunity from rise-time jitter modulation, system simplification, and automatic optimization of integration time.

## Problems Inherent in Window Amplifier Systems

### Rise-Time Jitter

Considerable error can be introduced into a nuclear spectroscopy system by collection-time jitter modulation of pulse amplitude. Such jitter originating in a particle detector can introduce considerable pulse amplitude modulation at the output of a connected pulse amplifier. Figure 1 displays the effects of collection-time jitter on the measurement of two identical-energy nuclear-produced events; these collection times produce dissimilar rise times in a conventional pulse amplifier system. Output amplitude comparisons for amplitude- and area-sensing methods of detection are shown in Fig. 1 (d) and (e) for the two dissimilar rise-time pulses.

As can be seen, considerable error is introduced into the output of a normal amplitude-sensing system when the input rise time varies, while none exists in the output of the area-sensing system. Figure 1 shows graphically what occurs to pulses processed in a conventional amplitude-sensing system and in an area-sensing system. In Fig. 1(a) are shown the detector output currents from two equal-energy events, one with fast collection of charge pairs or ion pairs, and the other with considerably slower collection time. Both pulses, having equal areas, will produce equal amplitudes if fed into an integrating or charge-sensitive input circuit [Fig. 1(b)]. We would like to maintain this equality in amplitude throughout our amplifier system, but such will not be the case. In order to process pulses further through an amplifier system, differentiation and integration must be provided in order to produce the best signal-to-noise ratio. In Fig. 1(c) both pulses have been differentiated (high pass filter) and will still have similar amplitudes if delay line clipping is employed and rise time is not too great.

In Fig. 1(d) the effects of integration (low pass filter) produce two pulses of dissimilar amplitude; if measured by a pulse-height analyzer, they will give two different readings.

If the same two pulses of Fig. 1(c) are, however, fed into an area-to-amplitude converter, both pulses will produce identical output amplitudes [Fig. 1(e)], providing true energy readings of the exciting events. Collection-time amplitude sensitivity can also be reduced over a limited range by either fixed integration [Fig. 2(a)] or delay line clipping [Fig. 2(b)].

To substantiate the claims made about Fig. 1 in the preceding two paragraphs, the test shown in Fig. 3 was performed. In this test, the rise times of pulses entering amplitude- and area-sensitive systems were varied by a common variable integrator. The center photograph shows very clearly the output amplitude variation produced by varying rise times ranging from 0.05 to 1.0 μsec in the amplitude-sensitive channel. This same photograph shows almost no change in the output amplitude of the area-sensitive channel for similar variations. [For easy comparison, both amplitude-sensitive (left) and area-sensitive (right) channels are shown on the same photo.] For further ease of comparison the right-hand photo shows area-sensitive channel outputs for 0.05-μsec and 1.0-μsec integration times and the left-hand photo shows the amplitude-sensitive channel outputs for similar integration times.

### Linearity

Aside from the usual nonlinearity problems plaguing amplifier circuits, most window amplifiers exhibit two additional problems, which can cause considerable measuring error. These problems are the nonlinearities arising from (a) poor transfer characteristics of the threshold determining elements, and (b) pulse-shape change occurring within the window range. These effects are depicted in Fig. 4, where nonlinearity of a threshold-determining diode introduces severe nonlinearity into the window amplifier output. Transistors and vacuum tubes having similar nonlinearities, when used for threshold determination, can also produce serious nonlinearities over the desired amplitude range.

Many schemes have been employed to minimize the nonlinear characteristics of threshold-determining

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elements. These schemes have avoided the nonlinear characteristics of the threshold-determining device by gating, or feedback lockout of the near threshold region,[1,2] or by driving the nonlinear threshold-determining element from a current source.[3]

Figure 4(b) shows how nonlinearity arises, after threshold determination. Pulses falling within the window range can vary considerably in width, especially at large expansions, since only the peaked tops of the driving pulses protrude above the threshold level. Within the window range, pulse widths can vary from extremely narrow near threshold to considerably wider at upper window levels.

The pulse-shape-sensitivity characteristics of the conventional pulse-height analyzer produce considerable nonlinearity because of this pulse-width change within the window range. In order to improve linearity in the presence of pulse-width variation, pulse broadeners have been widely employed.[3]

## Linearity Advantages of Pulse-Area Sensing

The scheme chosen to analyze pulses on an area basis makes it possible to eliminate both these causes of basic window amplifier nonlinearity. The technique of area sensing chosen permits the employment of completely linear circuitry for threshold determination, and produces output pulses of constant width and shape throughout the window range. Excellent linearity in threshold determination is afforded by the pulse subtractive method employed. Referring to Fig. 5, note that only fixed and linear elements are employed for threshold sensing. Pulse shape and width variations within the window range are also eliminated by sampling the integrator's and subtract generator's difference dc output voltage, following input pulse acceptance, by means of a programmed fixed-width linear gate.

Linearity comparisons of a conventional amplitude-sensitive window amplifier and an area-sensitive window amplifier, both with an expansion gain of 20, are shown in Fig. 6. The linearity improvement afforded by the area-sensitive technique is quite apparent. I do not imply that this poor linearity performance is typical of all amplitude-sensitive window amplifiers, but it does represent that of a unit in almost universal use at LRL and in wide use elsewhere. This pulse subtractive method of threshold determination can also be applied directly to an amplitude-sensitive window amplifier.

## System Simplification and Automatic Equalization

A nuclear pulse processing system is considerably simplified by the employment of an area-sensitive window amplifier. Since there is no need for prior integration, the same driver amplifier can be utilized more efficiently for processing pulse-timing information, as shown in Fig. 7. Also since integration and differentiation are automatically equalized, there is no need to provide this addition function in the amplifier system.

## Circuit Details

The block diagram of the integrating window amplifier is shown in Fig. 8. Incoming signals simultaneously drive signal and logic circuitry. A delay of 0.1 μsec in the signal circuit allows initiation of the logic sequence prior to signal arrival at the integrator input. If incoming signals are sufficiently large to trigger the Schmitt discriminators, logic sequences are initiated. Two Schmitt discriminators are provided to ensure complete overlap of input-signal-time width by the input-signal gate.

This overlap is provided by feeding both Schmitt discriminator outputs into an "OR" gate, which in turn provides control for the signal-gate driver. Whenever the Delay Schmitt discriminator is triggered, the trailing edge of this circuit's output pulse is differentiated and used to trigger the "READ" one shot. This read one shot in turn drives the read-gate driver, and mixes in another "OR" gate with the input-gate signal to provide the appropriate enable-gate drive signal for the integrator and the subtract generator.

Thus three gate-drive signals are developed with the following relationship: first, an input signal gate just overlapping the input signal; second, a read gate just following the disappearance of the input signal gate and having fixed width; and third, a subtract-pulse generator and integrator enable gate which overlap both signal and read gates.

Each input signal, while initiating logic sequences, arrives simultaneously at the input of the gated integrator (after passing through 0.1 μsec of delay line, a buffer-inverter amplifier) and a signal gate which has just opened. The integrator that has been enabled by the logic sequence charges from the signal pulse just arriving at its input.

As the signal pulse terminates, both Schmitt discriminators drop out, locking the signal gate and preventing further signal and noise entry. The integrator, having reached its charged condition, holds this information as a dc potential until the enable-gate signal disappears. This disappearance follows the read cycle and provides resetting for the integrator. Simultaneously with the opening of the integrator-enable gate, a negative-subtract-generator pulse of fixed accurate amplitude is also developed. This subtract generator pulse and the integrator-output pulse are fed simultaneously into a difference amplifier in order to develop the effective threshold cut. The difference and output amplifiers also provide the desired expansion gain and output drive capabilities. The subtract-generator-output amplitude chosen determines the amount of threshold cut, and the read gate provides signal sampling after the input-signal pulse disappears.

## Integrator

Probably the most crucial circuit of the entire area-sensitive window amplifier is that of the

Gated Integrator. This Integrator must gate on and off rapidly, on command, and must be extremely linear and stable. In order to provide rapid gating, the scheme shown in Fig. 9 was adopted. This is for an integrator having two time constants controlled by gating. A fractional-microsecond fundamental-time constant is provided in the integrator by RC feedback elements in the feedback circuit of an operational amplifier. Provision is made for locking out of the resistive feedback component by locking the center point of the resistive feedback element to ground. This immediately increases the Integrator's time constant to infinity, making it a true integrator. In order to provide good thermal stability and to minimize unwanted feedback to the input transistor's base, a dual cascode input employing transistors $Q_1$, $Q_2$, $Q_3$, and $Q_4$ is employed. Transistors $Q_5$ and $Q_6$ provide both current gain and low integrator-output impedance; zener diode $Z_1$ serves as a level shifter and $Q_7$ and $Q_8$ form a double-shunt feedback gate.

