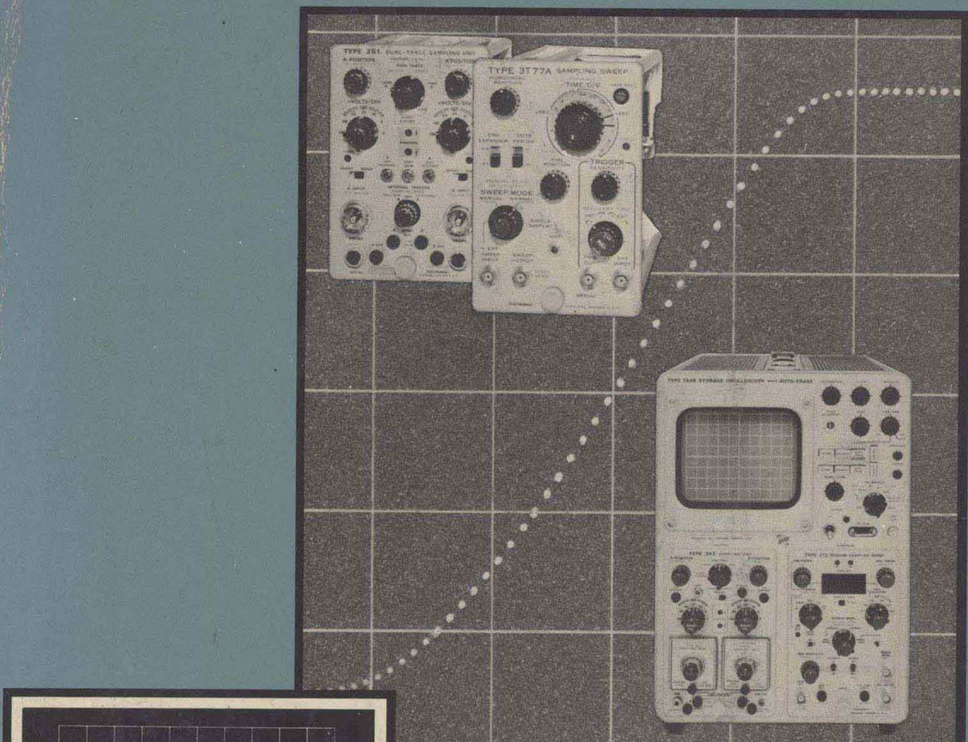
Sampling Oscilloscope Circuits



Circuit Concepts Series

SAMPLING OSCILLOSCOPE CIRCUITS

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CIRCUIT CONCEPTS

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PREFACE

This information is primarily for people who want to understand how sampling oscilloscopes work. It is particularly slanted toward instrumentation engineers, oscilloscope calibration men and owners and users who want best performance from their instruments.

Only key circuits and concepts unique to Tektronix sampling oscilloscopes are covered. Circuits common to sampling and conventional scopes are discussed in other books in this series. A list of those books will be found facing the inside back cover.

Probably the most imaginative sampling-circuit concepts are the ones that pertain to the manner in which the more basic circuits are related to each other. Understanding these broader *relatedness* concepts is normally tougher than perceiving ingenious circuit details. The best way we know to explain the relatedness concepts is by use of block diagrams and waveform time-relationship diagrams. Basic circuit functions are categorized, named and grouped into blocks showing their relationships. No one is expected to deduce the concepts from the diagrams alone. Each function is explained in detail in Chapter 2.

All the *circuits* discussed in Chapters 3, 4, 5 and 6 are good examples of the basic circuit *functions* described in Chapter 2. The circuit diagrams in this book are reproduced from actual diagrams that appear in the instruction manuals for various Tektronix sampling instruments in production in mid 1969. They do not include the 7S11 Sampler or 7T11 Sampling Time Base Unit announced in August 1969. Because the reproductions are greatly reduced in size, some details such as connector pin numbers and circuit symbol numbers are deleted for sake of clarity and simplicity. Sections of the diagrams have been shaded to correspond to the blocks in the block diagrams. We hope this helps you relate the details of how a circuit operates to its *purpose* for being there.

