

Random Sampling Oscillography

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Summary—A description is given of a sampling oscilloscope technique in which the sampling pulse recurrence rate is not in any way synchronized with the signal waveform. The technique eliminates the need for a signal channel delay line. An experimental system which employs only semiconductor devices is described, and experimental data demonstrating the practicality of the system is presented.

INTRODUCTION

AN INSTRUMENT has been developed to demonstrate the practical realization of a sampling system oscilloscope in which the sampling and signal pulses are not held in a synchronized relation with respect to time. The specific instrument described in this paper has a relatively limited bandwidth because of the components chosen for the sample pulse generation and the sample head construction. The principles of this technique, the random sampling technique, are demonstrated in this unit; furthermore, construction of a random sampling oscilloscope employing current state-of-the-art bandwidth components will yield bandwidths as good as, or better than, current state-of-the-art conventional sampling systems.

Significantly, in addition to its random sampling feature, the random sampling technique has the decided advantage of eliminating the need for a signal delay line in the vertical channel.

The random sampling technique allows a *periodic* sampling pulse generator to be used for observing an *aperiodic* recurrent signal. This means that sinusoidally driven pulse generators which achieve their sharpness by virtue of periodic excitation can be employed as sampling pulse sources for observing aperiodic recurrent signals. For example, by using sampling pulses derived from the periodic klystron pulse generator reported by Cornet and Josenhans¹ in conjunction with suitable random sampling technique circuitry, it should be possible to obtain sampled oscillographs of one nanosecond wide aperiodic recurrent pulses. From the klystron pulse generator, one would have extremely sharp pulses occurring at a 100 Mc repetition rate.

As a second example, one should also be able to derive a periodic sampling waveform from the periodic

excitation of nonlinear transmission lines.²

Of equal or perhaps greater importance is that the random sampling technique eliminates the need for an input signal delay line. In particular, with the elimination of the input signal delay line, the input impedance could be increased while the delay line bandwidth limitation would be eliminated.

RANDOM SAMPLING TECHNIQUE

General Description

In the ordinary sampling oscilloscope, samples of the signal waveform amplitude are extracted at successively delayed points in time with respect to the start of the signal waveform. The resultant CRT display then consists of an orderly plotting out of the signal waveform by a uniformly spaced succession of finely focused spots; hence, the spots occur in a periodic manner, one after another in increasing time, the spacing between each spot being constant and representing a fixed time in the signal time domain.

On the other hand, in the random-sampling oscilloscope, samples of the signal waveform amplitude are extracted at random points in time with respect to the start of the signal waveform.

The random-sampling technique determines the signal amplitude information by sampling the signal waveform with the usual sampling devices. However, the time position (with respect to the start of the signal waveform) of a given amplitude sample is determined by measuring the elapsed time occurring between the start of a given cycle of the signal waveform and the random collision between the signal and the sampling pulse.³

System Operation

The basic system is illustrated in Fig. 1. Three inputs are shown; the signal and the sampling pulse are not synchronized with respect to each other, but the trigger pulse arrives at the same instant as the leading edge of the signal.⁵ Hence, the trigger and signal pulses arrive

² R. Landauer, "Shock waves in nonlinear transmission lines and their effect on parametric amplification," *IBM J.*; October, 1960. Also, R. B. Riley, "An Analysis of a Nonlinear Transmission Line," Solid State Electronics Laboratory, Stanford University, Stanford, Calif., Tech. Rep. No. 1707-1; January 20, 1961.

³ One form of this technique was first employed by McQueen as an anti-jitter circuit.⁴ The equivalence of McQueen's technique and our random-sample technique was discovered after we had constructed our first random-sampling oscilloscope.

⁴ J. G. McQueen, "The monitoring of high speed waveforms," *Elec. Engrg.*, pp. 436-441; October, 1952.

⁵ Usually, the trigger pulse is derived from the signal pulse through the use of pulse-splitting networks or trigger pick-off systems.

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¹ W. H. Cornet and J. G. Josenhans, "A millimicrosecond pulse-generator tube," *IRE TRANS. ON ELECTRONIC DEVICES*, vol. ED-8, pp. 464-470; November, 1961.