Since the integrator is dc coupled from the signal gate to minimize rate sensitivity, a balance voltage to the balance side of the integrators input must be provided through $R_1$ to maintain a balance for the dc potential existing between gate and input base. Some output signal feed through to input base is present in the feedback gate, and is balanced out by $R_2$ which feeds a portion of the output signal to the balance side of the input circuit.

## Pulse-Width Sensing

Since noise modulation of the input signal is dependent upon band width, the Integrator's acceptance time is restricted to just slightly greater than the input pulse time. This is somewhat analogous to differentiation in the conventional amplitude-sensitive system. If fixed rather than dynamic timing were employed, some sacrifice in noise performance would have to be made in order to realize overall resolution improvement in the presence of collection-time jitter. Dynamic timing of the input gate allows the optimum time for each individual pulse for best overall energy-resolution performance. Figure 10 displays the scheme employed to accomplish dynamic timing. A prompt Schmitt Discriminator assures "on gating" just prior to signal arrival from the input delay line and inverting amplifier. The delay Schmitt Discriminator assures that the gate will remain open until the delayed input pulse disappears from the integrator's input. The Schmitt Discriminators employed are of low hysteresis design to ensure reliable "Off" and "On" triggering to 100 mV so that the entire area of all pulses will be seen by the integrator. Transistors $Q_1$ and $Q_2$ form the basic Schmitt trigger circuit and $D_1$ provides memory of the original emitter voltage for effective trigger pair turn off with low hysteresis.

The OR Gate provides only for mixing of the Prompt and Delay signals to develop the signal gate.

## Gating Circuits

Double shunt gates are provided for all gating operations. The circuit of a typical gate is shown in Fig. 11. Diodes, base emitter circuits, and capacitors in the base circuits of gate transistors $Q_1$ and $Q_2$ reduce turn-on and turn-off spikes. The other transistor $Q_3$ in the base circuit of $Q_2$ generates opposite-polarity drive pulses which cancel feed-through spikes passing from bases to collectors of $Q_1$ and $Q_2$. Normally the signal and Read gates are gated off by driving current into the bases of the shunting transistors. The integrator enable gate, however, is normally gated on.

## Other Circuit Detail

Logic circuits are quite conventional, as they include discriminators, a one shot, OR gates, a subtract pulse generator, inverters, and gate driver circuits. Amplifiers are also quite conventional, as they include operational amplifier loops with the output stage having complementary emitter follower output for low-output-impedance drive capability. Waveforms of logic and signal circuits are shown in Figs. 12-15. Figures 12 and 13 show circuit waveforms with 1-μsec delay line clipped, 05-μsec integration-time input signals, while Figs. 14 and 15 show those with 1-μsec delay line clipped, 1-μsec integration-time input signals.

## Conclusions

The area-sensing method of pulse analysis drastically reduces error produced by rise-time jitter modulation, provides excellent linearity in window amplifiers, allows for reasonable circuit simplification, and automatically equalizes Differentiation and Integration times. Signal-to-noise performance appears to be equal to that of the conventional amplitude-sensing systems.

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2. T. L. Emmer, "Nuclear Instrumentation for Scintillation and Semiconductor Spectroscopy," IRE Trans. of Nuclear Science, NS-9, pp. 311-312, June, 1962

3. R. N. Larsen, "Transistor Biased Amplifier Utilizing Current Techniques," Nucl. Instr. Methods, vol. 32, pp. 147-151, January, 1965.

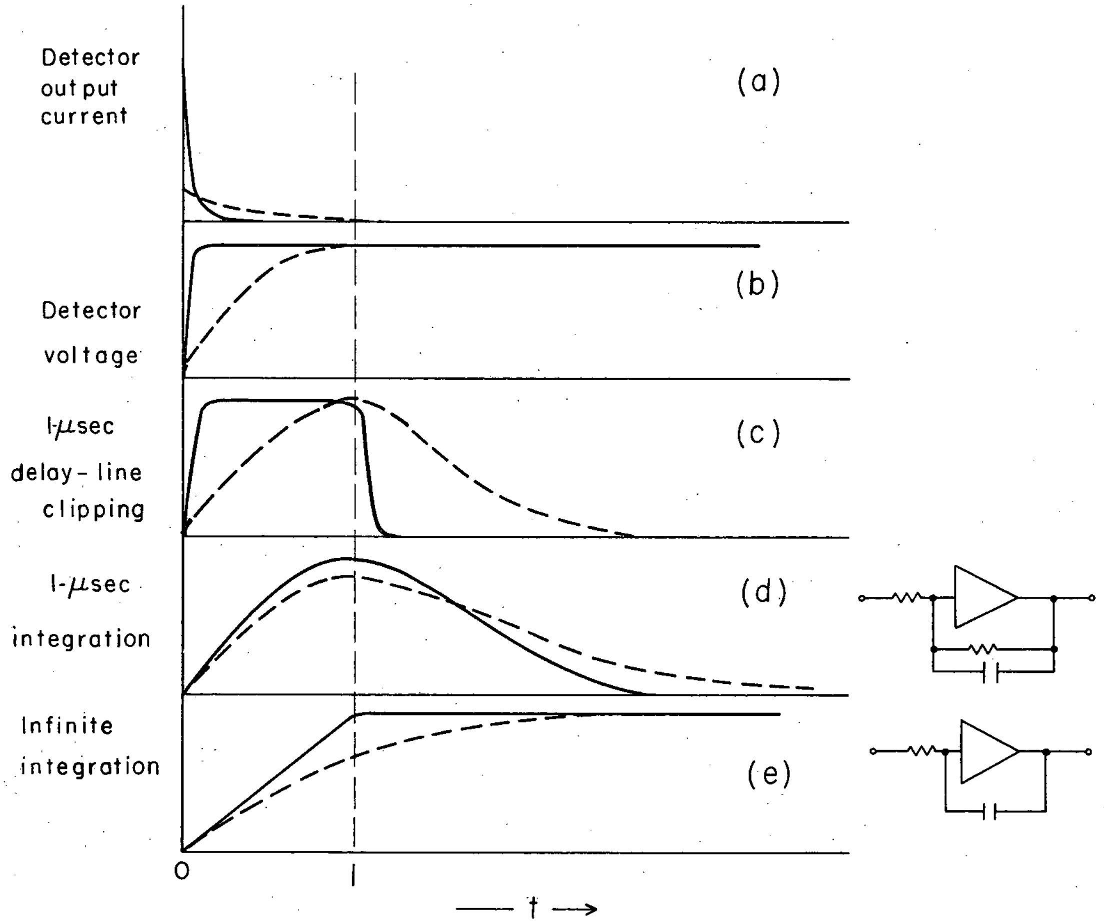

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Fig. 1. Amplitude area-sensing comparisons.