We have not extracted any section of a circuit diagram to place it closer to the text that describes that section even though we know it would make the job of switching your eyes between text and diagram easier. If you remember that the text always pertains to the closest diagram on an earlier page, relating the two will be simpler.

The diagrams were selected so that all of what might be called *key* sampling circuits (in mid 1969) could be described here. For sake of completeness, however, the circuits on each diagram that are not what might be called key circuits are also described. A list of circuits similar to the ones described appears as part of the index.

CONTENTS

1

INTRODUCTION TO SAMPLING PRINCIPLES

Sampling scopes have been commercially available since about 1959. Their primary advantage is their ability to respond to small fast-changing signal voltages better than conventional scopes.

The most fundamental sampling principle is analogous to the principle of optical stroboscopes. A stroboscope generates very brief flashes of light which, when properly timed, can make rapidly moving things appear to be at rest or occurring in slow motion. Sampling scopes graphically depict fast-changing voltages as if the changes were occurring slowly. Instead of generating flashes of light however, sampling scopes generate very brief electrical pulses. These pulses allow us to "look" at a repetitive signal one point and one cycle at a time and depict the signal character graphically but slowly over a period of many cycles. Until recently, the brevity of the pulses determined the shortness of risetime. For example, pulses 350 ps in duration are used in sampling scopes having a risetime of 350 ps. This risetime is comparable to a bandwidth of 1 GHz -- one-billion cycles per second! These pulses are called strobe pulses because of their similarity in function to the flashes of light from a stroboscope.

strobe pulses

Although the faster response of sampling scopes is their principle attraction, they have three other features that make them especially useful. First, the process of taking and storing samples of a repetitive signal is such that sampling scopes are almost completely free from display aberrations caused by overscanning the screen. Secondly, large, permanent, paper-chart recordings can be made of a displayed signal directly from X and Y coordinate output signals. And third, the process of sampling lends itself to digitizing time measurements directly, even extremely short intervals of time, and to making digital measurements of the voltage difference between two points on a very fast-changing signal. Sampling scopes were forerunners of digital-readout scopes.

useful features

The principle of sampling electrical signals was known before the turn of the century. In 1880 Joubert devised a way of sampling a power-generator waveform with a pen and ink recorder. This was well before the days of even simple oscilloscopes. In the 1950's when transistors became available, the work of J. G. McQueen, R. Sugarman, R. Carlson and others paved the way to practical commercial sampling oscilloscopes. Even the very first commercial sampling scopes had much shorter risetimes than any conventional scope which used a vertical-deflection amplifier.

using semiconductor devices

The fundamental reason why sampling scopes can respond to faster-changing signal voltages than conventional scopes is that with certain semiconductor devices we can generate much narrower pulses than we can amplify. With vacuum tubes this was not so.

Besides generating narrow pulses we must cause them to occur at the right moments. Tektronix presently uses four methods of timing strobe pulses. All four result in a CRT display comprised of a series of dots -- one dot per sample. When the dots occur at a high repetition rate and are closely spaced they may give the appearance of a continuous trace.

sequential and random sampling

Two of the names given to the timing methods are based on the appearance of a trace for that mode. The first and most common mode is called sequential sampling. With sequential sampling the display is comprised of a very orderly series of equally spaced dots resulting from equally spaced steps of the CRT beam. The second mode is called random sampling. With random sampling successive dots may occur at what appears to be random horizontal positions while plotting the graph.