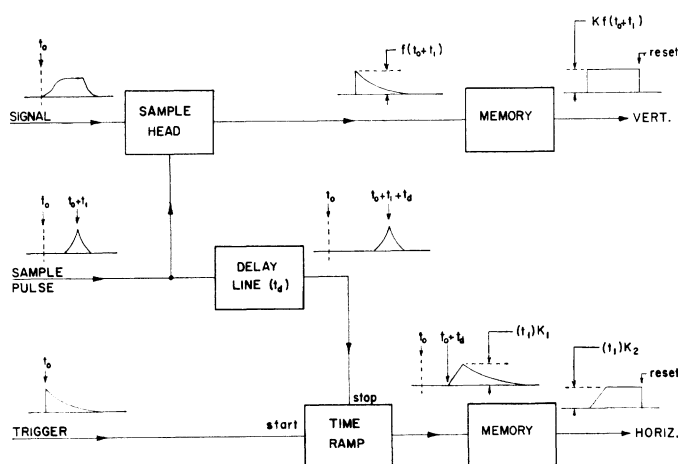


Fig. 1—The basic random sampling system.

simultaneously at time t_0 . The time ramp is triggered on; once started, the ramp produces a voltage which increases linearly with respect to time. A sampling pulse arrives at some time $t_0 + t_1$, and a sample is immediately taken of the signal amplitude at the time $t_0 + t_1$; this information is then stored in the vertical memory. The sampling pulse is also passed through a time delay t_d to the horizontal time ramp generator. The arrival of the delay sampling pulse stops the excursion of the horizontal time ramp at $t_0 + t_1 + t_d$. Then, the maximum excursion of the horizontal time ramp is stored in the horizontal channel memory. Therefore: two pieces of information are now stored in the memory, a) the instantaneous amplitude of the signal at the moment the sample pulse arrives; and b) the time position of the sample $t_0 + t_1$ plus a constant delay time t_d . If the memory voltages are now run to the vertical and horizontal channels of a cathode-ray oscilloscope, a spot will be formed at a point dictated by the memory potentials. After the spot has been displayed for two or three microseconds, the memories are reset, and the system is ready for another initiating trigger pulse.

The reason for delaying the sampling pulse (by t_d) is to allow for the nonzero starting time of the ramp generator; this is important when the leading edge of the signal pulse and the sampling pulse are coincident. Hence, the delay t_d is similar to the vertical channel signal delay normally used in triggered oscilloscopes to properly phase the signal and trigger pulses so that the leading edge of the signal waveform is presented.⁶

The sampled pulse is presented on the screen of the cathode ray oscilloscope indicator in approximately the following manner. If a relatively low repetition rate sig-

⁶ Note that the circuitry required to perform the delay t_d is of a different nature than that necessary to delay a wide-band signal of any shape in a triggered oscilloscope's vertical channel. In the former, the circuitry must delay a pulse waveform having fixed dimensions in amplitude and time; while for the latter, the circuitry must provide a fixed delay, *i.e.*, linear phase for any signal waveform which appears in the vertical channel.

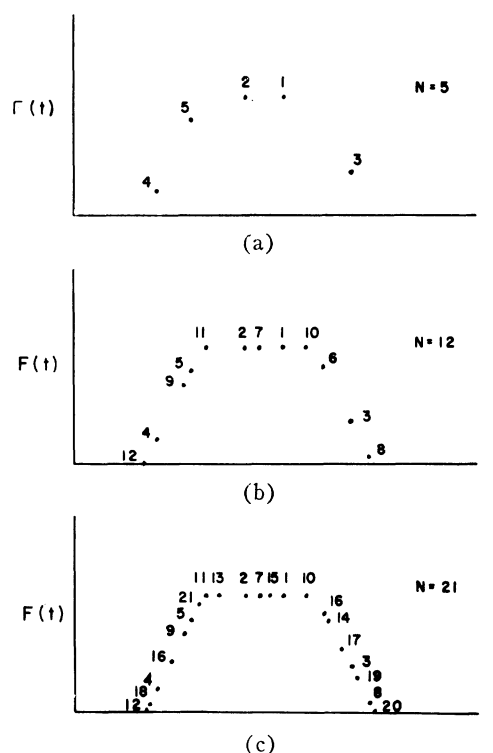


Fig. 2—Random sample oscillographic displays. The samples are numbered successively; N denotes the total number of samples. The number of samples increases with time. Note that the samples are displayed in a random fashion.