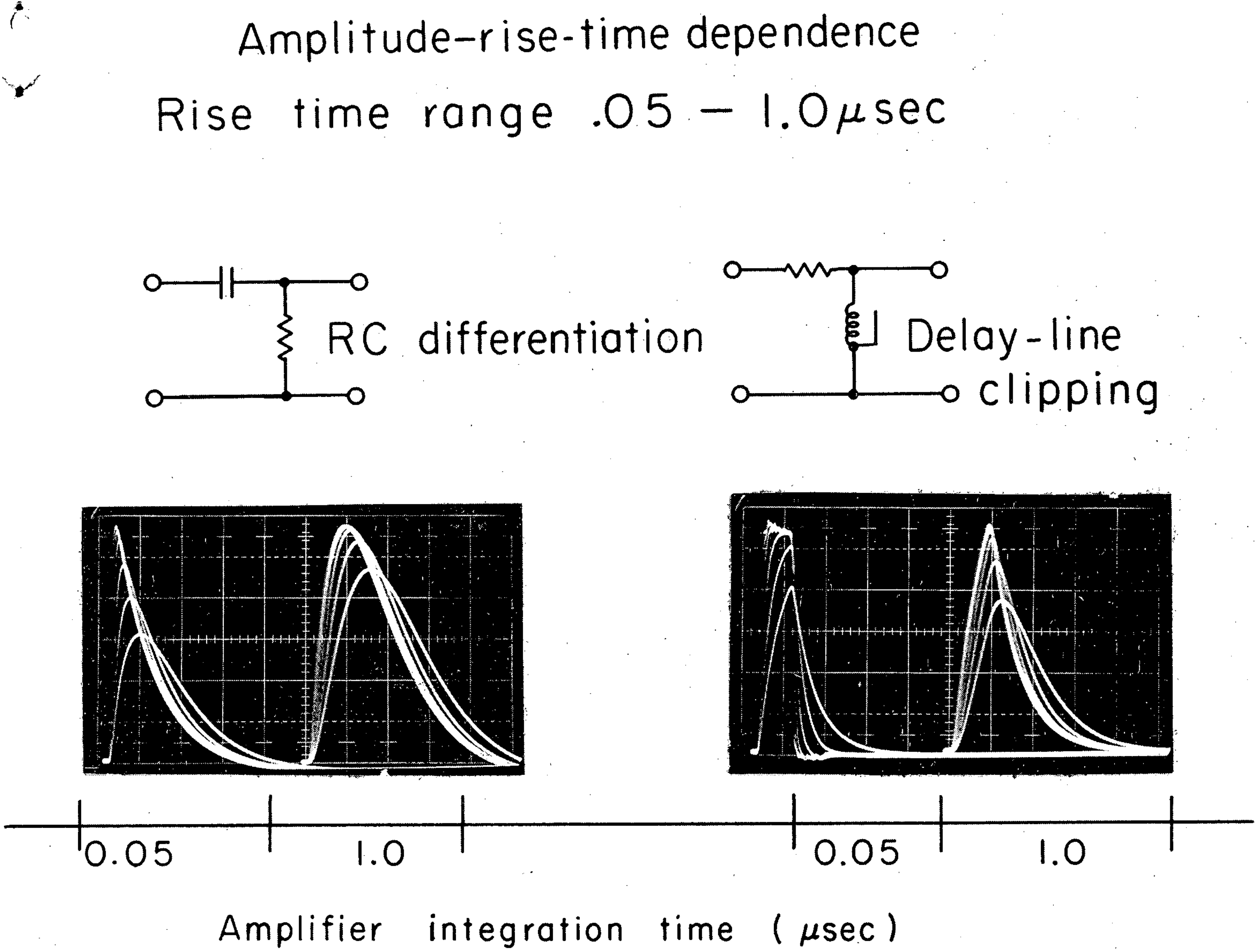

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Fig. 2. Amplitude rise-time dependency.

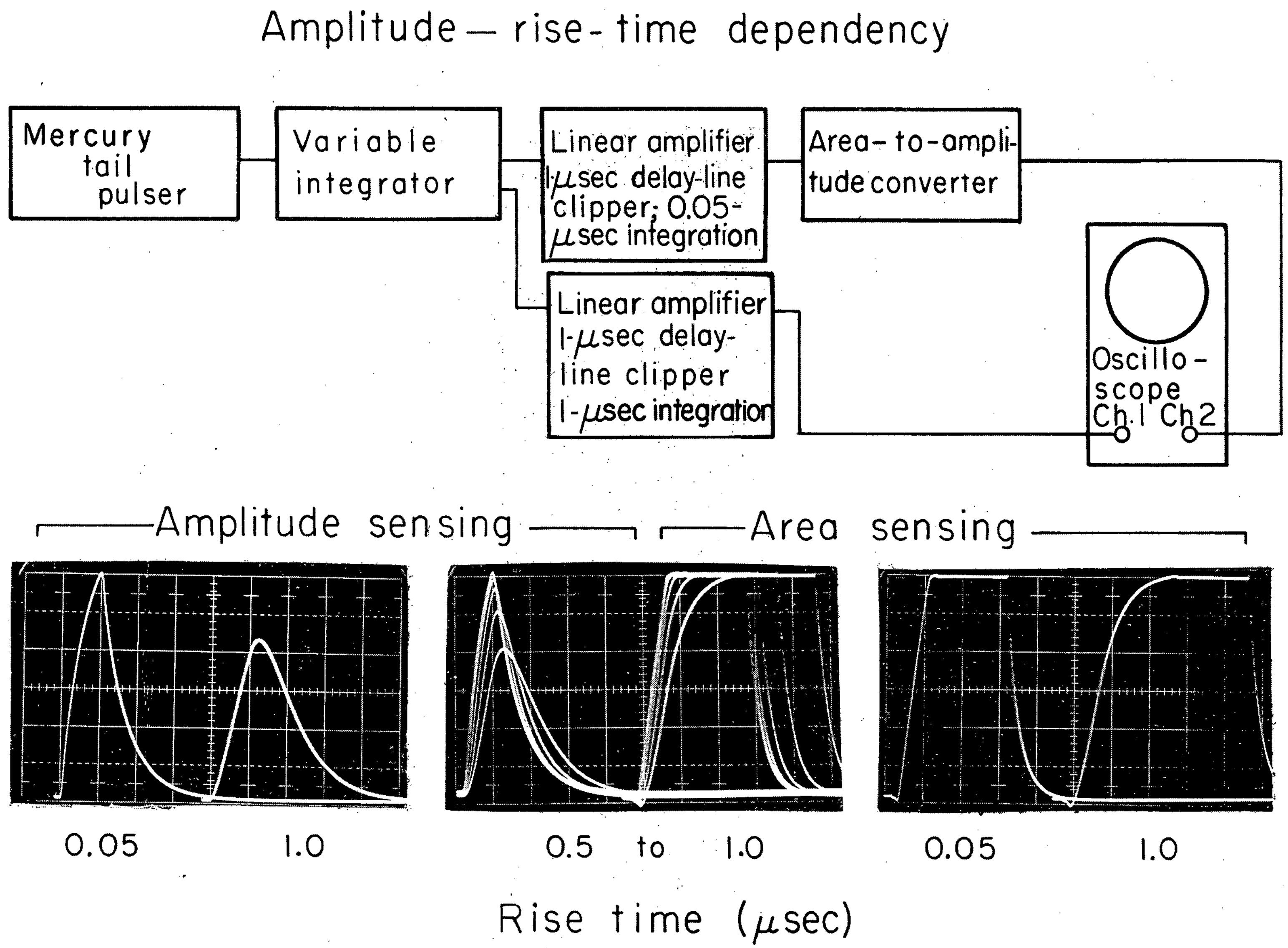

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Fig. 3. Comparing amplitude and area sensing.

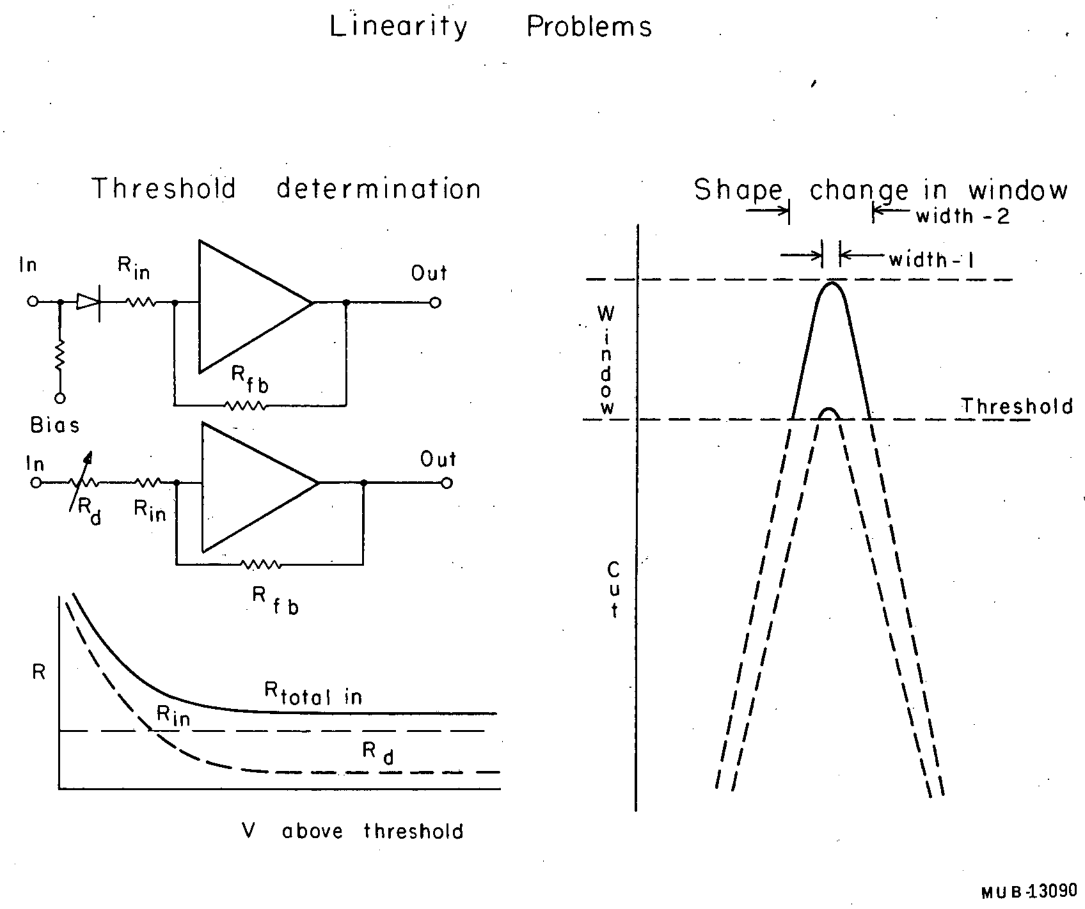

Fig. 4. Window amplifier linearity problems.

