TEKTRONIX

SERVICE SCOPE

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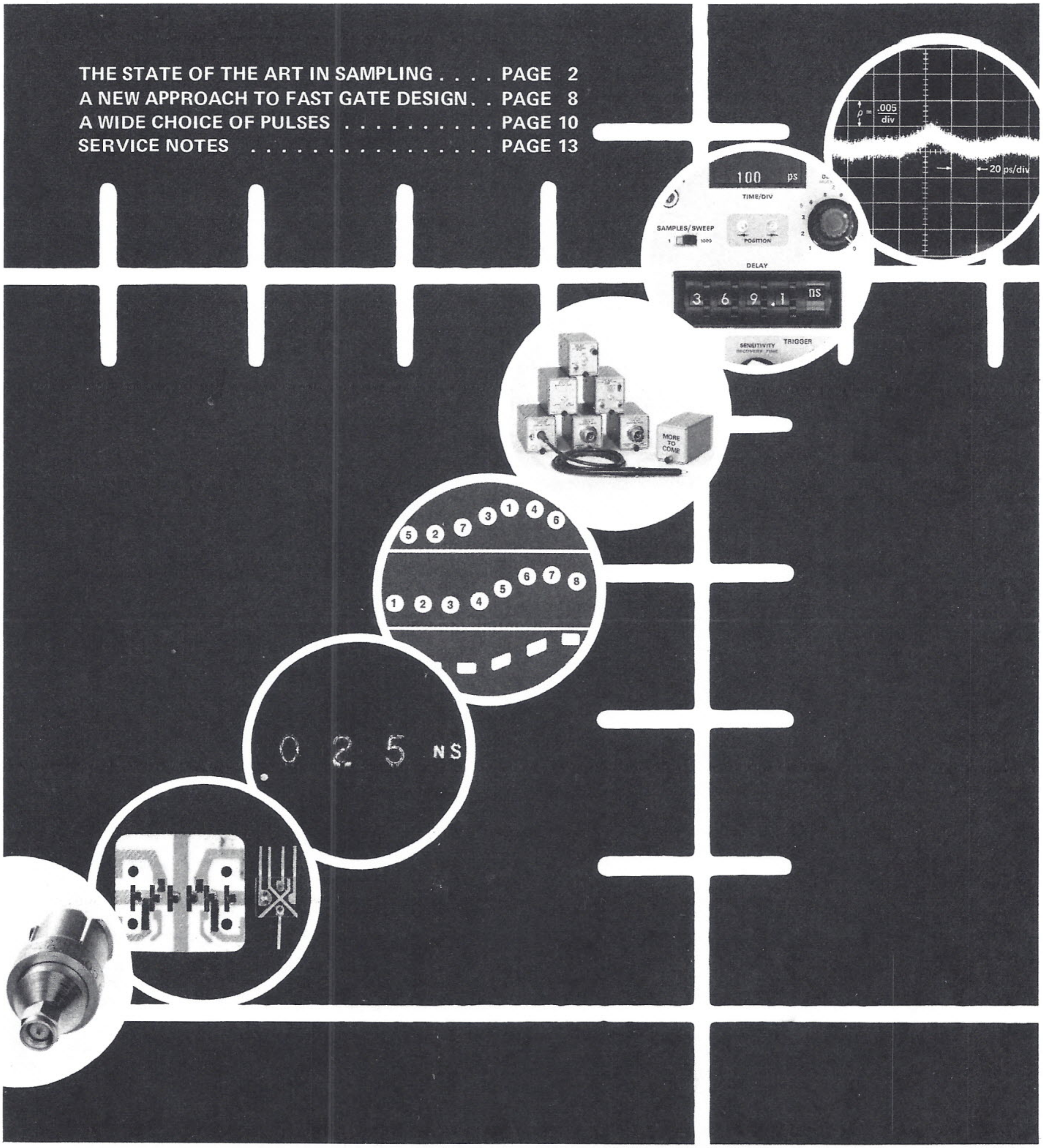
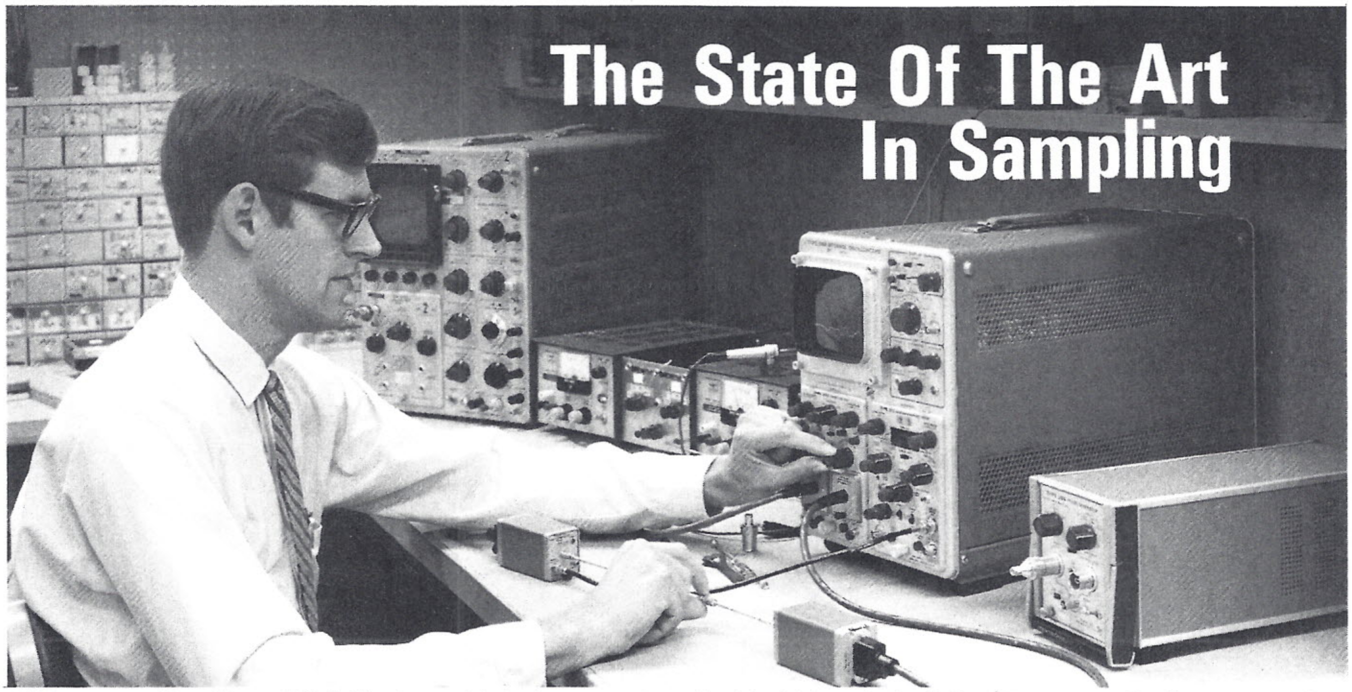