nal pulse was being observed, and a photographic plate were exposed to the cathode ray oscilloscope display, then a short time exposure to the sampled display might yield a picture as seen in Fig. 2(a). A longer exposure would yield the picture presented in 2(b), and still longer exposures would fill in the picture as seen in Fig. 2(c).

A TRANSISTORIZED RANDOM SAMPLING UNIT

General Description

The random sampling unit briefly described here has a bandwidth of better than 250 Mc; sweep speeds range from 10 nsec/cm to 1 μ sec/cm when the unit is operated into a cathode-ray oscilloscope indicator having a horizontal sensitivity of 0.2 v/cm. The vertical channel provides a gain of 10 times. Minimum noise as referred back to the signal input is about 3 to 5 mv. The input impedance of the sampling unit is 50 Ω .

The general arrangement is shown in Fig. 3. The block diagram of the unit is shown in Fig. 4. This diagram outlines the active and passive elements of the complete schematic diagram shown in Figs. 5–7.

It should be kept in mind that this random sampling unit illustrates but one method of realizing a random sampling oscilloscope system. Here, for convenience, the sampling pulse waveform and signal waveform are both relatively periodic; however, no frequency stabilization was employed in the generation of either of the two relevant waveforms, nor was any time synchronization employed between the two waveform generators.

The sampling pulse is derived from a 1N914 diode operated as a "snap-off" diode.⁷ The diode is driven by a free running 2N706A transistor blocking oscillator. The oscillator repetition rate is approximately 100 kc. A shorted 3 inch length of 50 Ω "subminax" coaxial cable is used to shape the snap-off diode transient into the narrow sampling pulse.

Horizontal Channel

The horizontal channel has a major function of providing the time position data for each "random collision" which may occur between the signal waveform and sampling pulse. This principal function is accomplished in the ramp circuitry, Fig. 7. The ramp generator is formed by a 2N705 transistor with a 2N1516 boot-strap emitter follower. The 2N705 is normally held saturated; it is turned off by a positive going pulse from the ramp drive tunnel diode, and is held off as long as the tunnel diode is in its high-voltage state. The arrival of a negative stop pulse from the 2N1516 ramp stop drive transistor resets the tunnel diode and causes the 2N705 to go back into conduction. When the sweep speed capacitor is discharged, the 2N705 transistor saturates. Hence, the maximum excursion of the ramp is determined by the time width of the positive rectangular pulse delivered to the base of the 2N705. This maximum excursion is remembered by the 2N706A memory circuit, and the information is retained until a reset pulse arrives from the reset emitter follower.

The ramp memory circuit operates in the following manner. The negative excursion of the ramp drives charge into the 100 pf blocking capacitor and thus forward biases the 2N607A collector to base junction. This forward bias condition clamps the negative-voltage ex-

⁷ The snap-off diode is also called the step-recovery diode. Such diodes are described by S. M. Krakauer, "Harmonic generation, rectification, and lifetime evaluation with the step recovery diode," *Proc. IRE*, vol. 50, pp. 1665-1676; July, 1962.

cursion of the collector to that value determined by the sum of the contact potentials of the collector to base junction and the IN34 diode. When the ramp is stopped and reset abruptly by the arrival of the stop pulse, the charge on the 100 pf capacitor is trapped by the fact that the positive going reset waveform tends to reverse bias the diode junctions which were previously in forward conduction. The collector to base voltage then rises to a value determined by the maximum excursion of the ramp. A positive reset pulse applied to the base discharges the 100 pf capacitor through the collector to the emitter to ground. Because of the contact potentials that must be overcome in the memory circuit, a step is generated on the leading edge of the ramp by the action of the diode circuit connected to the ground end of the sweep capacitor. This step insures that the sweep always starts at the same point on the cathode ray oscilloscope indicator screen, regardless of sweep speed.