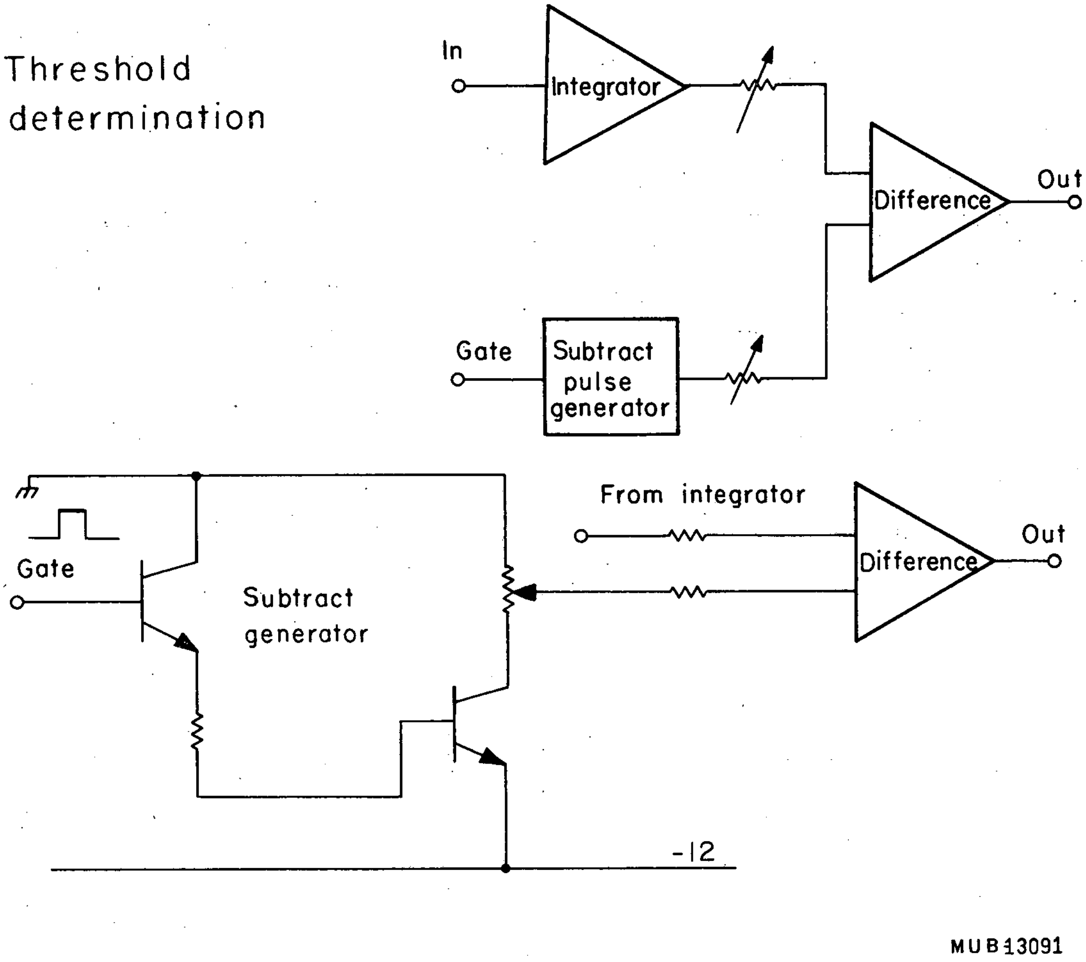

Fig. 5. Threshold determination.

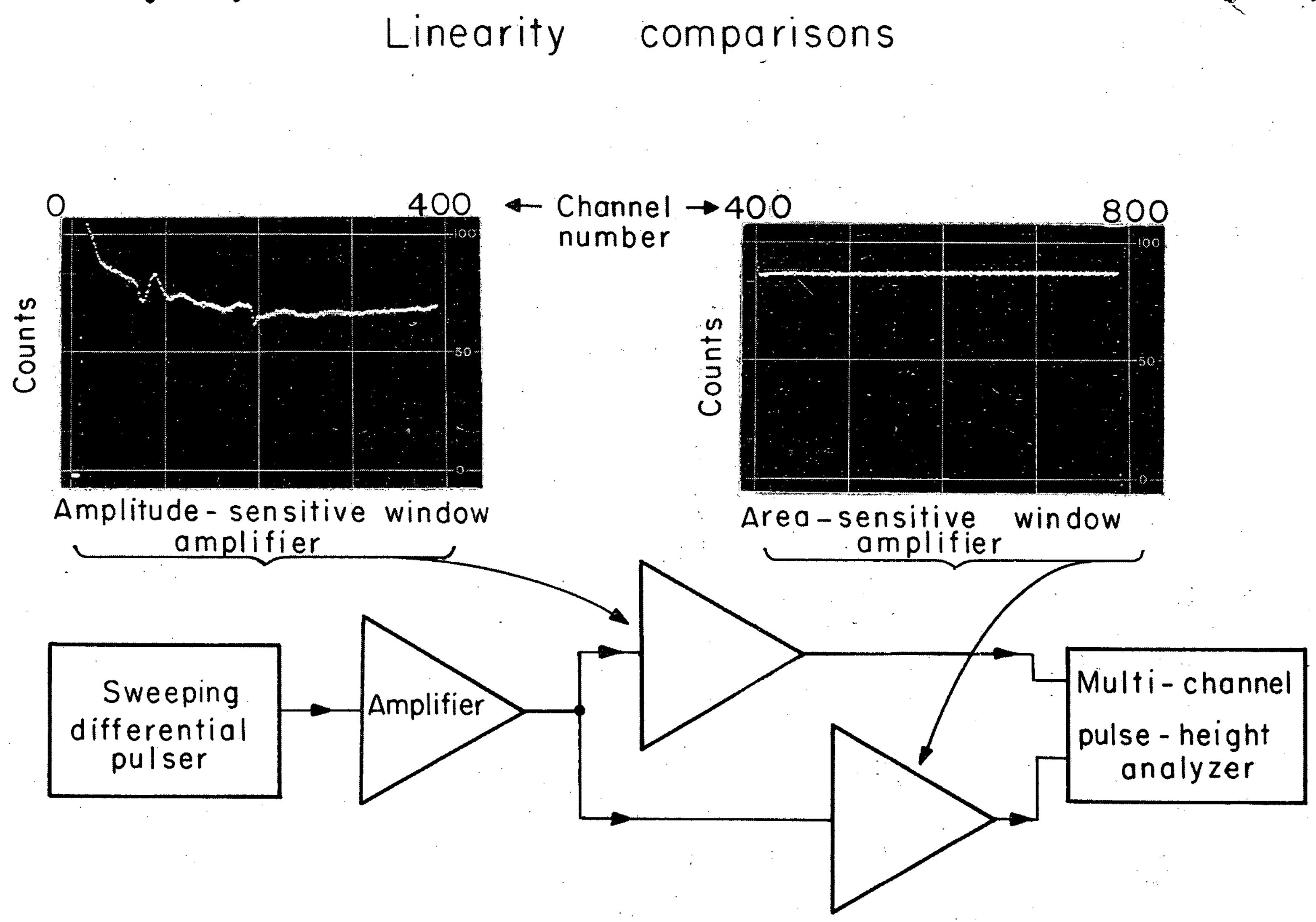

Fig. 6. Linearity comparisons. Window expansion = 20; window-amplifier input = 7.5 to 8 V; window-amplifier output = 0 to 10 V. A SCIPP-1600 analyzer is used.

