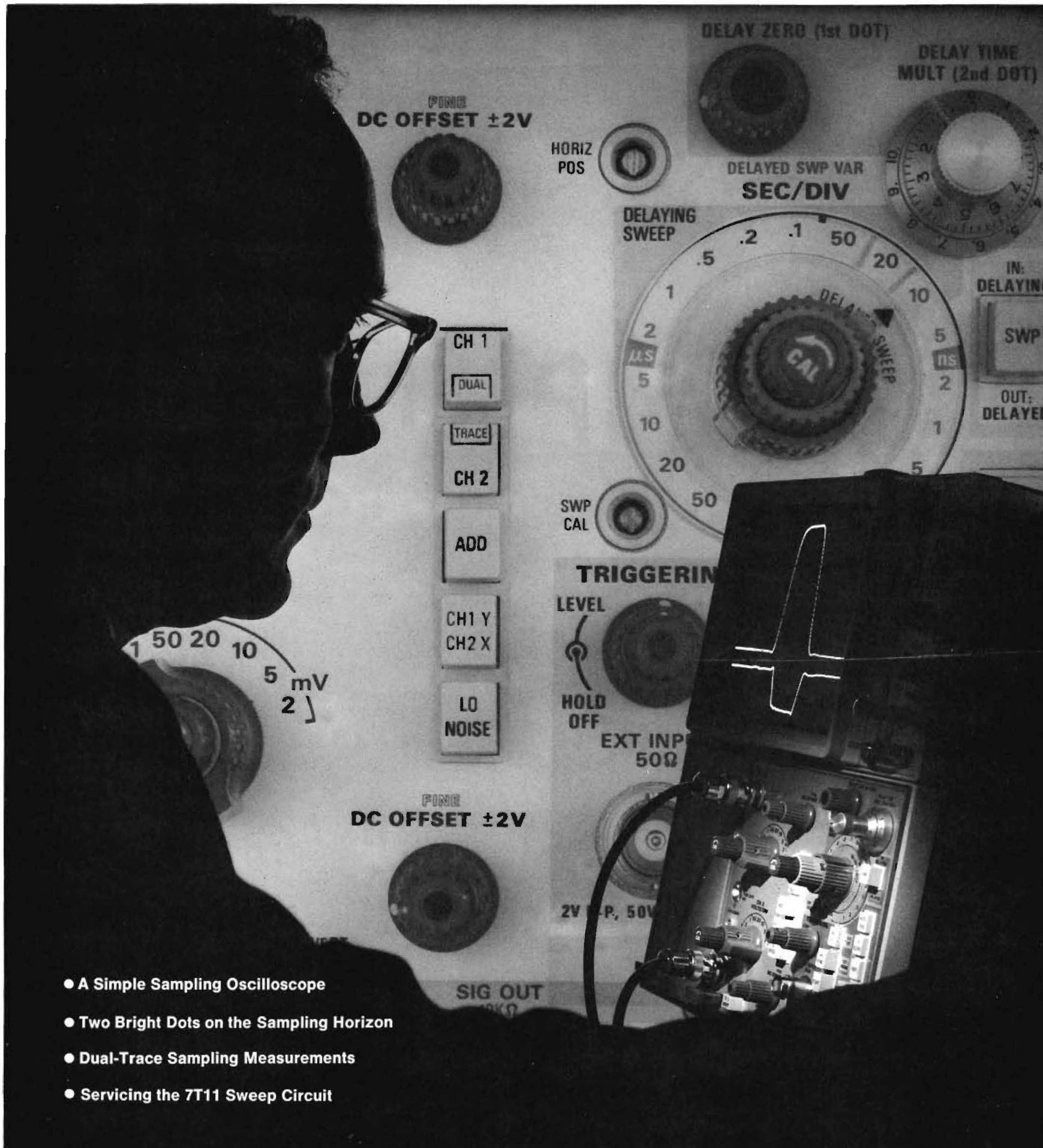
TEK SCOPE

MAY/JUNE 1973



- A Simple Sampling Oscilloscope
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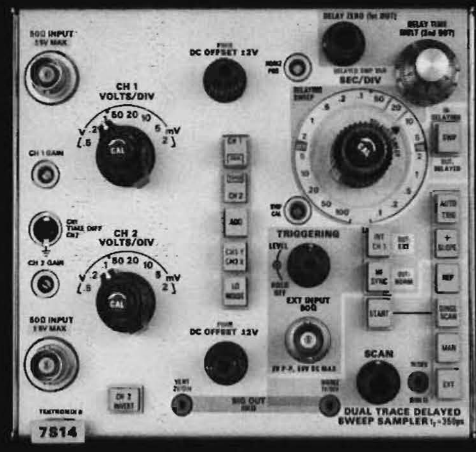
- Dual-Trace Sampling Measurements
- Servicing the 7T11 Sweep Circuit



THE SIMPLE SAMPLING OSCILLOSCOPE

SAMPLING

by *John A. Mulvey* Sampling Staff Engineer

Most engineers who use sampling oscilloscopes prefer to use conventional scopes. We sell both kinds—should we care which kind people prefer? The answer is "yes," for reasons that may not be obvious.

Oscilloscope bandwidth technology changed in a dramatic way when sampling oscilloscopes were first introduced commercially fourteen years ago. The widest bandwidth available in a conventional oscilloscope at that time was about 100 MHz, while the bandwidth of the fastest sampling oscilloscope was 1 GHz—ten times greater. Sampling was sophisticated. It was a brand new art and the additional bandwidth cost quite a few additional dollars.

Since then the bandwidth of sophisticated sampling scopes has moved to the 12 to 18 GHz region, and they are still the most expensive scopes you can buy. But a dual-trace sampling scope of 1-GHz bandwidth is no longer what you would call sophisticated. What's new is that such an instrument can now be offered for less money than a dual-trace conventional scope of top bandwidth; and top bandwidth in conventional scopes is still only half way to 1 GHz. We should no longer regard all sampling oscilloscopes as high priced.

Cover: The spotlight is turned on sampling in this issue. Two new sampling plug-ins bring unprecedented operating ease and measurement capability to users of sampling scopes.

Persistent customer preference for conventional oscilloscopes is not based on price alone, however. Conventional scopes typically are easier to use and understand, and that seems to be of equal importance. Part of what makes an oscilloscope easy to use is having familiar responses. But many of the unfamiliar responses in sampling scopes don't have to be there. Some may be designed out, and that is better than trying to explain them away.

These two factors, high cost and unfamiliar responses, are two major reasons why engineers tend to avoid sampling scopes whenever possible. Knowing these factors is important to us because they tell us what improvements are needed to make sampling scopes more useful to you. We would like to tell you what we've done about both of these areas lately.

Meet the 5S14N and 7S14

Two new TEKTRONIX sampling plug-in units have been designed which embody such improvements. They are the 5S14N and the 7S14. Cost was held down to where the 5S14N, used in a 5103/D10 mainframe, represents the lowest priced 1-GHz, dual-trace, dual delay line sampling scope available. That, we think, is real progress—especially when you consider the inflation that has occurred since sampling scopes first came on the scene!

Electrically, the 5S14N and 7S14 are almost identical. The 5S14N operates in 5100-Series mainframes, the 7S14 in 7000-Series mainframes. The main difference between these units is that the 7S14 is equipped with coding circuitry to activate the CRT READOUT System in 7000-Series mainframes, whereas the 5S14N is not so equipped. The CRT READOUT System displays the selected VOLTS/DIV on the CRT along with the waveforms.

Packaging the same circuit design for use in both series of mainframes has several advantages. It gives you sampling at minimum cost whether you own a 5100-Series or 7000-Series scope. For those of you who prefer to buy a complete sampling scope and don't need the flexibility of plug-ins, it gives you a choice of sampling scopes. For example, here are some of the choices available to you:

- A sampler with conventional CRT.
- A sampler with conventional CRT and CRT READOUT.
- A sampler with bistable storage.
- A sampler with bistable storage and CRT READOUT.
- A sampler with variable-persistence storage and CRT READOUT.
- A sampler and a real-time oscilloscope in one package using a four-hole 7000-Series mainframe.

And there are other possible combinations.

Sampling and Storage Teamwork

One of the bothersome characteristics of sampling oscilloscopes shows up when you display short-duration pulses occurring at a low repetition rate. Sampling only one pulse at a time, it may take such a long time to produce each horizontal scan that you forget what the start of the trace looked like by the time you see the end! The use of a storage scope neatly solves this problem. Inexpensive bistable storage works fine and is available in either series of mainframes. Variable-persistence storage available in the 7000 Series offers an ideal display for low-repetition sampling since the persistence can be adjusted so the first trace just fades before the second trace is written.

No More Lost Beam with Auto Triggering

When operating any oscilloscope, the first job is to get a trace on-screen. If you have trouble doing this on a conventional scope, you usually press the BEAM FINDER button, note where the trace is located and then position it near center-screen. If everything is working normally, you're in business. It's not that easy with a sampler, however. Unless strobe pulses are being generated, the beam drifts off-screen vertically and nothing you can do will bring it back. If you're not aware of what's taking place you may assume the instrument needs repair.