Experimental Results

Fig. 8 shows the signal pulse as displayed on a Tektronix Type 541 oscilloscope employing a Type 53/54 L plug-in unit. Figs. 9(a)–9(c) are random sampling oscillographic pictures which were obtained using the random sampling unit described above, a Du Mont Type 353 oscillographic camera as a long time integrator of the random sampling process, and a Hewlett Packard Type 130A Oscilloscope as the display unit.⁸ For all of the random sampling oscillographs cited here, the sampling pulse repetition was approximately 100 kc. The three random sampling oscillographs were obtained at three different signal repetition rates, and, consequently, the film exposure time had to be adjusted to compensate for each change in the signal pulse repetition rate. This was necessary, as the random collision rate between the sampling pulses and signal

⁸ Polaroid Type 47 Film was employed.

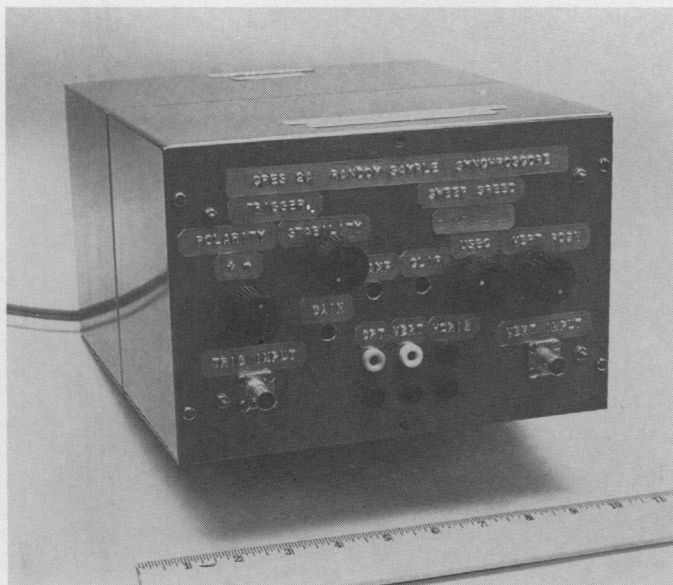


Fig. 3—Photograph of the random sample unit employing solid-state devices. Over-all dimensions are 6 inch \times 9 inch \times 10 inch.