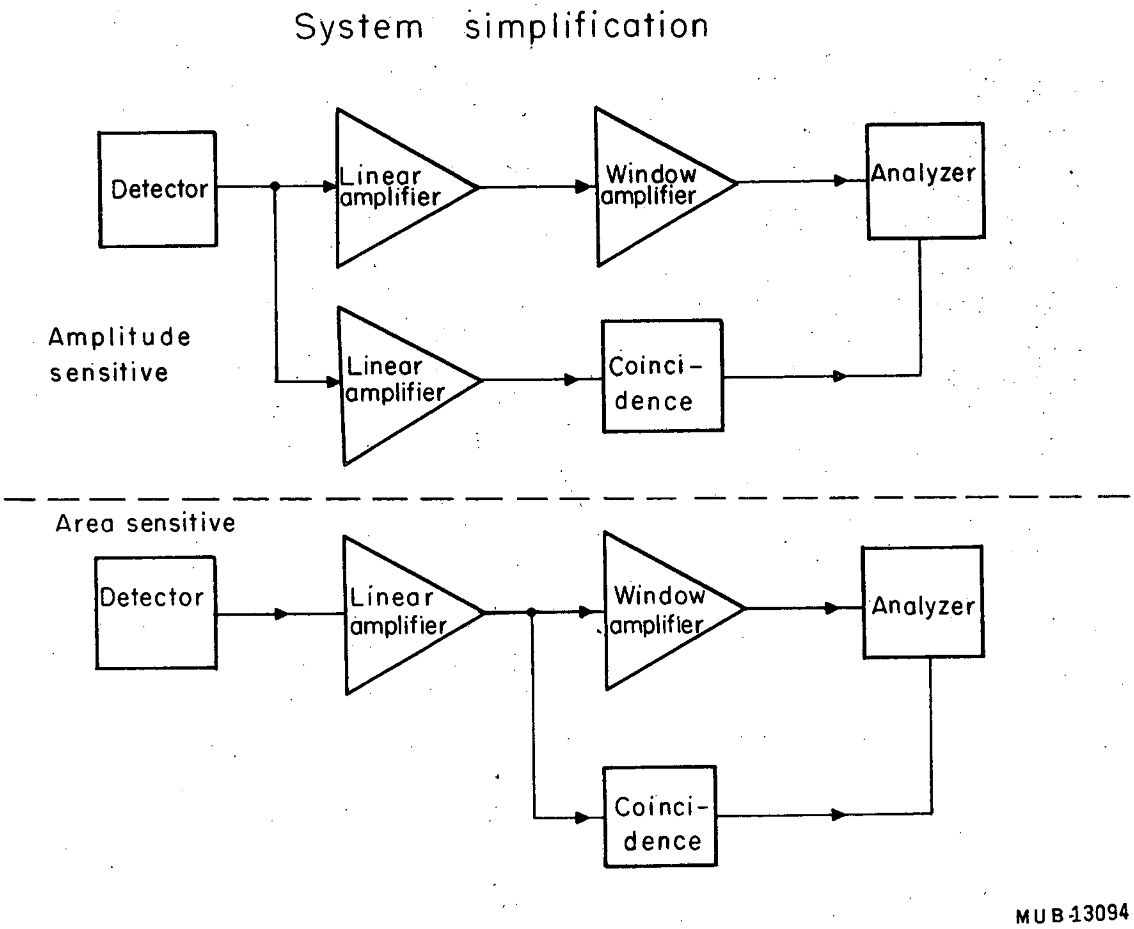

Fig. 7. System simplification.

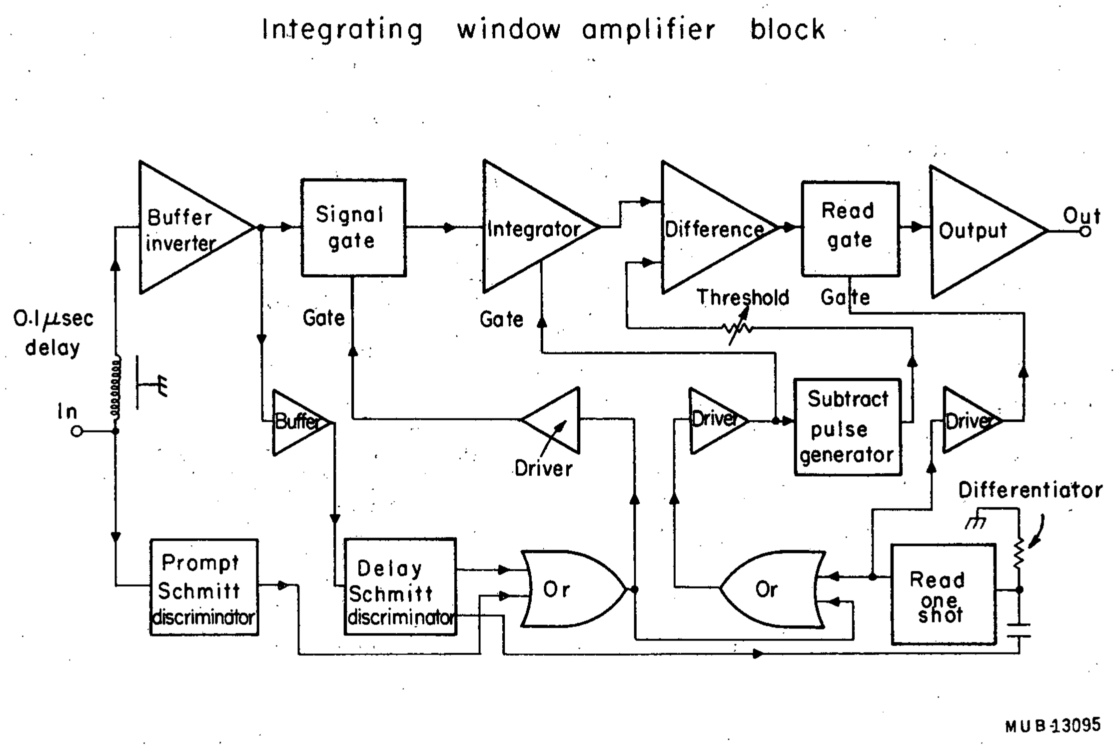

Fig. 8. Block diagram of integrating window amplifier.

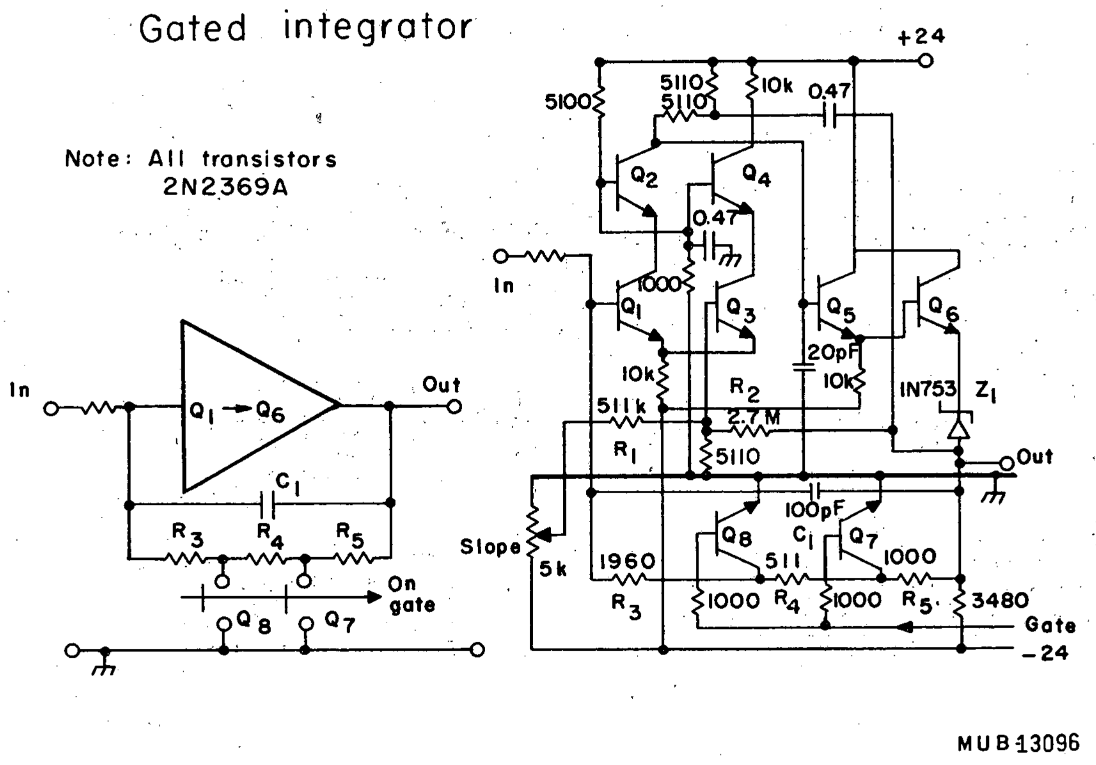

Fig. 9. Gated integrator circuit. All transistors are 2N2369 A.