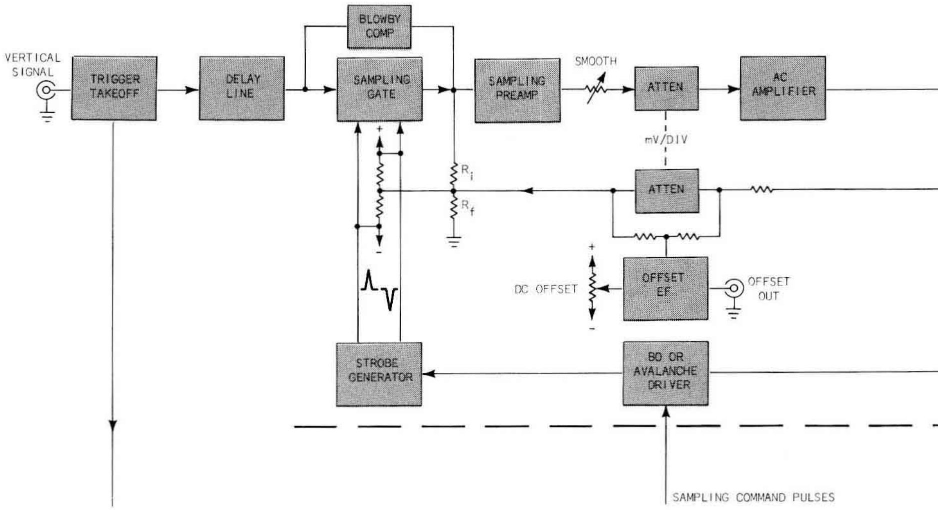
real-time sampling

The other two timing methods are used in the mode called real-time sampling. With real-time sampling we do not attempt to depict fast changes in slow motion. In fact, that system is not one of depicting fast changes at all, but rather is a way of extending the use of sampling scopes to look at very *slow* voltage changes. With real-time sampling, unlike sequential sampling and random sampling, the horizontal time scale of the scope is equal to the actual time the beam takes to traverse horizontally the divisions on the screen.

With sequential sampling and random sampling, the time required to make one complete sweep (scan) of the beam across the screen is vastly longer than the time represented by the full horizontal scale. That tells us the time per division of the scale is much less than the horizontal beam velocity. With either of the modes, the vertical and horizontal (*X* and *Y*) coordinate relationships are precisely maintained to produce a coherent, graphic, scope display. How all these good things are made to happen will be the subject for the following pages!

2

BASIC CIRCUIT FUNCTIONS AND RELATIONSHIPS


VERTICAL SIGNAL
TRIGGER TAKEOFF
DELAY LINE
BLOWBY COMP
SAMPLING GATE
SAMPLING PREAMP
SMOOTH
ATTEN
AC AMPLIFIER
mV/DIV
ATTEN
R_i
R_f
DC OFFSET
OFFSET EF
OFFSET OUT
STROBE GENERATOR
BO OR AVALANCHE DRIVER
SAMPLING COMMAND PULSES

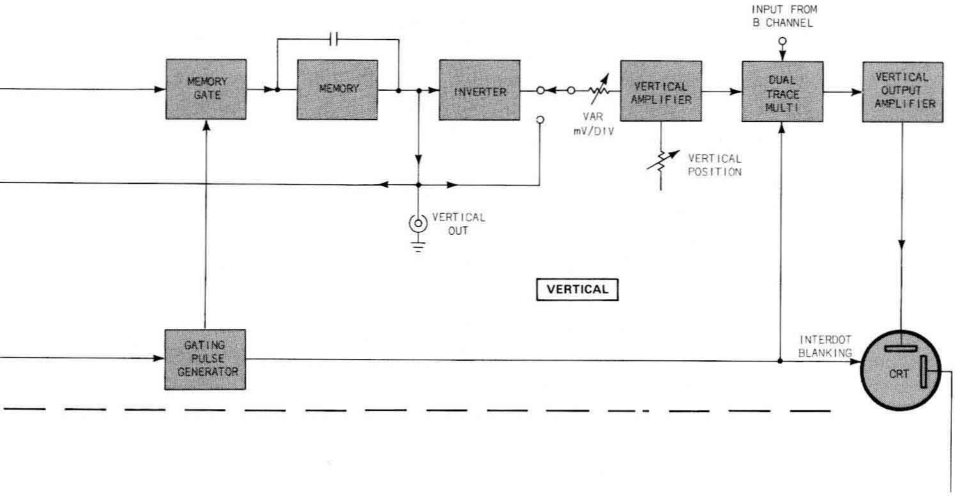


Fig. 2-1. Basic block diagram of vertical deflection section.