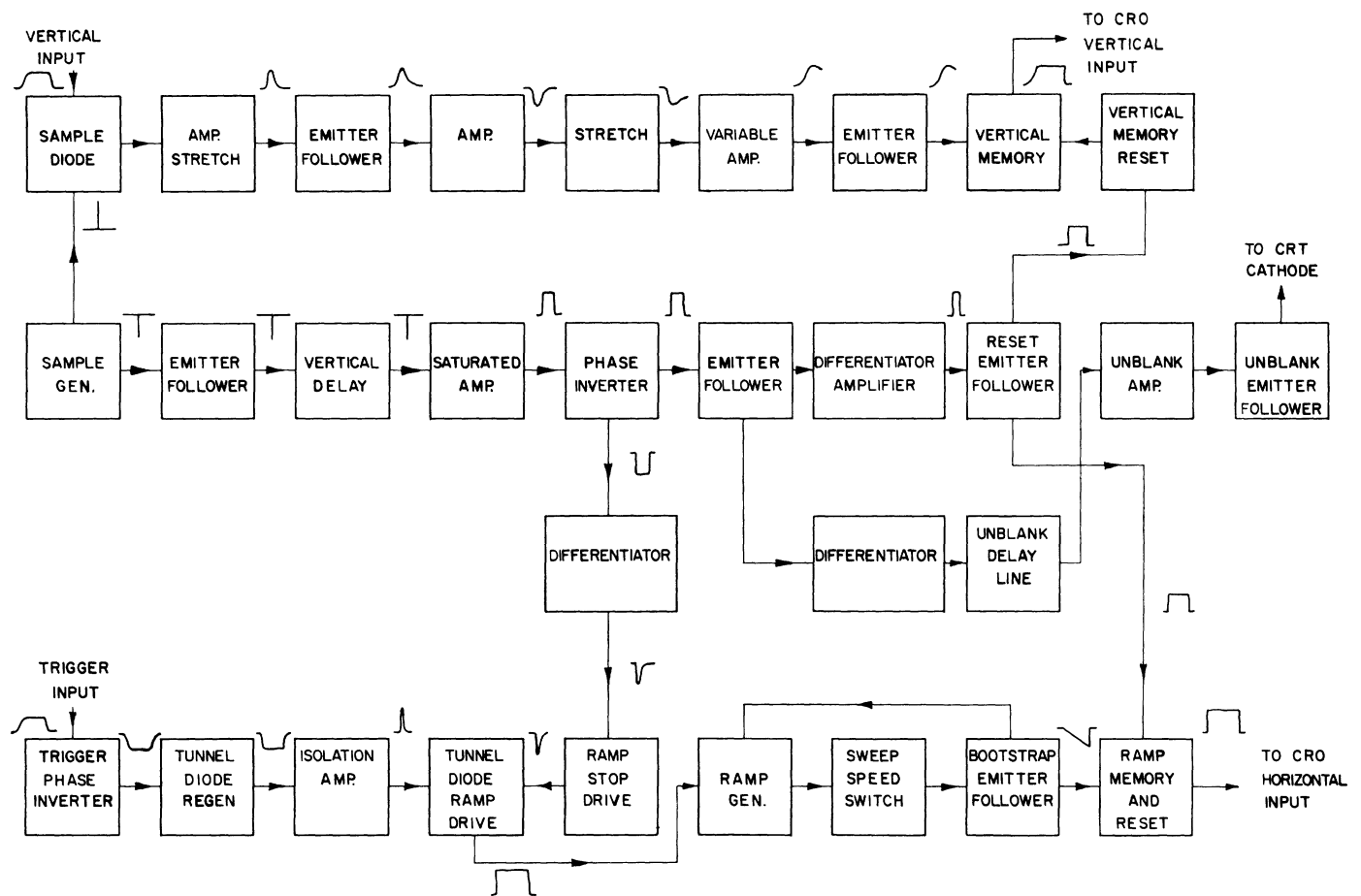


Fig. 4—The block diagram of the random sample unit.

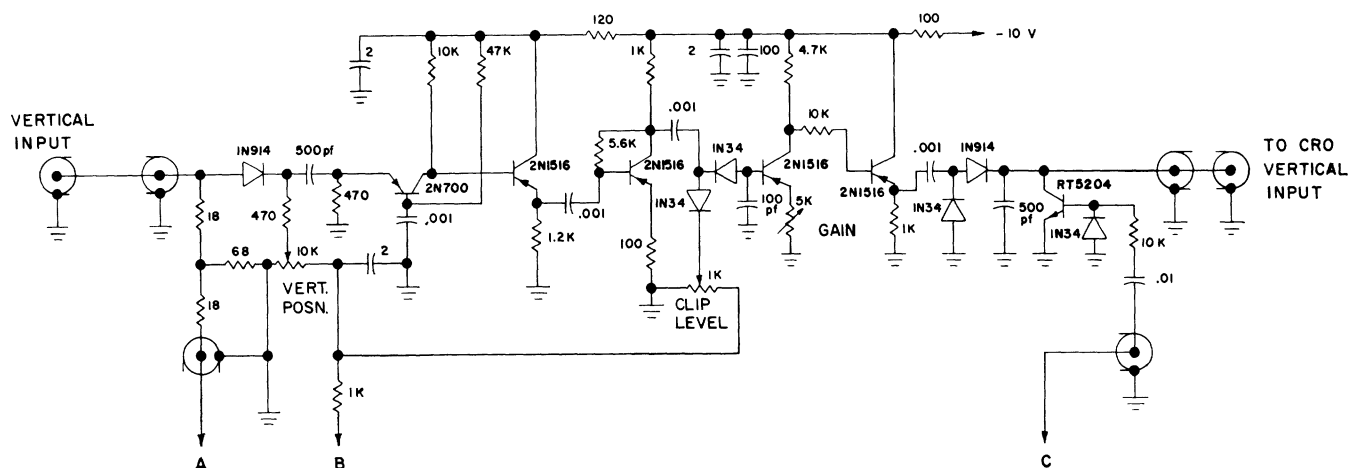


Fig. 5—The amplitude sampler and vertical channel memories.