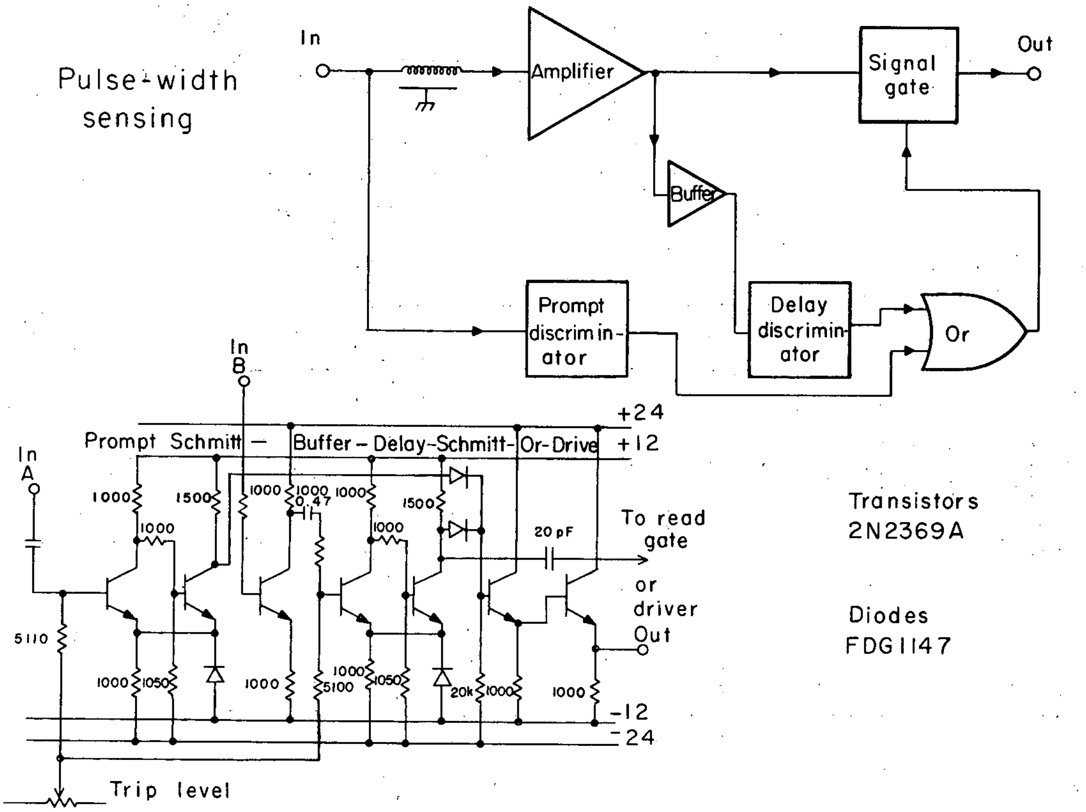

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Fig. 10. Pulse-width sensing.

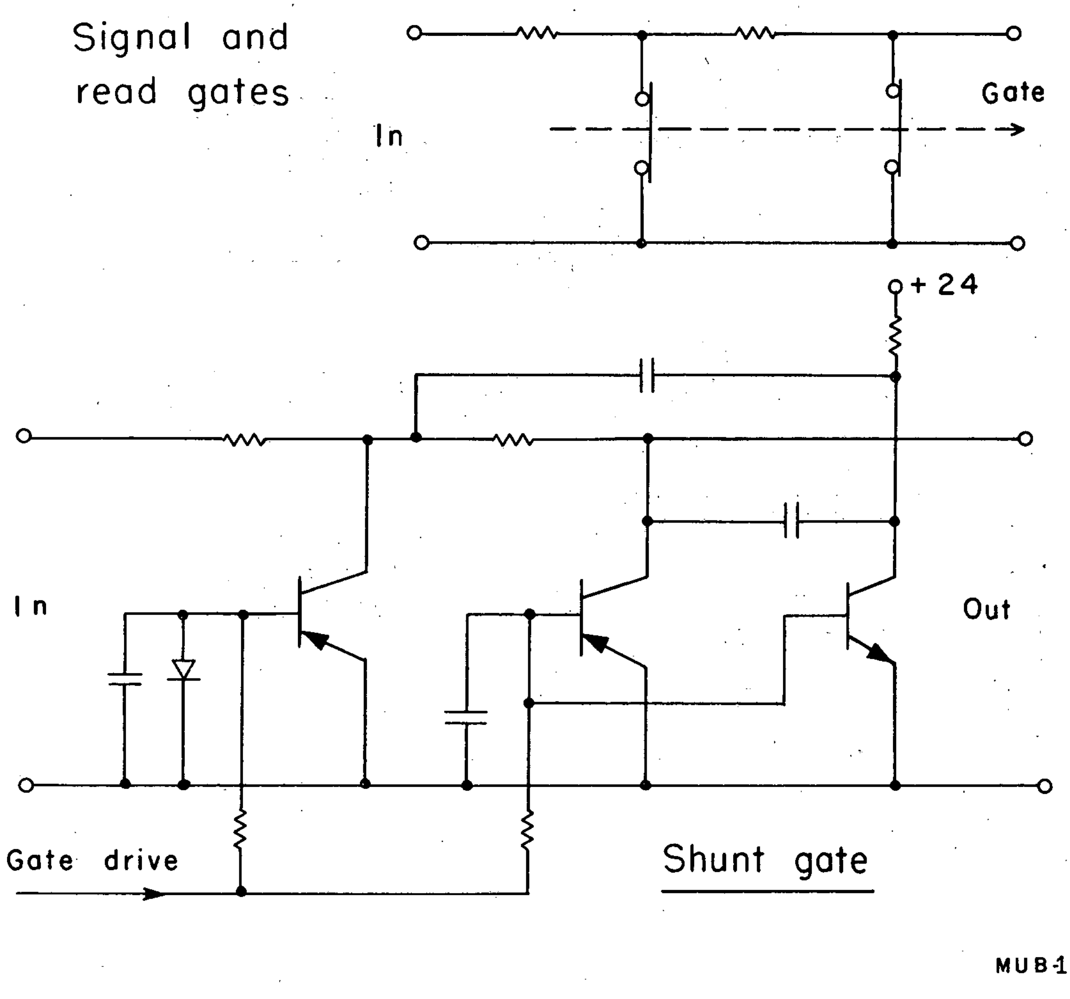

Fig. 11. Signal and read gates.