The 5S14N and 7S14 overcome this problem with an automatic triggering mode. When you're in the AUTO mode, strobe pulses are generated at a low rate, even in the absence of trigger signals. This provides a slowly moving sweep allowing you to establish correct trace position. If you can't get a trace on-screen with the input signal disconnected, CRT intensity control centered, and the AUTO button pressed, you can be practically certain that you've got a problem for the repair lab—it's that foolproof.

If you're familiar with the peak-to-peak auto trigger mode available on many of the newer TEKTRONIX conventional oscilloscopes, you'll applaud the automatic trigger mode in the 5S14N and 7S14. It's very similar. When a trigger signal is applied in the AUTO mode, the circuit senses the positive and the negative peak levels of the signal and effectively applies these two levels across the front-panel LEVEL control. As a result, you can trigger at any point on the selected slope of the signal. The circuit is responsive to amplitude changes in the triggering signal, giving you nearly as much LEVEL control range on small signals as on large ones; and triggering is much easier on small signals than in the normal mode.

Traditionally, tunnel diodes have been used in sampling oscilloscope trigger circuits because they were the only components providing acceptably low trigger time-jitter. Tens-of-picoseconds of jitter is hardly discernable with the fastest sweeps in a conventional scope but becomes highly objectionable in a sampling scope. Using new high-speed emitter-coupled integrated circuits, low trigger-jitter is maintained in the 5S14N and 7S14 while providing the normal level-selection type of triggering found in conventional scopes.

Wide-range variable trigger holdoff is the most convenient way to trigger stably on a train of pulses having nearly equal amplitude but varying widths and spacing. Digital words are a common example. The 5S14N and 7S14 have a wide holdoff range that is effective for all time-per-division settings.

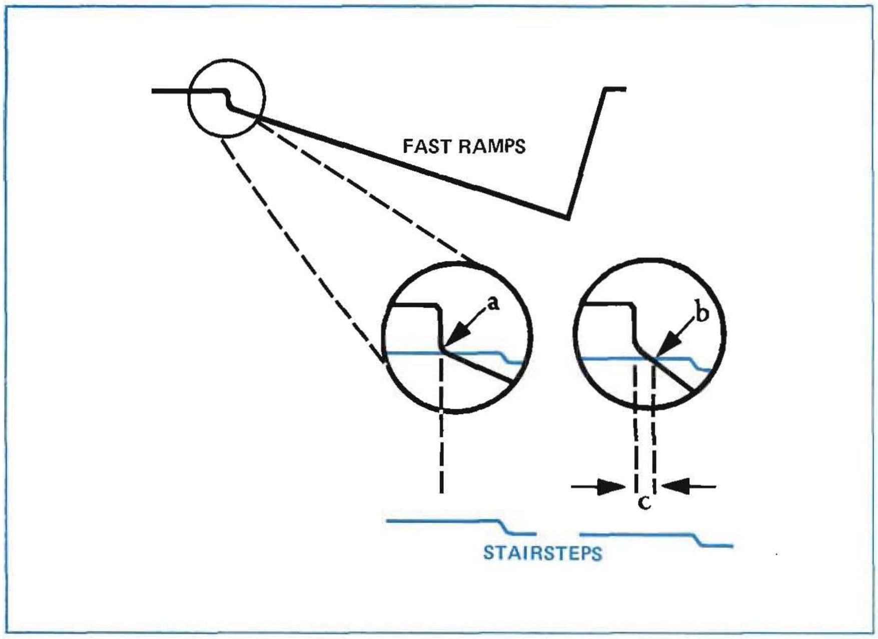


Fig. 1. *Timebase Non-linear Region*

A fast ramp is generated each time the triggering signal is recognized. A strobe pulse is generated each time a fast ramp crosses the existing level of a stairstep. Then the step generator advances one step and waits for the next fast ramp to cross the new level. Each fast ramp causes one sample to be taken of the vertical signal and causes the CRT beam to move horizontally one step.

If the top stairstep is set high enough to be above the linear region of the ramps (a) the time base will be non-linear. If the top level is set low enough to be in the linear region (b) leadtime will be lost. Lost leadtime (c) prevents leading edges of pulses from being displayed when time per CRT division is comparatively long.

Time base non-linearity may be confined to less than ½ of the first CRT division when sweep ***delay*** *instead of sweep* ***magnification*** *is provided. That permits leading edges to be displayed at practically any time per division.*

Ever Lose a Leading Edge?

The principal use for fast scopes is to look at fast signals, such as high-frequency sinewaves, very narrow pulses, or the risetime of very fast pulse edges. Scopes with built-in delay lines allow you to look at the leading edges of pulses when triggered on those edges. But when you decide to measure pulse width after measuring the risetime of a very fast pulse edge, you will have trouble with the average sampling scope if the pulses are microseconds wide and milliseconds apart. The same is not true of conventional scopes.

The trouble manifests itself in a very simple way. When you change the time per division enough to see the trailing edge of your pulse, the leading edge disappears! Often you can delay out and display the entire pulse following the one you are triggered on. But that involves a different set up and sometimes the period between successive pulses is not constant, causing excessive time-jitter in the display. At other times the sample rate may have to be reduced by a factor of 10 or more resulting in low sample-density and a flickering trace.

Why the Leading Edge Was Lost

The reason fast leading edges are not viewable on most sampling scopes when internally triggered and when the time scale is below about 50 or 100 ns/div, may be of interest. Most sampling scopes have only one fast-ramp generator circuit and the slope of this ramp is one thing that determines the time per division. In effect, any portion of the ramp may be magnified to reduce the time per division. The amount of magnification is another factor that determines the actual displayed time per division.

Because large amounts of magnification are invariably used to produce the shortest units of time per division, it is simple and convenient to let the fast ramp serve the additional function of producing time-base delay. For example, a ramp which is magnified 100 times can provide up to 100 screen-diameters of time delay.

Typically, an uncalibrated "time position" control on the front panel lets you select the amount of delay needed to position the signal of interest on-screen. When this time position control is set for minimum delay, the beginning of each scan corresponds to the beginning of the ramp. The first part of the ramp is always the most non-linear, and high amounts of magnification in this area may result in large timing errors over a large portion of the screen. There are two apparent solutions to this problem: (1) Adjust the circuits to skip the earliest part of the ramp; or (2) confine the non-linearity to a fraction of the first CRT division by not magnifying the ramp.

Sampling oscilloscopes have traditionally used the first alternative, skipping the earliest part of the ramp, and this is what causes fast leading edges to disappear at slower time per division settings. At the slower settings, fast leading edges are simply not sampled, therefore they can't be displayed.

Leading Edge Found

If you use only one fast ramp generator circuit and decide to confine the non-linear section to a fraction of the first division you lose delay capability for the slower ranges. However, by using two ramp generators, one mainly to delay the other, there is no penalty. With this arrangement you not only solve the problem but have a valuable conventional-scope feature—calibrated sweep delay. Borrowing familiar terminology we call one of the ramps the *delaying* sweep and the other the *delayed* sweep. The 5S14N and 7S14 bring calibrated delayed-sweep technology to the sampling world for the first time in an inexpensive sampling scope package.

Trailing Edge Tags Along Too

Using sweep delay instead of sweep magnification prevents another kind of problem—that of losing sight of a particular region of a waveform when merely trying to change the time per division. This happens if you inadvertently change the delay range when you mean only to change the time per division. This can easily happen when the delay-range switch and the time-per-division switch are operated by the same knob or are concentric interlocking knobs. In the 5S14N/7S14 two-ramp sweep delay system, the two knobs are not locked together. Therefore, the time delay doesn't change when you change the time-per-division knob.

Two Time Markers—A Happy Pair

In conventional delayed-sweep scopes the beginning of a bright segment of the trace identifies the end of the delay interval and the beginning of the delayed-sweep ramp. The sweep represented by the bright segment is displayed when the delaying sweep is selected as the CRT time base. When delayed sweeps are selected, the beginning of the trace corresponds to the beginning of the bright segment. This system works very well when identifying particular pulses in a pulse train, for example. But for delay measurements it leaves some doubt about where the delay interval commences.

What you would like to have is a bright spot in the trace, to show you where delay started. To produce such a bright spot at the fastest sweep rates of a conventional scope would require the generation of very narrow, high-amplitude pulses. But that tough requirement is not applicable to sampling scopes since the displayed equivalent- time sweeps are relatively slow. Accordingly, we've included just such a capability as a standard feature in the 5S14N/7S14.