The State Of The Art In Sampling



Al Zimmerman (Sampling and Digital Instruments) checks a connector pair with a high resolution in-line TDR setup. See fig 5b on page 5 for more details.

Development of a 25-ps (14 GHz) instrument, a line of "plug-in plug-ins", and realization of much of the potential of random sampling provide a new criterion for sampling measurements. These new developments in sampling circuitry and sampling packaging have combined to offer the user more versatility than ever before.

Al Zimmerman

Program Manager,
Sampling & Digital Instruments

COVER

Seven characteristics of state-of-the-art sampling are symbolized by samples of an oscilloscope display. From lower left: 3-mm connectors; Tektronix-developed devices (S-4 chip, S-3 chip); 25-ps digital readout; 3 sampling modes (random, sequential, and real-time sampling); the current line of Tektronix sampling heads; digital delay; and 35-ps risetime TDR.

The Type 3S2 Vertical Sampling Unit was announced at IEEE '68 with two plug-in heads—the Type S-1, 350-ps Sampling Head and the Type S-2, 50-ps Sampling Head. At WESCON '68, less than 6 months later, four more heads were introduced: the Type S-3, 350-ps high-impedance Sampling Head; the Type S-4, 25-ps Sampling Head; the Type S-50, 25-ps risetime Pulse Generator Head; and the Type S-51, 1-to-18 GHz Trigger Countdown Head. The latter two special-purpose heads are not capable of producing a display since they contain no sampling gate.

Concurrent with these sampling heads, the Type 285 Power Supply was designed to power the special-purpose plug-in heads in the event both vertical channels are required. Using these components, the user has a number of ways to combine the various heads for the most versatility from his sampling oscilloscope.