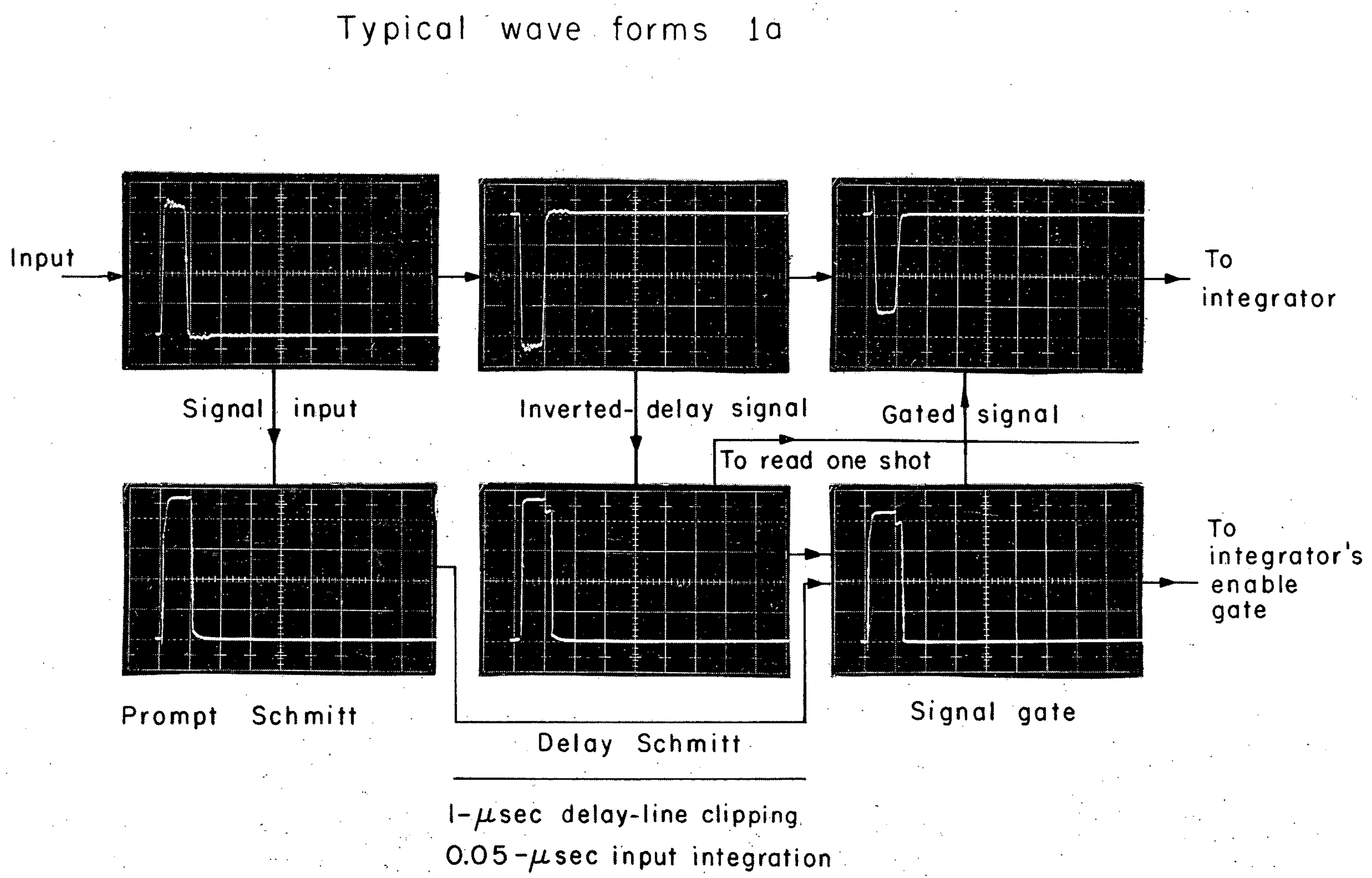

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Fig. 12. Waveforms (1 through 6) with 0.05-μsec input rise time.

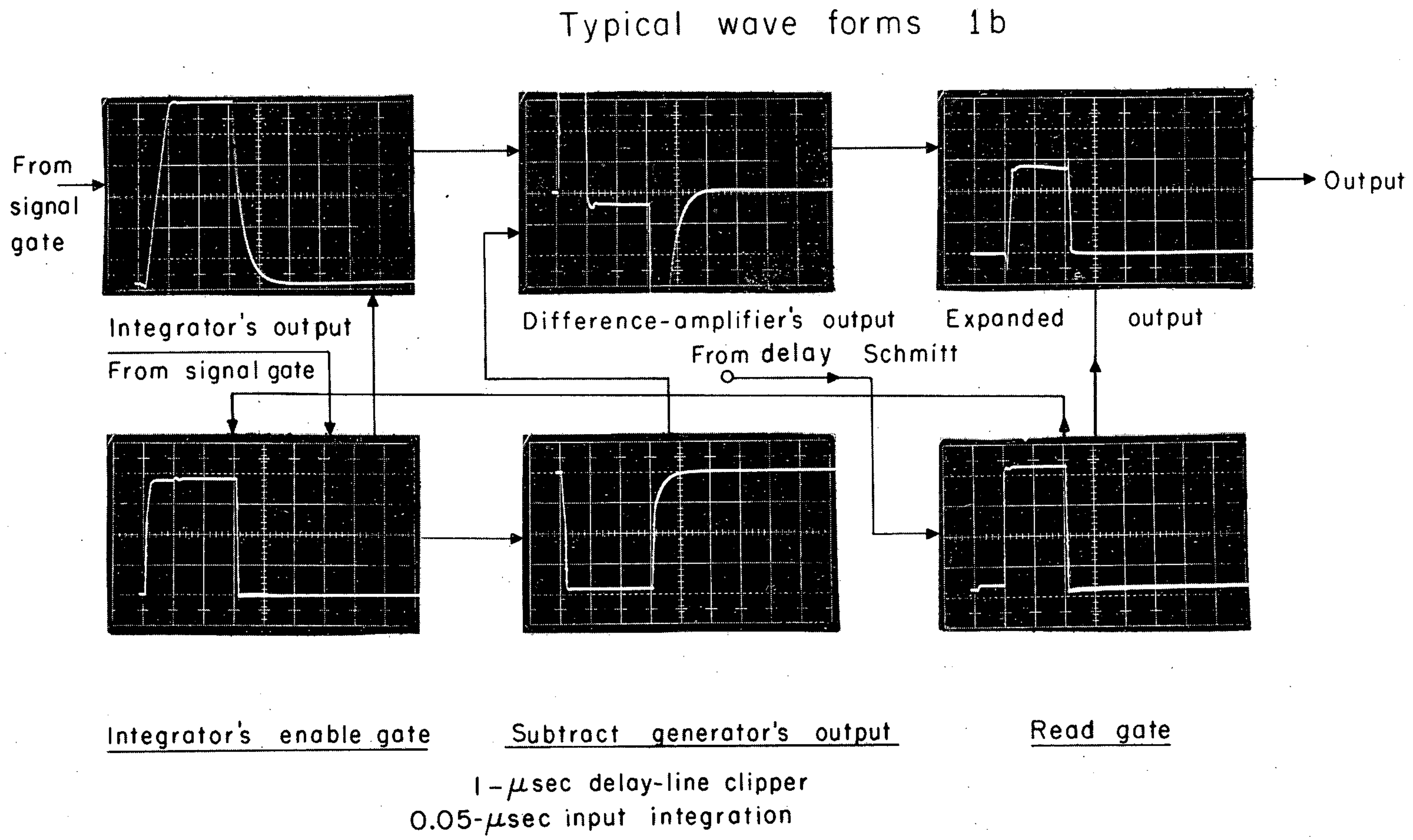

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Fig. 13. Waveforms (7 through 12) with 0.05-μsec input rise time.

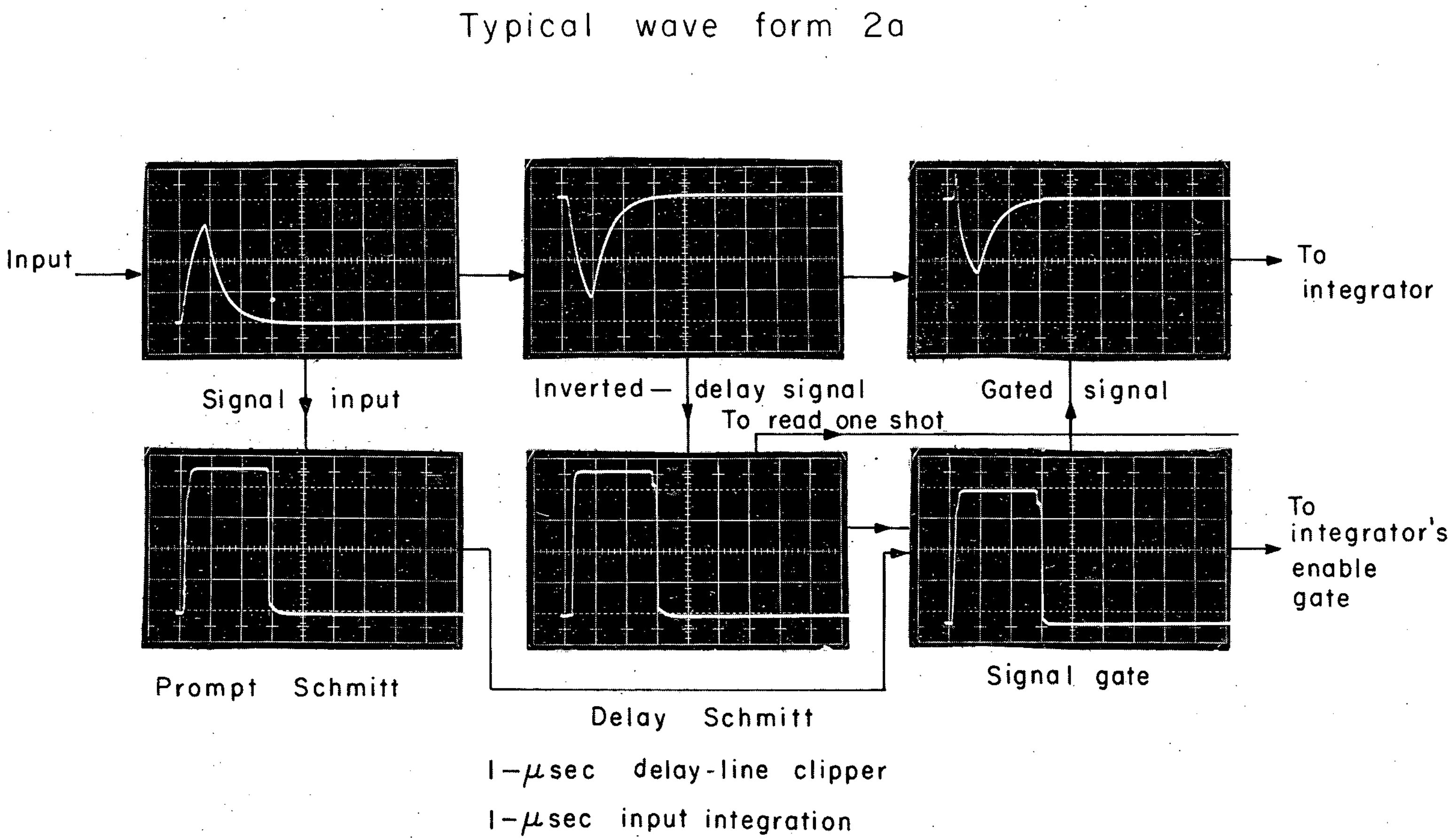

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Fig. 14. Waveforms (1 through 6) with 1.0-μsec input rise time.