With these plug-in units, two bright dots appear in the trace when the delaying sweep is selected. The first dot corresponds to time-zero and the second dot corresponds to the end of the delay interval—the point at which the delayed-sweep ramp starts. The position of the first dot is even controllable. With the DELAY ZERO control, it can be positioned anywhere over at least the first 9 divisions of the trace, allowing the user not only to know where delay starts but to choose where it starts. The second dot can be positioned anywhere on screen to the right of the first dot with the 10-turn precision DELAY TIME MULT dial. Each full turn of the dial

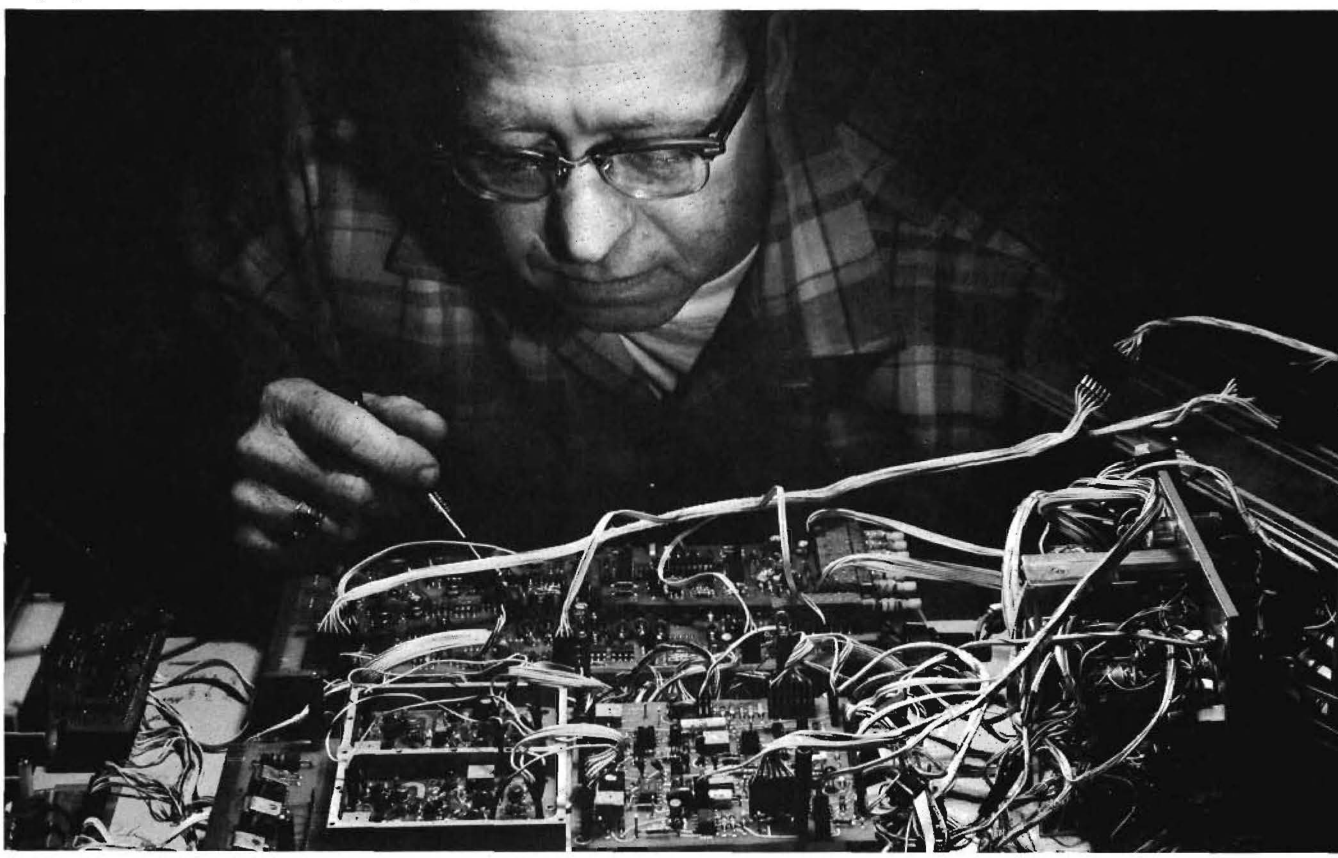


Fig. 2. *Manufacturing economies are achieved by testing and calibrating circuit boards before installation in the plug-in*

corresponds to the time of one division on the CRT. The position of the second dot can be made to coincide with the position of the first dot by setting the dial to 000, and if that position happens to be at the left edge of the screen it means the delayed sweep can be started with zero delay, or coincident with the delaying sweep.

To prevent the second dot from going off-screen when the DELAY TIME MULT dial setting is increased beyond that necessary to position the dot to the right end of the trace, the first dot is made to automatically back up. In other words, the 10-turn dial setting is always proportional to the separation between dots. The DELAY ZERO knob actually controls the position of both dots at the same time, maintaining a fixed separation between them until one of the dots reaches the end of the trace. At that point the knob may be turned further but without effect.

Two-Dot Time Measurements

The two dots identifying the beginning and end of the delay interval provide an accurate, unique and convenient way to make time measurements not even related to sweep delay. By positioning the two dots to the desired points on the waveform, the time between the points may be read from the 10-turn DELAY TIME MULT dial. This technique is particularly attractive for checking whether the time between the desired points is less than, or greater than, a predetermined amount selected by the dial. It is like being able to arbitrarily select the horizontal separation between any two vertical graticule lines to correspond to any specific time interval you may want to measure, e.g., 46.7 nanoseconds, and then being able to position the two lines any place across the screen.

Incidentally, you can even make corroborative checks on timing accuracy by seeing whether the number of CRT divisions between the dots equals the number of turns on the DELAY TIME MULT dial.

Two-Channel Delta Delay

One of the main reasons for having a dual-trace oscilloscope is to compare two signals. When the purpose of the comparison is to measure small time differences between the two signals, fast scopes are needed. Often the difference in signal delay through two similar cables is enough to impose a problem. For example, just a centimeter of difference in length between two identical cables can cause as much as 50-picoseconds difference in delay. When the cables are precisely the same length but have different propagation velocities there may be as much as 16 ps of difference in delay for each centimeter of length. A front-panel screw-driver control on the 5S14N and 7S14 lets you compensate for these differences (up to ± 1 ns) and, in effect, equalize the delay. You simply apply one signal to the inputs of both cables and minimize any difference in the display with the screwdriver control.

By pushing the CH2 INVERT button and the ADD button, the two sampled input signals should be equal and opposite in phase and amplitude, and nearly cancel each other to display a straight horizontal trace. With the CH2 INVERT pushbutton you can also make critical comparisons of two similar pulses that have opposite polarity.

Delta delay is also convenient when comparing the shapes of two similar signals that occur nanoseconds apart. You can superimpose them with the control after first selecting two input cables of unequal length to provide the right delay difference to bring the two signals into approximate coincidence.

Summary

The bandwidth of sampling oscilloscopes has increased by a greater factor than conventional scopes in the fourteen years since sampling scopes were introduced commercially, and the original gap in bandwidth has not yet been closed. Sampling scopes of 1-GHz bandwidth are no longer sophisticated or high priced. Some sell for less than conventional scopes that have half that bandwidth.

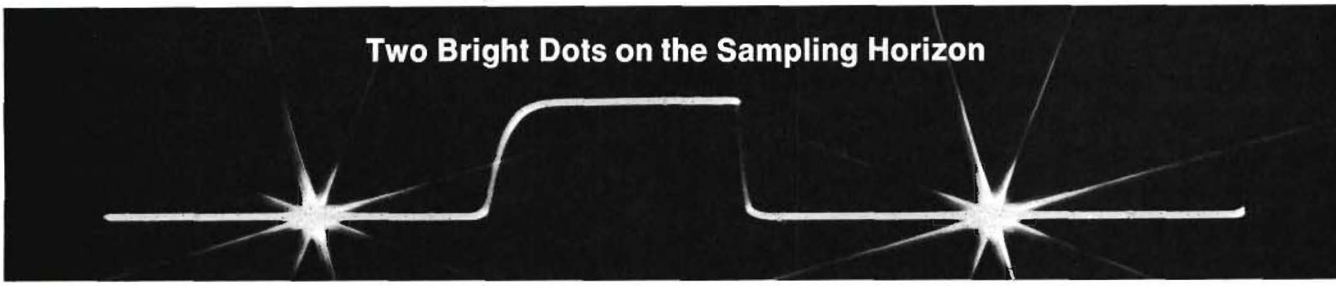
But sampling oscilloscopes have not been quite as easy to use or understand so they have not been readily accepted. A surprising number of response differences between sampling scopes and conventional scopes are not basic and may be eliminated by suitable design. The 5S14N and 7S14 are two new TEKTRONIX sampling plug-in units designed with these factors in mind. Some valuable new features not found in conventional scopes, or other sampling scopes, have been added.

John celebrated his 20th year with Tektronix last November. Most of this time, except for six years as a Field Engineer in the late 50's, he has been providing training and technical support to Field Engineers.

John is author of two Tektronix Concepts books—one on Semiconductor Device Measurements and one on Sampling Oscilloscope Circuits.

He enjoys golfing, fishing and philosophizing. Recently, with one of his three children, he has become a hot-air balloon enthusiast. His wife, Anne, will become a registered nurse this month fulfilling a lifelong ambition.

John A. Mulvey



Two Bright Dots on the Sampling Horizon

Two bright new dots appear on the sampling horizon with the introduction of two new sampling plug-ins by Tektronix, Inc.—the 5S14N and 7S14. These two bright dots herald new measurement capability and operating ease for those of you making sampling measurements.

We might well name the dots "Alpha" and "Omega" since they mark the beginning and ending of a time window—a window that can be as short as 10 ns, as long as 1 ms, or any interval in between. You can set the window to an accuracy of 1% and position it anywhere on the sweep displayed on the CRT.