A sampling oscilloscope makes use of a great deal of relatively slow-speed signal processing circuitry. The input to the signal processing circuitry is an ideal choice to apply the plug-in idea. These miniature (4½ x 1¾ x 2 inch) sampling heads contain all of the high-speed circuitry which normally make up the front end of a sampling oscilloscope. Use of plug-ins allows the sampling oscilloscope to adapt and interface with much more versatility to the numerous signal sources available.

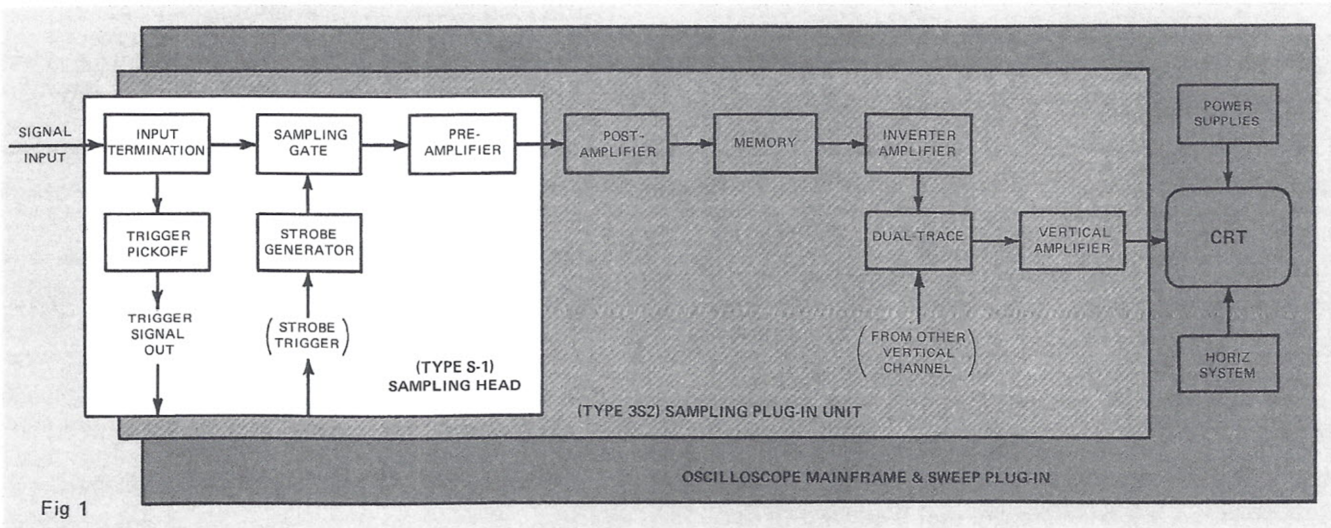
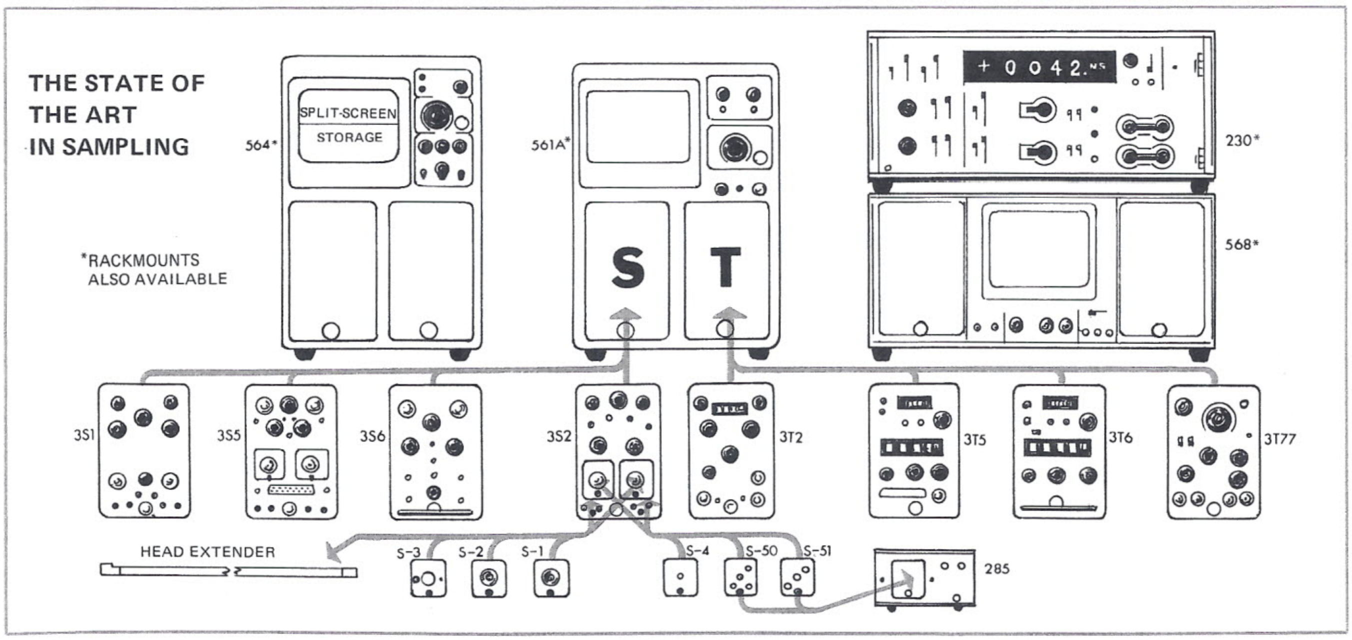