Typical wave form 2b

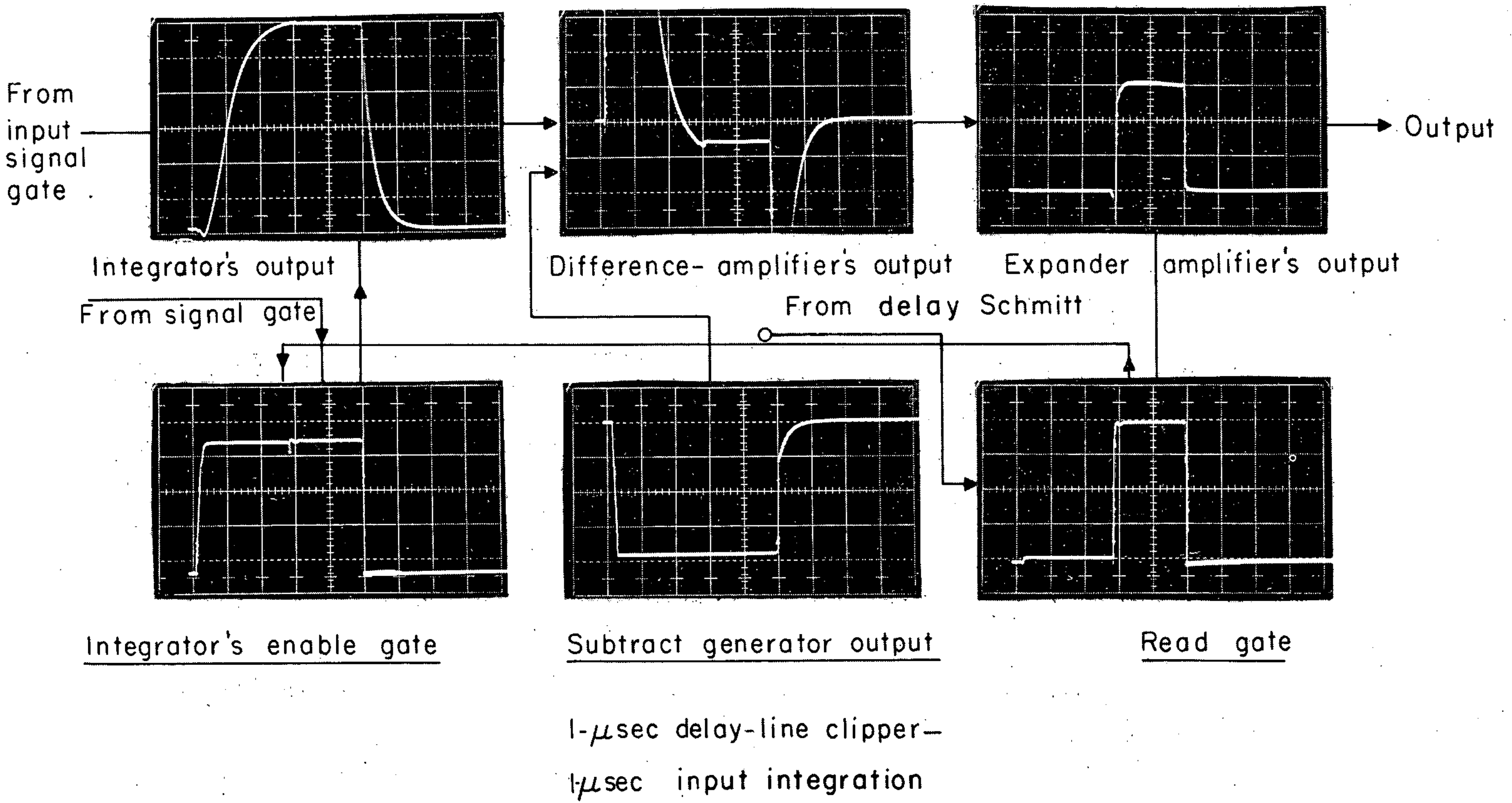

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Fig. 15. Waveforms (7 through 12) with 1.0-μsec input rise time.

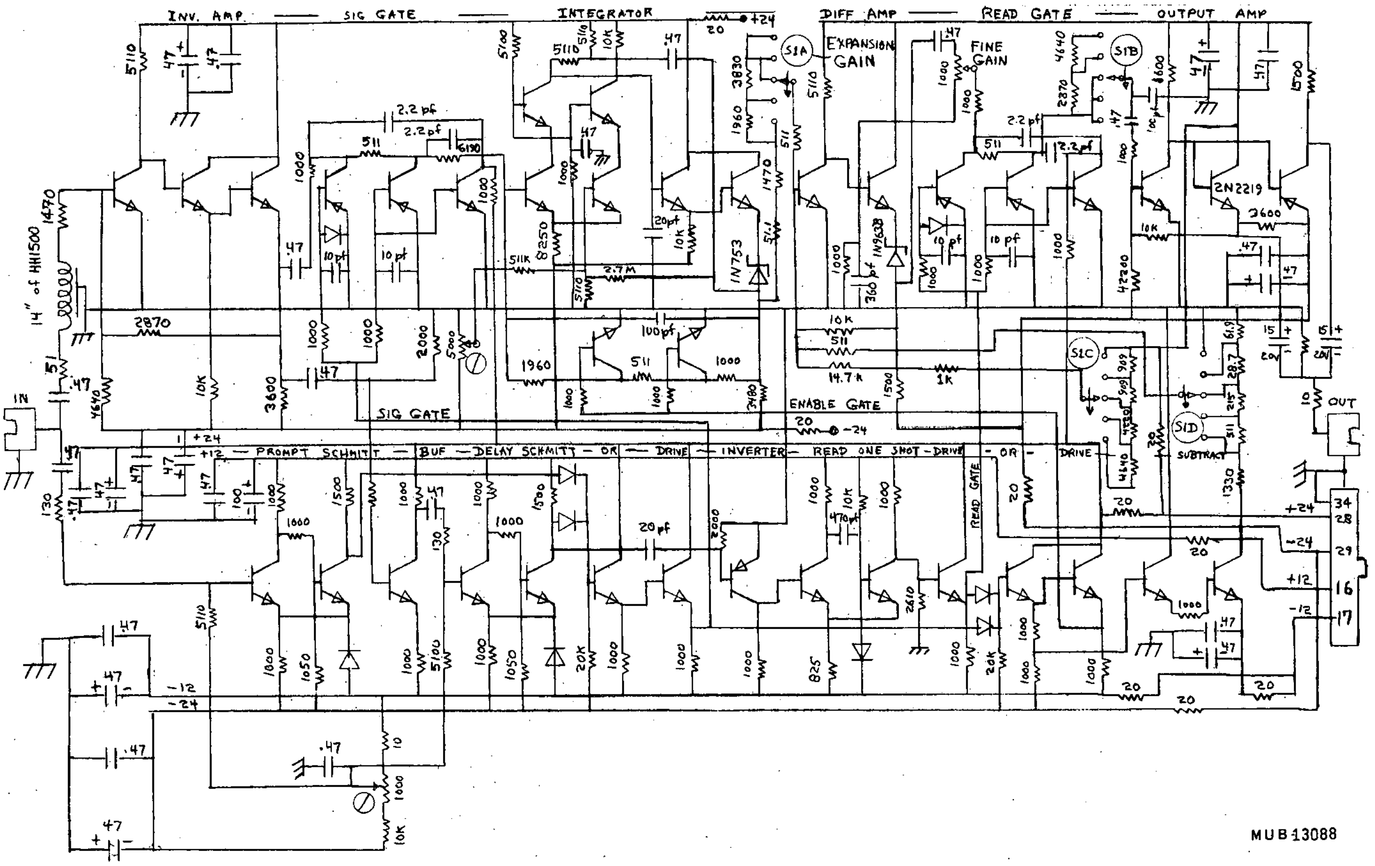

Fig. 16. Schematic of integrating window amplifier.