Actually, the two dots represent two points in time on the delaying sweep of the 5S14N/7S14. The position of the first dot is set by the front-panel DELAY ZERO control and the second dot is positioned by the DELAY TIME MULT dial. A broader discussion of the "why" and "how" of two-dot is presented in the article entitled "A Simple Sampling Oscilloscope."

Several applications for such a measurement capability come readily to mind; let's look at a few of the more useful ones.

Pulse Width Measurements

We often need to make pulse width measurements, and while they are not particularly difficult, they can be time consuming. Especially if the 50% points don't conveniently fall on the vertical graticule lines of the CRT. With these two dots it's relatively simple. The pulse to be measured is displayed using the Delaying Sweep. Sweep rate and vertical deflection factor are selected to present the entire pulse on-screen as you would for conventional pulse width measurements. The first dot is then set to the 50% point on the leading edge; the second dot to the 50% point on the trailing edge (see Fig. 1). The pulse width is then the product of the DELAY TIME MULT dial setting and the SEC/DIV setting.

If the rise and fall times are fast, you may notice that more than one sampling dot on the rise and fall are bright. This is because the bright dot occupies about one-tenth of a division on a horizontal trace. The beam is sometimes deflected vertically more rapidly than it is horizontally so the brightened portion appears longer vertically than horizontally. To avoid making an error in the time measurement, make sure you set the beginning of both the "start" and "stop" dots at the 50% points. Remember that the sweep is moving from left to right so the beginning of the bright dot is at the left.

A Variable Accurate Time Reference

In the opening remarks of this article we referred to the two-dot system as a time window that could be positioned anywhere on the trace. In production testing, this time window, or time reference, can be a real time saver. For example, suppose you need to check several devices for a pulse width of not more than 56.2 ns at the 50% points. The pulse is displayed on the Delaying Sweep with the SEC/DIV control set at 20 ns. Then the DELAY TIME MULT dial is set to 2.81 giving us a time interval of 56.2 ns. With the DELAY ZERO control the first dot is set to the 50% point on the leading edge of the pulse. Now note the position of the second dot. It should be at the 50% point on the trailing edge. If it is below the 50% point

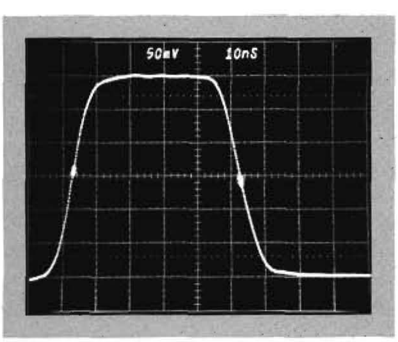


Fig. 1. Pulse width measurements with the two-dot system.

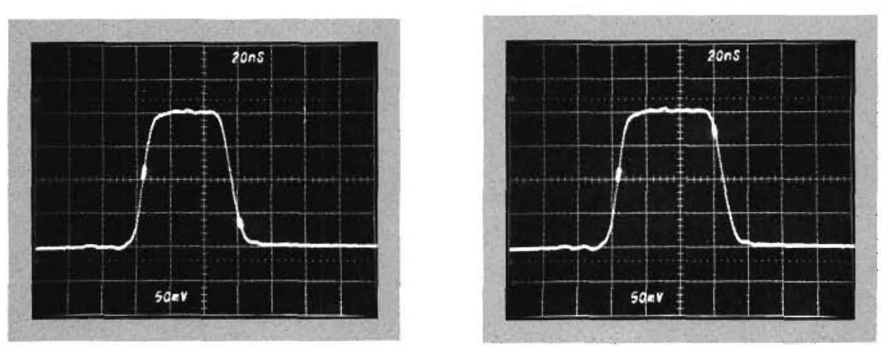


Fig. 2. Using two-dot to establish an accurate time reference on-screen.

A. Pulse width less than reference. *B. Pulse width greater than reference.*

(see Fig. 2a), the pulse width is less than 56.2 ns; if above the 50% point (Fig. 2b), the pulse width is greater than 56.2 ns. Now you can rapidly test for proper pulse width on several devices without changing the setup. All you have to do is set the first dot to the 50% point on the leading edge and note the position of the second dot on the waveform.

Time Between Pulses Using Dual Trace

The two-dot system is also very useful for measuring the time between two independent pulses. The Teknique article in this issue discusses some of the precautions to be observed when making sampling dual-trace measurements. It would be well to review that article when setting up for this type of measurement.

Once you have the two pulses properly displayed on-screen, making the measurement is easy. Simply adjust the DELAY ZERO control to set the first dot to the 10% point on the rising edge of the first pulse. Then set the second dot to the 10% point of the rising edge of the second pulse, using the DELAY TIME MULT. (The 10% points are used to provide more accurate measurements between pulses with different risetimes.) The delay between the two pulses is now determined by multiplying the DELAY TIME MULT setting by the Delaying Sweep SEC/DIV setting.

You will notice there are now four dots on-screen (see Fig. 3). The first dot on each trace indicates the delay zero point, and the second dot the delay selected by the DELAY TIME MULT. You can ignore the two dots that are not indicating a measurement point.

Measuring Phase with Two-Dot

The two-dot system has several advantages when making phase measurements. Not only can they be made more quickly, but also more accurately since the time base accuracy doesn't have to be considered in the result. Fig. 4 shows the signals properly displayed for the measurement. Here again it would be well to refer to the Teknique article for setup procedures to minimize the possibility of error caused by differences in cable lengths, etc.

Once you have the signals displayed as in Fig. 4, the first dot is set to the point where the reference waveform first crosses the center. The DELAY TIME MULT is set to position the second dot to the point where the reference waveform crosses the center line one complete cycle later. Note the reading on the DELAY TIME MULT dial. The number of dial divisions corresponds to 360°, or one cycle. Now change the DELAY TIME MULT setting to move the second dot to where the second waveform crosses the center line the first time, and note the dial reading. The phase difference between the two signals is calculated using the simple formula:

$$\text{Phase Difference} = \frac{\text{Second DTM Reading}}{\text{First DTM Reading}} \times 360^\circ$$

Handy Reference Flags

Another convenient use of the two bright dots are as markers to flag points of interest on the display. For example, in the pulse train shown in Fig. 5, the marker is used to flag and identify the seventh pulse. To obtain this display, set up the system to show the complete pulse train. Turn the DELAY ZERO control fully counterclockwise to position the first dot to the left side of the graticule. Then, set the DELAY TIME MULT dial to 0 and slowly turn it clockwise to move the second dot across the screen. You can easily count the pulses as the bright dot moves across them until you are flagging the desired pulse. Note that the marker, or flag, is no longer on the correct pulse if the triggering or time-per-division is changed, or if the input signal changes.

Summary

This is but a brief overview of some of the measurement capabilities of the two-dot system, a standard feature of the new 5S14N/7S14 sampling plug-ins. Coupled with the operating ease of these new samplers, two-dot will help you get better answers, faster, in the arena of high-speed signals.

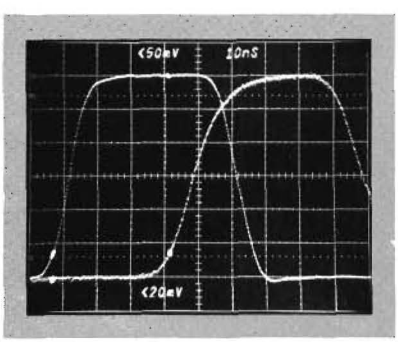


Fig. 3. Making time difference measurements between two pulses with two-dot.

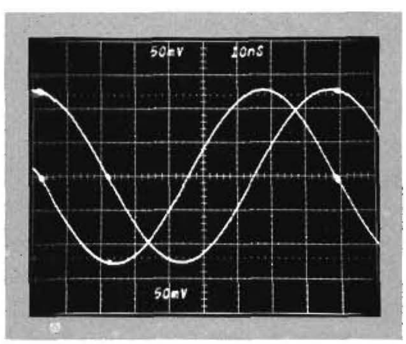


Fig. 4. Phase measurements are quickly and accurately made using two-dot.

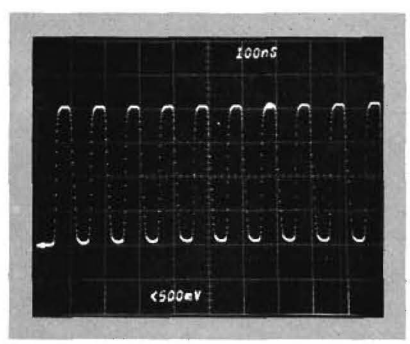


Fig. 5. Using two-dot as a flag on a complex waveform.

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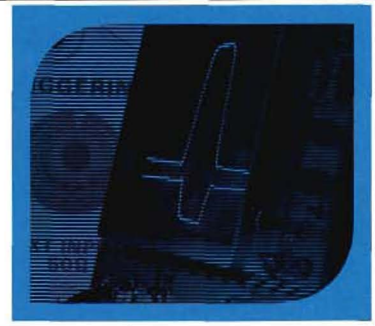


Dual-Trace Time Difference Measurements with Sampling

Sampling techniques have been a vital part of electronic measurements for many years. However, both the complexity and high cost of sampling have limited its widespread application. With the introduction of the 5S14N/7S14 Dual-Trace Delayed Sweep Sampler (see feature article in this issue), sampling becomes easy to use and lower in cost than many conventional oscilloscopes. To aid the newcomer to sampling oscilloscopes as well as to refresh the techniques for the experienced sampling user, we present this review of some basic sampling measurements.