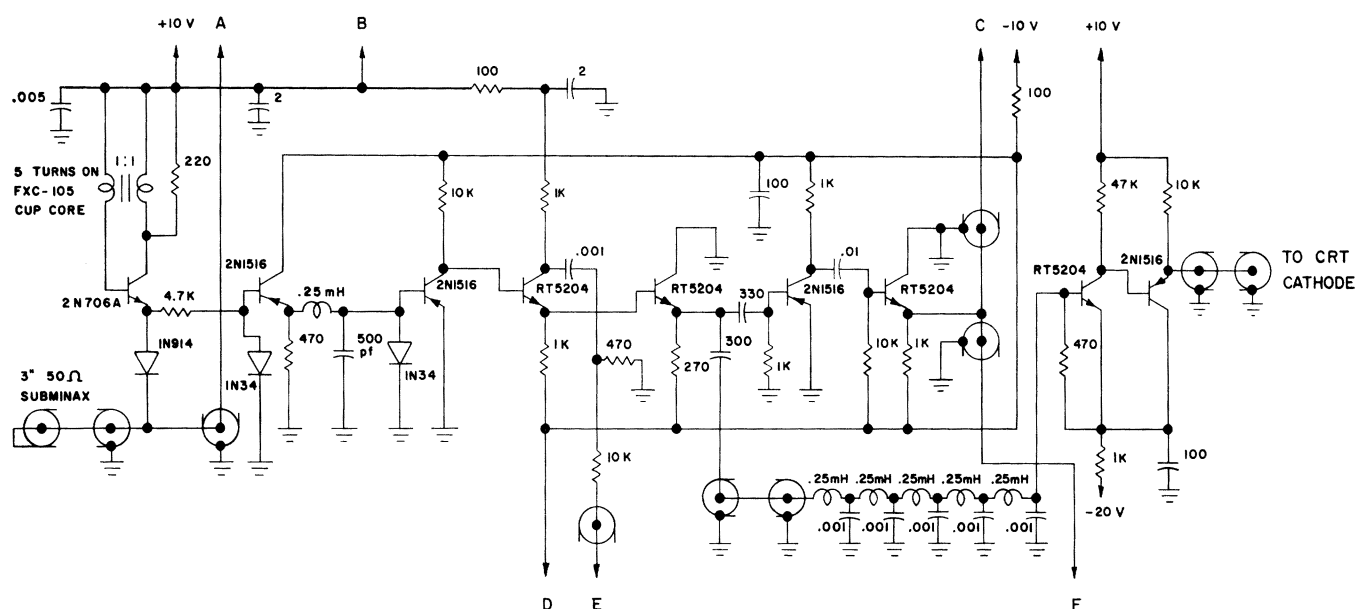


Fig. 6—The sampling pulse generator and CRT spot intensifier circuitry.