Fig 1

Prior to the sampling head development at Tektronix, a typical sampling unit occupied roughly 75% of its circuitry with the processing of slow speed signals (i.e. sampling-loop amplifiers, memories, dual-trace switching, and the main vertical). As a result, when changing from a 50-Ω general-purpose sampler to a high-impedance sampler, or to a higher speed 50-Ω sampler, nearly 75% of the sampler purchased was redundant circuitry. By creating a module which contains only those circuits which determine the input configurations, noise, sensitivity, and bandwidth of the sampler, these problems have been effectively solved with a degree of adaptability not possible before. This allows a wide range of operational characteristics by changing only the sampling head and *not* requiring the replacement of a complete plug-in vertical sampling unit.

Fig 1 shows how a typical sampling head relates functionally to the rest of the oscilloscope. The nature and extent of the circuitry contained within the sampling head depends on whether it is intended for general purpose, low noise, high speed, 50 Ω, probe type, or other applications (i.e. trigger countdown or 25-ps pulse generator).

Because an individual sampling head represents a relatively small investment, both for the user and in terms of development cost for the manufacturer, there is more incentive to design heads and pursue additional performance trade-offs. The development costs of a sampling head are appreciably less than that of a complete vertical sampling unit. As a result, performance trade-offs may be pursued that were not economically feasible prior to the development of this concept. The table on page 4 shows some of the performance characteristics for the current line of sampling heads.



Sampling heads may either be plugged directly into the larger plug-in unit or may be used remotely at the end of a 3 or 6-foot extender cable. The ability to put the sampling head right at the measurement source allows dual-trace displays of signals originating at different locations—*without* interconnecting signal cables. Cross-talk between display channels is eliminated by the shielding afforded by completely separate sampling heads. The physical independence of the two channels further permits intermixing of head types so performance and input configuration may be matched to the particular measurement requirement. There is no longer the necessity of purchasing a dual-trace sampling unit if only a single-trace display is required.

Signal losses in the cables used to interconnect a system can also be eliminated by using sampling heads on extender cables. This practice can result in significant savings in signal level at frequencies above 5 GHz. For example, both RG8A/U and RG58A/U have losses of well over 1 dB/ft at 10 GHz.

Fig 3 dramatically illustrates the loss in amplitude when a 3-ft coaxial cable transmits a 15-GHz signal. Such losses are minimized by using extender cables and physically placing the individual head adjacent to its source.

Type S-1 Clean Response/Low Noise

The Type S-1 Sampling Head offers excellent transient response, low-noise characteristics, 50-Ω input impedance, and low cost. The Type 284 Pulse Generator and the Type 3S2/S-1 provide the cleanest 350-ps response currently available. Its transient response is specified as +0.5%, −3% or less for 5 ns after transition; ±0.5% after 5 ns (with Type 284 Pulse Generator).

Type S-2 High Speed/Low Cost

The Type S-2 Sampling Head is a 50-Ω, 50-ps risetime unit with 7-GHz equivalent bandwidth. In this unit, the design compromise is faster risetime (at the expense of noise and transient response) for an "economical" price. Unsmoothed noise is 6 mV and the transient response is ±5% for the first 2.5 ns and ±2% thereafter (with Type 284 Pulse Generator).