Dual-trace vertical systems, whether in sampling or conventional oscilloscopes, have greatly broadened the usefulness of the oscilloscope. Coupled with the unique features offered by sampling oscilloscopes, dual-trace operation makes possible some very useful and accurate measurements on the applied signals. In addition to being able to simultaneously view two signals and determine the time and amplitude relationship between them, dual-trace operation also allows interactive displays of the two signals; e.g., X-Y and added algebraically.

Accurate measurement of the time relationship between two independent signals is an important application of dual-trace oscilloscopes. Dual-trace sampling oscilloscopes provide new versatility for making these measurements. Many sampling oscilloscopes provide a delay-matching feature[1] which makes possible more precise time-difference measurements; these applications will describe the use of this feature in making accurate time measurements. While the same basic measurement techniques with which you may already be familiar can be used with sampling, some special precautions must be observed. Particular care should be taken in the areas of signal connections and cables; refer to the instruction manual accompanying your sampling system for further information.

Let's look at some of the basic techniques for measuring the time relationship between two signals with a dual-trace sampling system.

PHASE DIFFERENCE MEASUREMENT

Time difference between two sinewave signals of the same frequency may be measured using one of the signals as the reference and observing the phase difference between them. There are two convenient methods of measuring phase difference with a dual-trace sampling system. Both methods can measure signals up to the bandwidth limit of the vertical system. The main differences between these methods are in terms of accuracy and convenience.

Although these techniques can be applied to non-sinusoidal signals, we will only be looking at sinewave applications. With other than sinewave signals, the resultant display will depend on the waveshape of the applied signals. Also, the calculation methods given apply only to sinewave signals.

X-Y Phase Measurements

When displaying sinusoidal signals, the X-Y phase measurement method provides the familiar Lissajous display. This method can be used to measure the phase relationship of two identical frequencies, or to display the frequency relationship between two signals which

[1]Standard feature on all current TEKTRONIX sampling oscilloscopes that can be used for dual-trace measurements.

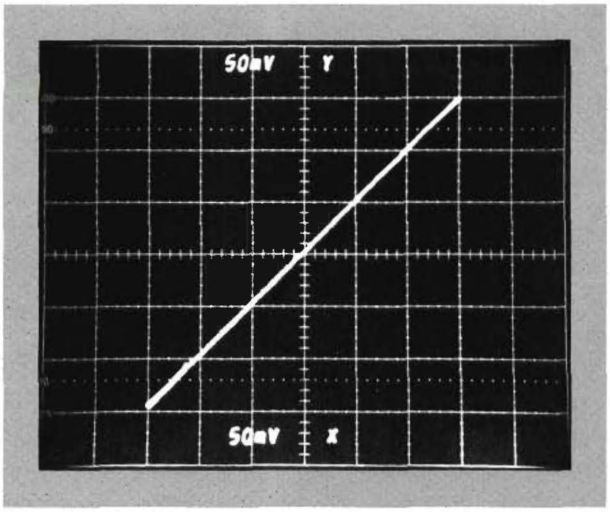


Fig. 1. An X-Y display of two sinewave signals in phase.

are harmonically related. Other uses for the Lissajous display are to check distortion of a signal or as a "null detector" for accurately matching phase. X-Y phase measurements with sampling can be made up to the bandwidth limit of the sampler. This is possible since sampling requires high-freqency circuitry only at the input to the system; low-frequency techniques are used through the amplifiers and to produce the display.

The prime prerequisite for the X-Y measurement is a dual-trace sampling system which has the X-Y display feature–some single-trace sampling vertical plug-in units can be installed in a horizontal compartment to provide the "X" portion of the display. To set up the units for correct display, set the vertical mode switch to X-Y and the time-base triggering controls to free run so it produces strobe pulses. Then, connect one of the signals to both inputs through a power divider and identical cables (the same cables which will be used for the measurement). Here's where the delay-matching adjustment comes in handy! Adjust this delay control for a straight-line display, slanted from the upper right-hand corner of the CRT to the lower left-hand corner. Now carefully adjust the deflection factors of both channels, using the variable controls as necessary, to obtain a display that is exactly six divisions both vertically and horizontally. Then, if necessary, readjust the delay for as straight a line as possible (if the sine-wave has any distortion, it will be impossible to get a straight line). The display should appear similar to Fig. 1, indicating that the cables and two channels have been matched for minimum difference. If you're using a sampler that doesn't have the delay-matching feature, use the X-Y phase measurement method shown in Fig. 2 to determine how much phase shift is involved in the display. This inherent phase shift must be included in the final calculation of phase.

The smoothing controls on either channel should not be used unless the display requires it. If noise is excessive, on the display, adjust the smoothing controls of both channels the same amount (time-base triggering must be adjusted so the strobe pulses are triggered on one of the signals when using smoothing). Then, check that the display still indicates correct delay matching between channels. If necessary, repeat the delay-matching procedure.

Disconnect the power divider and connect the signals to be measured to the two inputs using the same cables as before. Check that the display is still six divisions both vertically and horizontally; adjust the deflection factor as necessary for the correct display. A difference in phase between the two signals is shown by the amount of opening in the loop. A circle display shows 90° phase

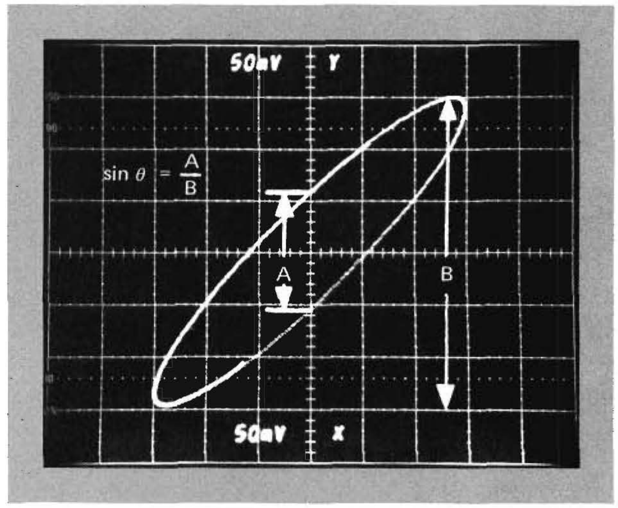


Fig. 2. Phase shift is easily calculated from this X-Y display.

difference and a straight line from upper left to lower right shows 180° phase shift. The phase difference between two signals can be measured accurately by using the method shown in Fig. 2 to calculate the sine of the phase angle between the two signals. The angle can then be obtained from a trigonometric table.

If the instrument you are using cannot be adjusted to offset the inherent phase shift between the two channels and the cables, take this into account in the final calculation. It's often difficult to determine if this inherent phase shift should be added to, or subtracted from, the final result. To resolve this, use the method given under Dual-Trace Phase Measurements to determine if the inherent phase shift is leading (greater than 0°) or lagging (less than 0°). Maintaining one signal as a reference, repeat this check after measuring the phase on the Lissajous display to determine if the signal being measured is leading or lagging the reference. Now, algebraically add the inherent phase shift of the system and the measured phase shift between the signals to determine the overall phase shift.

The Lissajous figure can be used as a "null indicator" to adjust the phase shift through a device, or between devices. First, obtain an X-Y display as described previously. For best results, the sampler should have a front-panel delay control as units without this feature do not lend themselves well to this application. After the delay compensation has been correctly adjusted, apply the signals to the inputs through the cables used for setup. Then, calibrate the unit under test for a "null" indication, or zero delay, as shown by a straight line display from upper right to lower left. Other reference points can be chosen such as a full circle to indicate 90° delay, straight line from upper left to lower right for 180° delay, or any other display which indicates the desired amount of delay.

The "null" display can also be used for accurate frequency adjustment. After setting up the system with the reference signal, connect the signal to be adjusted to the other input. As the frequency of this signal is adjusted, a stable Lissajous display will be obtained only when the frequencies of the two signals are matched. At other frequencies, the display will appear to rotate on screen.

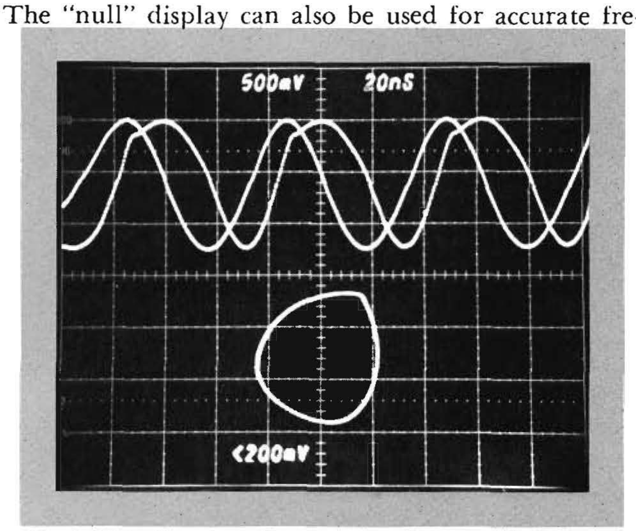


Fig. 3. Distortions in a sinewave signal are readily detected using an X-Y display.