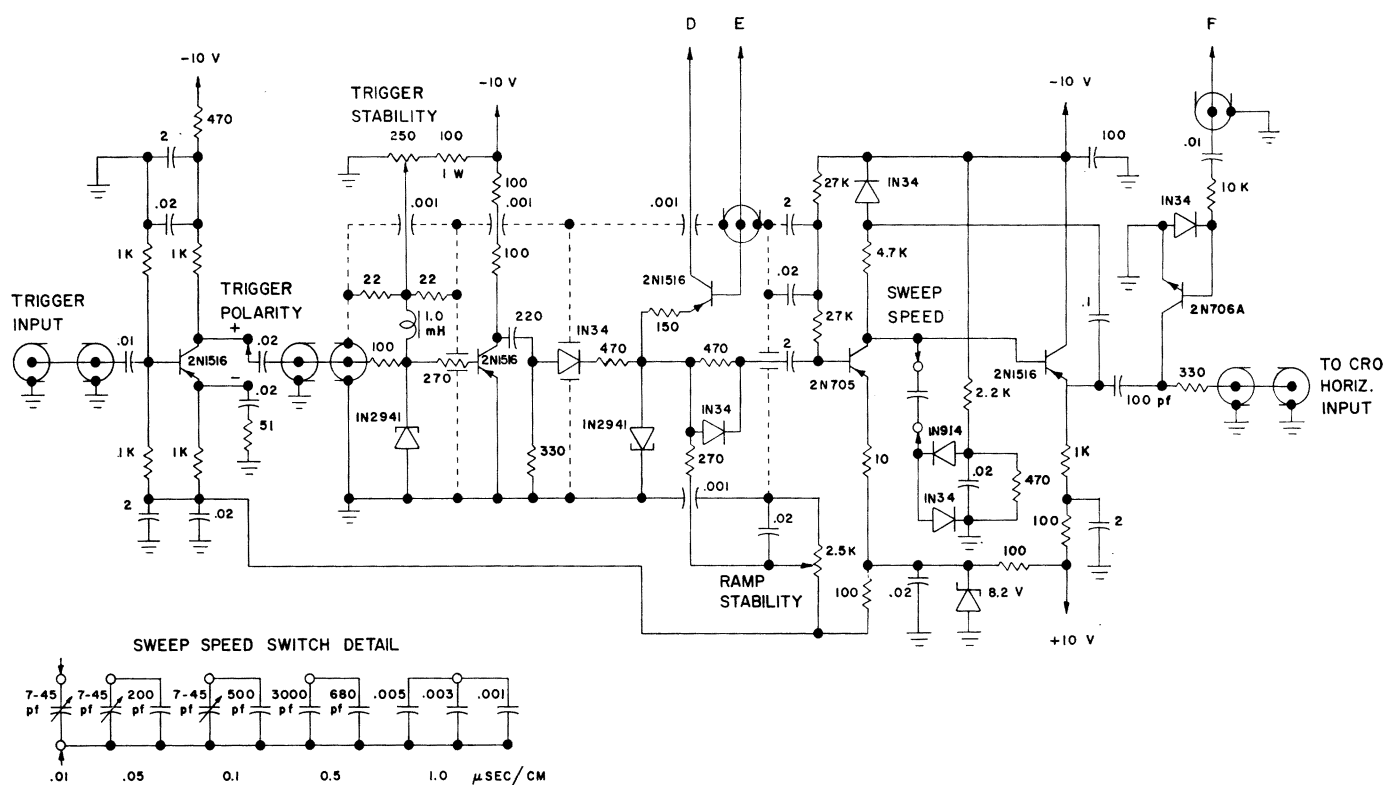


Fig. 7—The horizontal time ramp and memory channel.

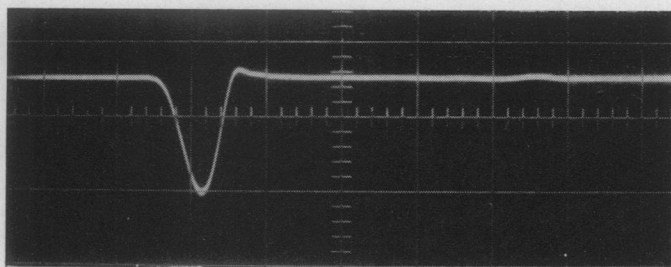
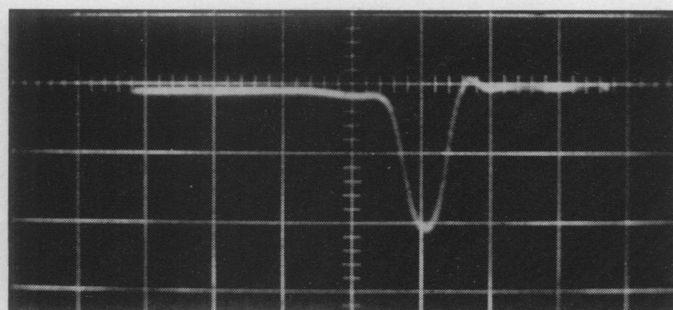
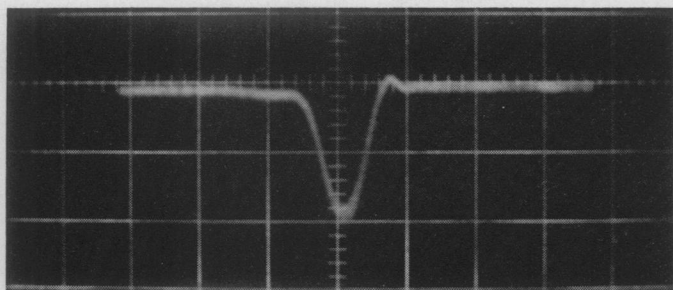