SAMPLING HEADS

Type	Risetime	Equivalent Bandwidth	Trigger Pick-Off	Noise (Unsmoothed)	Input Z	Input Connector	Price
S-1	350 ps	1 GHz	Yes	2 mV	50Ω	GR874	$250
S-2	50 ps	7 GHz	Yes	6 mV	50Ω	GR874	$300
S-3	350 ps	1 GHz	No	3 mV	100 kΩ 2.3 pF	Probe	$375
S-4	25 ps	14 GHz	Yes	10 mV	50Ω	3 mm	$750

NON-SAMPLING HEADS

Type	Description	Output Connector	Price
S-50	25-ps risetime, tunnel-diode pulse generator	3 mm	$450
S-51	1-18 GHz trigger countdown	3 mm	$425

PLUG-IN VERTICAL UNITS

Type	Remotely Programmable	Physical Configuration	Program Connector	Adjustable Inter-channel Delay	Real Time Sampling	Price
3S1	No	Non Plug-In	None	No	Yes	$1150
3S2	No	Plug-In	None	Yes	Yes	$ 800
3S5	Yes	Plug-In	Front	Yes	Yes	$1450
3S6	Yes	Remote	Rear	Yes	Yes	$1450

PLUG-IN HORIZONTAL UNITS

Type	Type of Sampling	Sweep Delay	Remotely Programmable	Jitter	Price
3T2	Random, Sequential	Up to 5 cm on any time/div	No	30 ps	$ 990
3T5	Sequential, Real Time	999.9 ns in 100-ps increments; 9.999 μs in 1-ns increments (Digital)	Yes	30 ps	$1550
3T6	Sequential, Real Time	999.9 μs in 100-ns increments (Digital)	Yes	30 ps	$1550
3T77A	Sequential Only	Min 100 div/variable	No	50 ps	$ 690

OSCILLOSCOPE MAIN FRAMES

Type	Storage	Digital Readout	Price
561A	No	No	$ 530
RM561A	No	No	$ 580
564	Yes	No	$ 925
RM564	Yes	No	$1025
567	No	Yes	$ 750
RM567	No	Yes	$ 850
568	No	Yes	$ 875
RM568	No	Yes	$ 925

Type S-3 High-Impedance Sampling Probe

The Type S-3 Sampling Head employs a unique design approach for an active sampling probe. A 50-kΩ resistor provides two times attenuation and is designed as an integral portion of the probe. The first stage of the sampling preamplifier (an FET stage) is physically located in the probe itself. These improvements result in a larger voltage signal from the sampler with an improved signal-to-noise ratio.

A portion of this improvement is traded off for other advantages. This approach, however, still has four major advantages. (1) More rugged mechanically. Screw-on attenuators. (2) More rugged electrically. The 50-kΩ series resistance limits the current for diode protection. 100 V DC may be applied to the probe tip. (3) Since the source impedance is isolated by the 50-kΩ resistor, varying the source impedance has much less effect on the sampling bridge than conventional sampling probe designs. (4) The built-in attenuator automatically reduces any kickout that the balanced bridge may still have.

Type S-4 25-ps State Of The Art

The Type S-4 provides state-of-the-art sampling performance with its 25-ps, 14-GHz performance. This unit introduces the first use of a 3-mm (mates with OSM®)† connector used on an oscilloscope. The Type S-4 is specified with less than 10 mV of noise (unsmoothed) and a ±10% transient response as observed with the S-50 25-ps risetime Pulse Generator. Fig. 5 illustrates the Type S-4 Sampling Head and the Type S-50 Pulse Generator Head used in a Type 3S2 for a high-resolution TDR measurement.

The user is assured of more sampling head types evolving because of the relatively low development cost associated with the head. In addition, development times are shorter since only the input characteristics are being changed. These two factors, combined with the development of new devices, offer promise of an even wider line of performance trade-offs in the future. With each advance in measurement technology, new heads can be added quickly to extend performance or convenience features. The current family of existing sampling heads is an excellent example of the speed with which these new heads may be developed.