Distortion of similar sinewaves is shown by irregularities in the proper shape of the Lissajous figure. After connecting the two signals to the inputs, adjust the front-panel delay control for a circular display; if this control does not have enough range to obtain a circular display, add delay in one channel with an additional length of cable. The distortion will appear as an anomaly in the display (see Fig. 3).

Dual-Trace Phase Measurements

This phase measurement method provides a very accurate means of determining phase, particularly where very small differences exist between the two signals. For this measurement, the signals must be the same frequency.

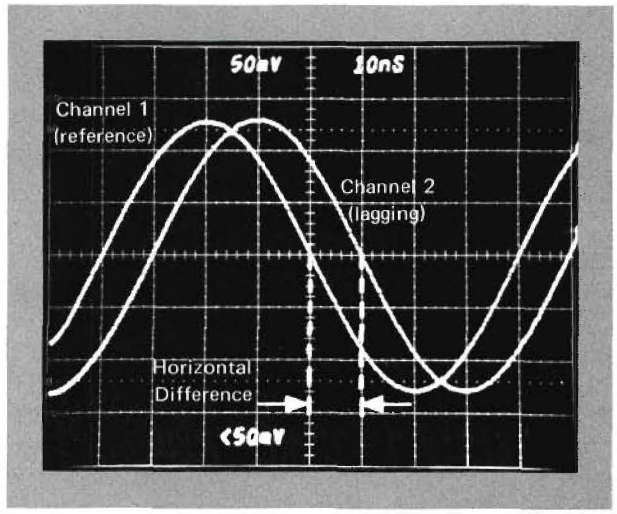


Fig. 4. Phase measurements are conveniently made using the time base and dual-trace display.

To set up the units for correct display, connect the primary or reference signal to both inputs through a power divider and identical cables (the same cables which will be used for the measurement). While displaying only one channel, adjust the time per division and the variable control so one complete cycle of the signal spans exactly eight horizontal divisions. This calibrates the system in terms of degrees/division which can now be expressed as 45°/division (i.e., 360° in the complete waveform, divided by 8 divisions of display equals 45°/division).

Now, set the sampler for dual-trace operation, triggered internally from the reference signal on one of the channels (if the sampler does not have the capability to internally trigger from only one channel, externally trigger the unit from the reference signal). With the same vertical deflection on both channels, adjust the front-panel delay control so the two traces coincide exactly. If your sampler does not have this feature, measure the horizontal difference between the two traces at corresponding points; then note the amount and direction of inherent delay (i.e., leading or lagging the reference) for use in the final calculation.

Disconnect the power divider and reconnect the reference signal to the channel which is providing the trigger. Connect the other signal to the remaining channel; adjust the vertical deflection factors if necessary, so the waveforms are the same height vertically. Now, measure the distance between corresponding points on the waveforms and multiply by 45°/division to determine the exact phase difference (see Fig. 4). If the inherent delay in the system could not be compensated, multiply this measured difference by 45°/division. Observation of the present display should indicate whether to add or subtract this inherent delay for the correct final result. For small phase differences, a more precise measurement can be made by increasing the time per division with the sweep magnifier or by using the delayed sweep for magnification (do not change variable control setting). The magnified horizontal rate can be determined by dividing the previous rate (45°/division) by the amount of magnification. Fig. 5 shows a typical magnified display.

This display can also be used as a "null indicator" similar to the X-Y method. First compensate for the inherent delay and connect the two input signals as described. Now, the delay of the unit under test can be adjusted for zero delay or phase shift. It can also be used to adjust the frequency of the unit under test. Since the display is triggered from the reference signal, the signal at the output of the unit under test will appear to "float" across the screen unless the two frequencies are closely matched.

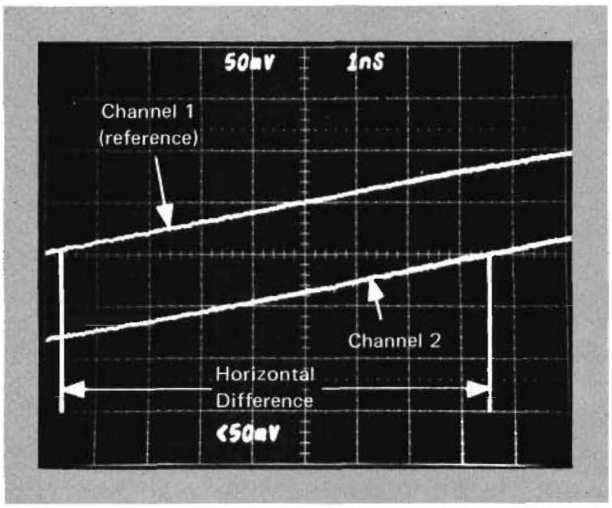


Fig. 5. High resolution multi-trace phase measurement with sweep rate increased 10 times.

TIME DIFFERENCE MEASUREMENTS

The basic techniques of time-difference measurements are the same as for phase measurements. This measurement method is normally used when looking at pulses or two signals that are not time related.

In setting up the instrument for accurate measurement, connect the primary or reference signal to both inputs with a power divider and identical cables. Set the sampler for dual-trace operation, triggered internally from the signal on only one channel (if the sampler does not have internal triggering from only one channel, externally trigger the unit from the reference signal). Adjust the front-panel delay control so the two traces coincide exactly (this is easiest if the vertical deflection from both channels is the same). If your sampler does not have the delay compensation feature, note the amount and direction of horizontal difference (i.e., leading or lagging the reference) and take it into account in the final calculation.

Disconnect the power divider and reconnect the reference signal to the channel which is providing the trigger. Connect the other signal to the remaining channel. Adjust the vertical deflection factors, if necessary, so the waveforms are the same height vertically. Adjust the time per division so the points on the two waveforms between which the time-difference measurement is to be made are displayed within the graticule area (see Fig. 6). Now, measure the distance between the desired points on the two waveforms and multiply it by the time per division (take into account any inherent delay). This will provide accurate time difference if the horizontal variable control is in the calibrated position.

This display can also be used as a "null indicator". First compensate for the inherent delay and connect the two input signals as described. Then adjust the

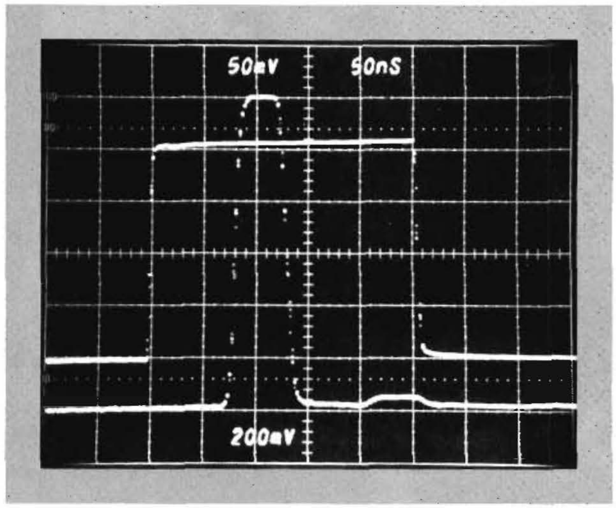


Fig. 6. Measuring time difference between two pulses.

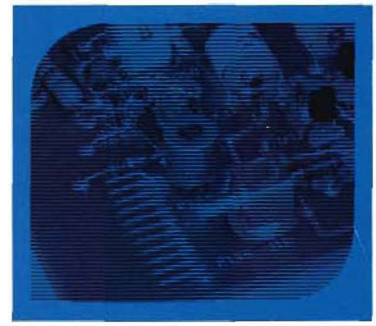
delay through the unit under test so the desired points on the reference trace and the output of the unit under test coincide. Of course, this setup can also be used to adjust the unit under test for a calibrated amount of delay using the graticule as a time reference to determine the correct amount of delay.

SUMMARY

Although the basic applications for sampling and conventional oscilloscopes are very similar, it's often easy to overlook some of the simple uses for sampling. Recent advancements in sampling instruments have made them easier to use and make many of these measurements easier and more accurate than with conventional oscilloscopes. We've only looked at some of the basic techniques for making accurate time measurements with a dual-trace sampling system. As you apply these basic techniques in your sampling measurements, you'll discover many new and useful applications for your sampling oscilloscope.

SERVICE SCOPE

by *Ken Lindsay* Sampling Staff Engineer



Servicing the Sweep Circuit in the 7T11 Sampling Sweep Unit

In the March/April issue of TEKSCOPE, we looked at servicing the Trigger Circuit of the 7T11. This article provides a simplified method for adjusting and trouble-shooting the 7T11 Sweep Circuits.

Before beginning calibration or troubleshooting of the instrument, it's a good idea to review the basic theory of operation as given in the 7T11 Instruction Manual. This will help to identify the inter-relation of the stages within the Sweep Circuit so you can more easily locate problems or check the interaction of adjustments. A simplified block diagram of the 7T11, which identifies the active components associated with each block, is included in this article. The checkout procedure also includes information on instrument operation as it relates to the checks and adjustments to be made.