SAMPLING, AMPLIFYING, HOLDING, FEEDING BACK

The block diagram in Fig. 2-1 represents the function to be discussed.

delay line

Notice that a delay line is shown between the trigger takeoff and the sampling gate. Sampling instruments having a shorter risetime than about 350 picoseconds do not have delay lines. But delay lines are not always used, even when the risetime is 350 picoseconds or longer. This delay line is a specially constructed, 50-ohm coaxial cable about thirty to fifty feet long having a delay of about 45 to 75 ns. A delay line this long, having dimensions small enough so it can be wound up and placed inside of a sampling scope, will degrade the response to fast-step signals. In particular, the top corner of a rising-step signal (or the bottom corner of a falling-step signal) will be rounded. See Fig. 2-2. When we use such a delay line, therefore, we usually have a passive compensation circuit at the end of the delay line that provides a correction for the degradation of waveshape introduced by the delay line. The end of the delay line is terminated in this network.

sampling gate

The sampling gate is connected at the end of the network and at this point blocks further passage of the input signal nearly all the time. The purpose of the sampling gate is to block the signal except during the very brief moments when the signal voltage is allowed to go through the gate and into the sampling preamplifier.

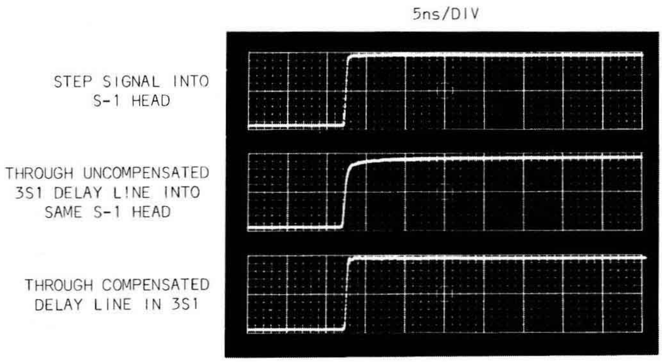


Fig. 2-2. Delay-line dribble-up. 70-ps step signal from Type 284 displayed on 561B (projected graticule).

Typically, Tektronix sampling instruments do not sample any signal more often than 100,000 times a second, regardless of the signal frequency. Trigger countdown is always to 100 kHz or less. Sampling 100,000 times a second, when the sampling gate is opened for only 350 picoseconds for each sample, provides a sampling duty factor of only about one part in 30,000.

The sampling gate consists of two to six very fast low-storage diodes. These diodes are arranged to have a back-bias voltage applied across them at all times except when we wish the signal energy to pass through. The back-bias voltage is usually derived by tapping a couple of points in a resistive DC-voltage divider. In the block diagram shown, we can see that the two inputs to the bottom part of the sampling gate block have two different voltages applied; one negative and one positive with respect to ground. The center-tap voltage is normally within ±1 volt of ground. The back-bias voltage must be high enough to be greater than the peak amplitude of the signal being applied to the input of the sampling gate, or the signal itself will cause one or more of the diodes to conduct, passing the signal at the wrong moments. The sampling-gate diodes are only supposed to conduct at the moments when we want samples to be taken. The same two lines coming into the sampling gate that bring in the back-bias voltage also bring strobe pulses from the strobe-generator block.