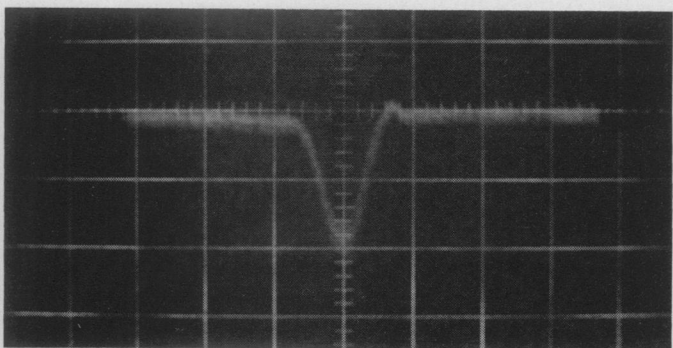
Fig. 8—The signal waveform displayed on a Tektronix 541 oscilloscope, vertical deflection 10 v per major division, horizontal deflection 0.1 μ sec per major division, repetition rate 50 kc/sec.



(a)



(b)



(c)

Fig. 9—Experimental random sample displayed on a Hewlett-Packard type 130A oscilloscope, sampling pulse PRF 100 kc per second, displayed time base 0.1 μ sec per major division, camera lens opening f:8. (a) Signal PRF 50 kc per second, exposure 10 seconds. (b) Signal PRF 10 kc per second, exposure 60 seconds. (c) Signal PRF 1 kc per second, exposure 12 minutes.

pulses decreased with the decrease in the signal PRF because the sampling pulse PRF was relatively constant.⁹

The increase in trace width which appears in the longer exposure time oscillographs results from the cumulative effects of instabilities in the electronic circuitry along with the scattering and storage characteristics of the CRT phosphor.

CONCLUSION

The basic idea in the random-sampling technique is to allow the signal waveform and the sampling pulse to collide with each other in a random manner. By means of suitable electronic circuitry, each random collision provides an instantaneous value of the signal waveform, each value being recorded in terms of its instantaneous amplitude and associated time position within the signal waveform. Because of the simultaneous determination of time position with each amplitude sample, the necessity for time synchronization between the signal waveform and the sampling pulse, or both, could be random. Furthermore, another feature of the random-sampling technique is the elimination of the need for a signal input delay line with its usual low impedance.

On the other hand, the random sampling technique has its disadvantages. Compared to conventional sampling methods, the display rate is not equal to the signal occurrence rate but is equal to the rate of collision between the sampling and signal pulses. If the sampling and signal pulses are so phased that they infrequently collide with each other, the display rate will be very low. Techniques similar to McQueen's might be used to increase the collision rate for reasonably periodic signals. another disadvantage is that random sampling does not permit the use of feedback methods currently used in conventional sampling oscilloscopes to stabilize sensitivity and linearize the display. Feedback techniques could possibly be applied for reasonably periodic signals.

As we have shown through one example, random processes offer some intriguing possibilities for sampling oscillography. It is very probable that such processes will have a greater role in future instrumentation.

ACKNOWLEDGMENT

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⁹ It is interesting to note that in McQueen's⁴ oscilloscope, steps were taken to maximize the sampling rate by centering the sampling pulses within the most probable point of the signal population.