Initial Set-Up

1-4. Follow Steps 1 through 4 under initial Set-Up given in the previous article. Then, add the following steps:

5. Using a 5/16″ open-end wrench, remove the nut holding the 7T11 EXT TRIG INPUT jack to the front panel. Remove the jack from the front panel but leave the other end connected to the 7T11 Trigger circuit board.

6. Loosen the four locking screws that hold the Trigger circuit board in place; carefully lift the board loose. This board should always be handled with the utmost care so as not to break any of the delicate components or bend any of the closely spaced leads. Lift the whole circuit board up enough to slide the entire top edge of the board into the slot in the 7T11 upper chassis rail. This will support the trigger circuit board giving access to the adjustments and test points on the Timing circuit board.

Sweep Checkout

In the SEQUENTIAL equivalent time sampling mode, the 7T11 employs three separate ramp generators; a slow ramp generator and two fast ramp generators (refer to the simplified block diagram, Fig. 1). The Slow Ramp Generator produces a positive-going ramp from zero to about +10 volts with its slope controlled by the front-panel SCAN control. The main function of this ramp is to set a changing reference voltage for the Slewing Comparator and to indirectly produce horizontal deflection voltage to drive the mainframe amplifier. The output of the Slow Ramp Generator is applied to an inverting amplifier with a selectable gain from X.5 to X.001 determined by the front panel TIME/DIV switch. To check the operation of the Slow Ramp Generator, use a 10X probe and scope with an overall sensitivity of 2 volts/div. Check for a +10-volt ramp at TP636 on the Analog Logic circuit board with the slope adjustable with the SCAN control. In order to get a waveform at TP636, the TIME POS RNG must be set to 50 μs or faster and the trigger circuit should be free-running (push H-F SYNC button in).

One of the fast ramp generators is called a TTH (Time-To-Height) generator and is used to determine the basic timing of the 7T11. The slope of the TTH ramp output sets the basic timing and is controlled by the front-panel TIME POS RNG control. The stopped voltage level of the ramp, in conjunction with the Horizontal Amplifier, directly determines the horizontal drive voltage to the mainframe amplifier. The TTH

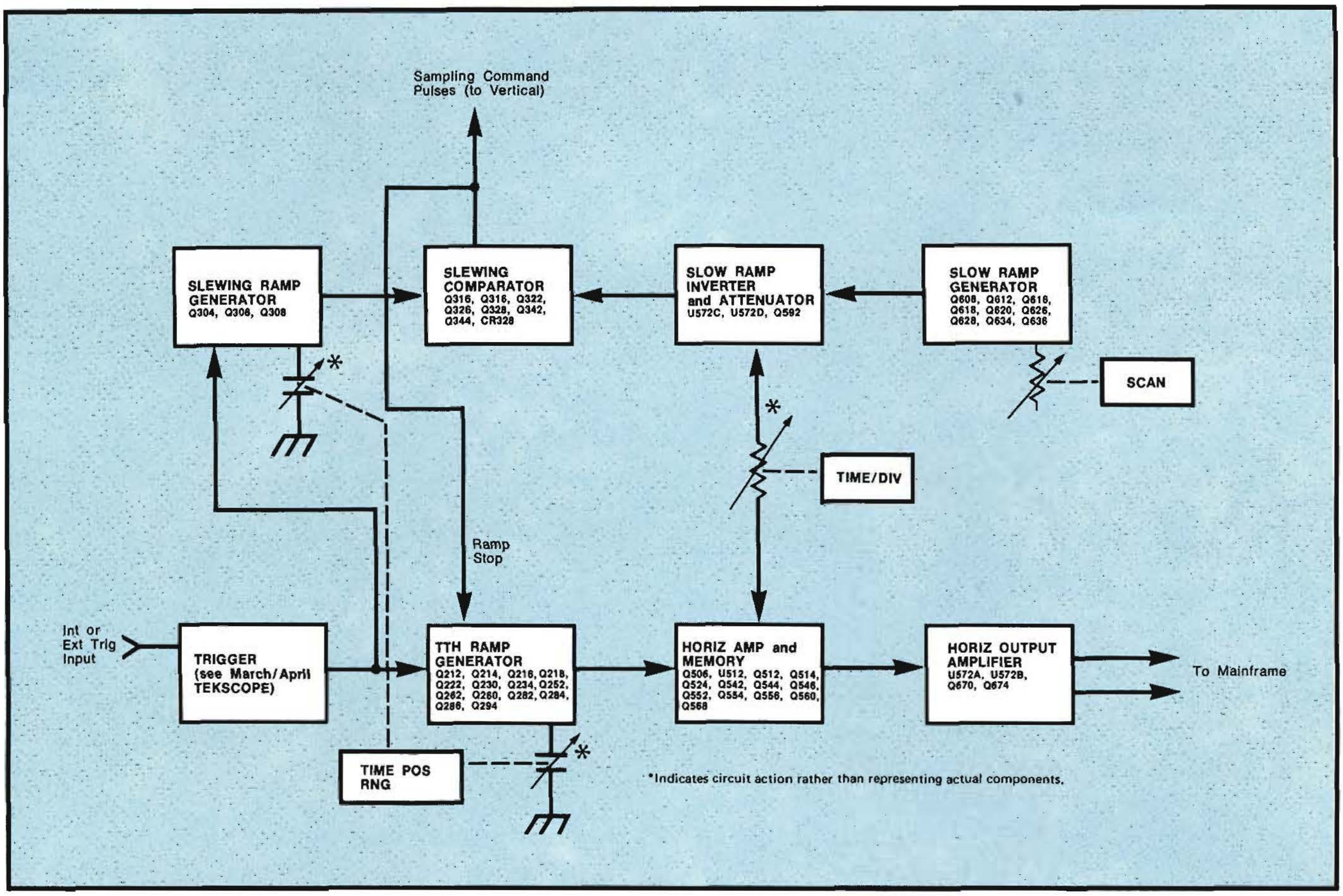


Fig. 1. 7T11 Sequential Mode block diagram (Components not shown are not active in this mode).

ramp output is always negative going in the SEQUENTIAL mode of operation, but may be positive, or produce no output at all in the RANDOM mode. The TTH ramp is initiated by an output from the Trigger circuit in the SEQUENTIAL sampling mode. To check the output of the TTH ramp generator use a 10X probe and scope with the overall sensitivity set at 1 volt/div. Connect the probe to TP286 on the Timing board and set the 7T11 controls as follows:

TIME POS RNG	50 μs
TIME/DIV	5 μs
TIME POSITION & FINE	Fully CW
SCAN	12 o'clock
REP	Pushed in
SEQUENTIAL	Pushed in
HF SYNC	Pushed in

The waveform at TP286 should be a succession of negative-going ramps starting at approximately zero volts and successively going to approximately −5 volts. If a component needs to be replaced in the TTH circuit, care should be exercised to match the lead length and component proximity of the part removed.

The other fast ramp generator, called the Slewing Ramp Generator, drives the other side of the Slewing Comparator. The slewing ramp runs at the same rate and slope as the TTH ramp and always runs negative. As with the TTH ramp, the slewing ramp is started by an output from the Trigger circuit. When the slewing ramp runs negative and reaches the level of the inverted slow ramp, an output is produced by the Slewing Comparator to two circuits. First, to the Vertical Sampling Unit to drive the Strobe Pulse Generator and cause a sample to be taken. The second is to the TTH Ramp Generator, stopping the run-down of the TTH ramp. This stopped level is then applied to the Horizontal Amplifier and Memory.

The Horizontal Amplifier is composed mainly of U512A, U512B, and U512D. U512A has a gain of X1, X2.5, or X5. Both U512B and U512D have a gain of X10. By changing the front-panel TIME/DIV switch, the overall gain can be changed between X1 and X500 in a 1, 2.5, and 5 sequence. As the gain of the Horizontal Amplifier is increased, the attenuation in the Slow Ramp Inverter is increased by the same amount. As a result, the Horizontal Amplifier amplifies a proportionately smaller section of the TTH ramp even though the gain is now greater. This provides a means of changing the TIME/DIV without altering the slope of the TTH ramp. The output of the Horizontal Amplifier is then