back-bias voltage

strobe generator

Strobe generators usually employ snap-off diodes (also called step-recovery diodes) to generate very narrow pulses. The pulses are invariably applied push-pull with the right polarity to overcome the back-bias on the sampling-gate diodes. In this block diagram the strobe generator is being driven by either a blocking oscillator or a transistor operated in the fast-switching avalanche mode. In turn this circuit is driven by the sampling-command pulses that originate in the horizontal-deflection section. Everytime a sampling-command pulse is generated, a pair of strobe pulses is delivered to the sampling gate. The strobe pulses admit the signal to the preamplifier but for only a very brief time. That time is normally equal to the duration of the strobe pulses themselves.

sampling preamplifier

Let's consider what happens just before and during the time when the sampling gate allows the signal to come through into the sampling preamplifier. A pair of strobe pulses are generated and applied to the sampling gate, overcoming the back-bias on the sampling-gate diodes and admitting the signal through the sampling gate into the sampling preamplifier. There is invariably a small amount of stray capacitance to ground at the input to the preamplifier, and this capacitance gets partially charged to the voltage which exists on the input side of the sampling gate. The capacitance would get fully charged if the strobe pulses were wider. When the sampling gate stops conducting, a small voltage will have been developed across this capacitance and will last for a relatively long time because it has a high-resistance path through which to discharge. The waveform at the input to the sampling preamplifier is a step signal having a transition time about equal to the risetime of the sampling scope.

The resistor R_i shown in the path to ground at the input of the sampling preamplifier has a relatively high resistance compared to the input impedance of the sampling gate. When driven by the input signal, the stray input capacitance can charge or discharge rapidly compared to the time taken for discharge through resistor R_i. We may see that a voltage step has been applied to the sampling preamplifier which is captured as a charge on the input capacitance. The sampling preamplifier responds to this step as fast as it can and its output is applied through a couple of attenuators, one of which is called a smoothing control, amplified further through a stage usually called an AC-amplifier stage, and then is applied to a gate at the input to the memory.

memory gate

The memory gate is very similar in some respects to the sampling gate, but is operated for a much longer period of time. Typically, the memory gate will pass the amplified signal for about one-third *microsecond* each time there is a sampling-command pulse. Compared to a third of a nanosecond or less when the sampling gate is passing the input signal, we have approximately a 1000-to-1 ratio. Notice, however, that the memory gate and the sampling gate are both turned on by the sampling-command pulses that come from the horizontal-deflection section. Not evident in the block diagram is the fact that the memory-gating pulses, although starting simultaneously with the strobe pulses, are not turned off until much later. This tells us that a small step voltage, applied to the input of the sampling preamplifier, can be amplified for a large fraction of a microsecond while being applied through the memory gate to the memory, before the memory gate interrupts the amplified step-signal.

memory

The memory is a DC-coupled inverting amplifier with the output fed back to the input through a memory capacitor. Whenever the memory gate is open and not allowing a signal to go through, the gate disconnects the input to the memory capacitor providing only a very high impedance to ground at the input side. That tells us that whatever voltage is stored in the memory capacitor can remain essentially constant until another sample is taken. The output voltage of the memory amplifier goes to the vertical amplifier, producing vertical deflection. Each change in voltage at the output of the memory is a step change, a step proportional in amplitude to a step at the input to the preamplifier.

The amplifier stages which follow the memory output are very similar to the amplifiers in conventional oscilloscopes. There is nothing very unique about these stages.

feedback attenuator

The output of the memory amplifier also goes back to the sampling-preamplifier input, through an attenuator. The attenuator circuit consists of the resistor connected directly to the output of the memory, plus a selectable resistor connected to the first resistor, then to the resistor to ground, R_f. The amount of voltage which is developed across resistor R_f is the voltage which is applied to the sampling preamplifier from the memory output. The voltage at the memory output is, therefore, attenuated a certain amount before being reapplied back to the sampling-preamplifier input. The voltage existing across this resistor is partly determined by the DC-offset setting. For the time being we will consider the voltage across this resistor to be determined only by the output of the memory. That is, we will assume the DC-offset voltage is set to zero volts.