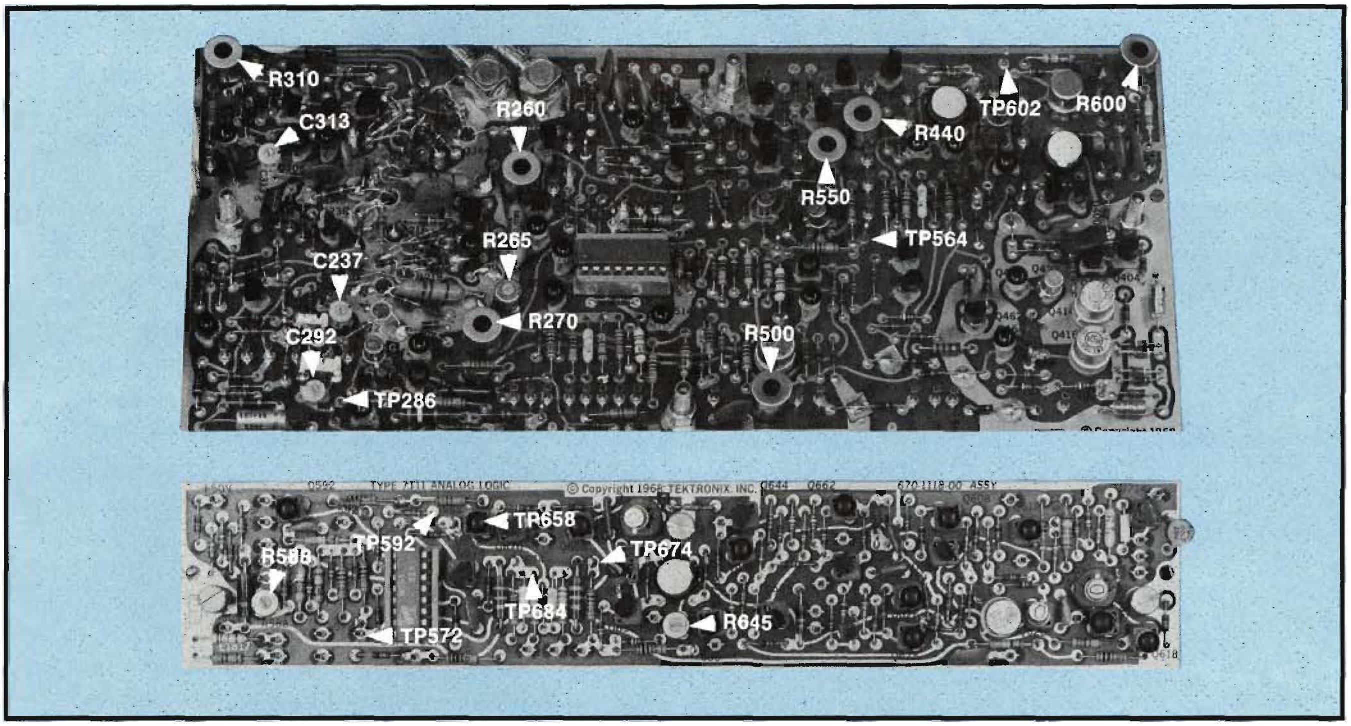


Fig. 2. Location of Sweep test points and adjustments.

gated through Q556 to the Horizontal Memory. The output of the Horizontal Memory may be checked at either the front-panel SWEEP OUT jack or TP564 on the Timing circuit board. Using a 10X probe and scope with the overall sensitivity set to 5 volts/div, check for a staircase output going from +5 to −5 volts with the rate controlled by the SCAN control (50 μs or faster range).

The output from the Horizontal Memory is applied to the Horizontal Output Amplifier. The Horizontal Output Amplifier, comprised of U572A and U572B, converts the staircase waveform input into the proper polarity waveforms to drive the 7000-Series mainframe. The output of U572A (at TP674) goes from −5 volts to +5 volts and the output of U572B (at TP684) goes from +5 volts to −5 volts.

Sweep Adjustments

This procedure provides a quick method for the experienced technician to adjust the 7T11 Sweep Circuit. For a detailed calibration procedure including description of the equipment used and typical waveforms, refer to the 7T11 Instruction Manual.

Refer to Fig. 2 for the location of adjustments and test points in this procedure.

1. Measure the voltage at test point TP602 on the Timing board using a precision DC voltmeter or differential comparator plug-in unit such as the 7A13. The voltage should be within about 1% of +10 volts. If not adjust R600 so it is.
2. Preset the 7T11 front-panel SWEEP CAL fully counterclockwise (ccw) and the 7T11 front-panel POSITION fully clockwise (cw). Set both front-panel TIME POSITION controls fully cw. Preset the Memory Gate Bal pot (R550) fully ccw.
3. Connect a 5X, 50 ohm BNC attenuator to the marker output of a time mark generator such as the TEKTRONIX 2901. To that, attach a BNC Tee and to the tee connect two 50 ohm cables (42 inch). To the far end of one cable attach a BNC-to-3mm adapter and to the other cable, attach a BNC-to-GR adapter. Set the 7S11 for 200 mV/DIV, the Dot Response pushbutton to NORMAL, and the DOT RESPONSE control with the white dot straight up. Set the 7T11 SWEEP RANGE switch fully clockwise for a 50 ms TIME POS RNG and set the TIME/DIV control for 5 ms. Press the HF SYNC pushbutton and a trace should appear. Position the trace with the 7S11 DC OFFSET control to center screen. Connect one of the two cables attached to the time mark generator to the Sampling Head in the 7S11 and the other to the EXT TRIG connector on the 7T11.
4. On the 7T11, push the 50Ω (EXT) button, the X1 TRIG AMP button, and the + SLOPE button. Push the 5 ms button on the Time Mark Generator and trigger on these pulses using the 7T11 TRIGGER LEVEL and STABILITY controls.
5. Note the position of the first marker and adjust the Real Time Zero pot (R500) so that the marker doesn't move to the left and moves no more than

about two divisions to the right while magnifying with the TIME/DIV control for any time per division from 5 ms through 50 μs. Be sure both TIME POSITION controls are fully cw while making this adjustment. Restore the TIME/DIV to 5 ms.

6. Adjust the Memory Gate Bal pot (R550) cw until the first pulse just barely starts to disappear.

7. Disconnect the markers from both the 7S11 and the 7T11 and free-run the trace using the STABILITY and TRIGGER LEVEL controls. The trace should free-run if the STABILITY control is fully cw and the TRIGGER LEVEL is set with the white dot approximately straight up.

8. Set the SCAN control fully cw. Push the REP and SEQUENTIAL buttons and change the SWEEP RANGE to the 50 μs TIME POS RNG. The time per division should now be 5 μs and there should be a free-running trace with about 5 to 10 dots per division. Push the MAN button. The SCAN should be able to move the beam left and right across most of the screen.

9. Connect a test scope to TP568 on the 7T11 Analog Logic board with a 1X probe. Set the vertical sensitivity to 50 mV/DIV and Input Coupling to DC. Free run the test scope time base at 50 μs/DIV.

10. Preadjust R588 for zero volts at test point TP658. Then, while rotating the SCAN control back and forth through about 180 degrees, preadjust R310 to minimize any shift in the DC level of the test-scope display.

11. Set the SCAN control fully ccw and adjust R645 so that the spot just becomes fully unblanked. Now set the SCAN fully cw and check that the spot does not blank. If it does, adjust R645 slightly ccw until it unblanks. Recheck that the spot does not blank with the SCAN control fully ccw.

12. Push the REP button and set the SCAN control to about 9 o'clock. Readjust R588, if necessary, for zero volts on the test-scope display. Fine adjust R310 to minimize any trace shift or bounce on the test-scope display.

13. Push the MAN button and set the front-panel SWEEP CAL and POSITION so the beam moves precisely 10 divisions between the left and right hand edges of the graticule while rotating the SCAN control throughout its range. It is normal for these pots to interact.

14. Reapply 5 ms time markers from the time mark generator to both the vertical and trigger inputs as before. Change the TIME POS RNG to 50 ms and the time per division to 5 ms and trigger on the markers. Adjust R265 for precisely one marker per division. The TIME POSITION controls may be used to line up the markers.

15. Change the TIME POS RNG to .5 ms. The time per division should now be 50 μs. Select 50 μs markers on the 2901 and trigger on them. Adjust R260 for precisely one marker per division.

16. Push the REP button and change the TIME POS RNG to 50 ns. Select 5 ns (sinewave) markers and trigger on them. Adjust C292 for precisely one marker per division.

17. Push the MAN button and set the TIME POSITION control cw. Using the test scope as before, adjust C313 for a minimum shift in DC level at test point TP658 as the SCAN control is rotated back and forth.

18. Push the REP button and set the SCAN control cw. Set both TIME POSITION controls fully cw and adjust C237 while observing how the beginning position of the trace moves. Adjust C237 to display as many of the early cycles of the sinewaves as possible without leaving a gap between the left edge of the graticule and the first dots in the trace while the time per division is changed from 5 ns to 100 ps.

19. Change the time markers to 50 ns, set the TIME POS RNG to .5 μs and the TIME/DIV to 50 ns, and trigger on the sinewaves. Switch to the MAN mode and position the beam precisely to center screen with the SCAN control. Push the RANDOM button and adjust R440 so there is no horizontal movement of the beam when switching back and forth between RANDOM and SEQUENTIAL. Push the REP button.

20. Disconnect the cables and the 5X attenuator from the time mark generator and place the 5X attenuator at the input to the sampling head. Connect a BSM-to-BNC adapter to the 7T11 PULSE OUT connector and connect a 50-ohm cable between the PULSE OUT and 5X attenuator on the sampling head input.

21. Free-run the sweep at 5 ns/DIV (50 ns TIME POS RNG). Push the RANDOM button and display the PULSE OUT. Use the TIME POSITION controls to place the step-signal near the left edge of the screen. Set the 7T11 to 1 ns/DIV and center the step signal. Set the 7S11 to 20 mV/DIV and center the signal with the 7S11 controls. Adjust the 7S11 DOT RESPONSE controls for the cleanest trace. Adjust R270 through its range while keeping the step on screen and set for the cleanest rise on the step signal.

This completes the timing adjustments on the 7T11. Replace the coax leads at J344 in the 7T11 and J430 in the 7S11. Fasten the 7T11 Trigger board in place and reinstall the TRIG IN jack in the front panel.