Random Sampling Eliminates Need For Signal Delay Lines

The introduction of the 3T2 Random Sampling Sweep Unit in 1967 provided the impetus to develop the sampling head concept. Prior to this time, sampling oscilloscopes offering internal triggering used trigger pick-off circuitry and delay lines to develop the necessary pretrigger. Two compromises were involved: (1) There was always some signal degradation since the signal passed through the delay line element; and (2) input

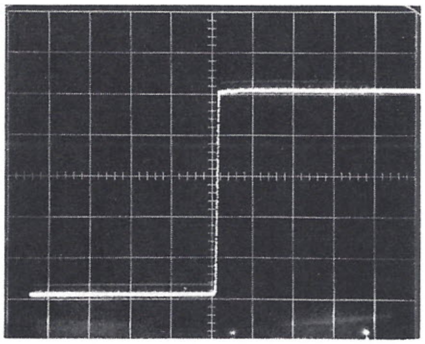


Fig 2. Transient response of Type S-1 and Type 284. Vert: 50 mV/cm. Horiz: 2 ns/cm.

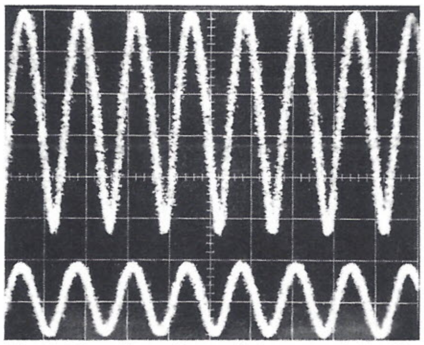


Fig 3. Signal loss due to 3-foot coaxial cable at 15 GHz. Vert: 100 mV/cm. Horiz: 50 ps/cm.

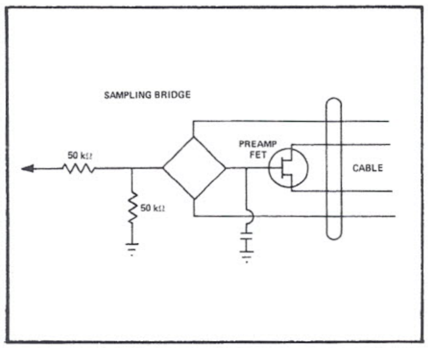


Fig 4. Type S-3 Sampling Head.

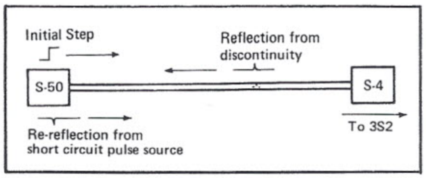


Fig 5a. In-line TDR system.

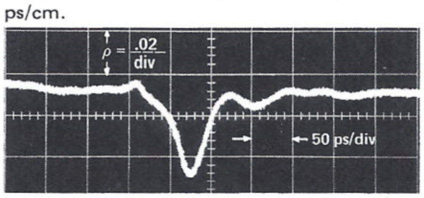


Fig 5b. Discontinuity from connector pair.

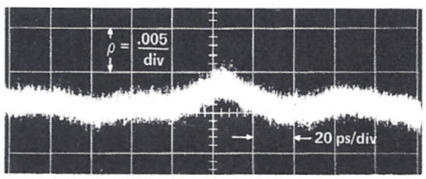


Fig 5c. Maximum amplitude resolution.

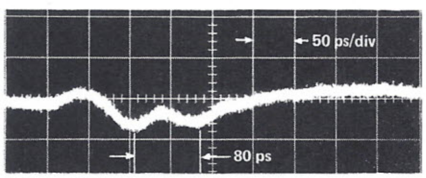


Fig 5d. 40-ps time resolution.

Fig 5. The in-line TDR system is particularly well-suited for studying discontinuities in short, high-quality transmission systems. The Type S-50 Pulse Generator propagates the pulse down the test line until it encounters the point discontinuity which reflects energy to the generator. The short circuit source impedance (3 Ω) of the TD generator re-reflects the energy back through the test line into the sampler for observation. Signal-to-noise considerations are optimized since the full 400 mV of the pulse is available. Fig 5c shows an observed ρ (reflection coefficient) of 0.004 which corresponds to a shunt capacitance of 0.008 pF. Fig 5d shows two discontinuities separated in time by 40 ps (80 ps displayed) or a distance of 8.4 mm in a solid Teflon* transmission line.

† Registered trademark of Omni Spectra, Inc.
* Registered trademark of DuPont

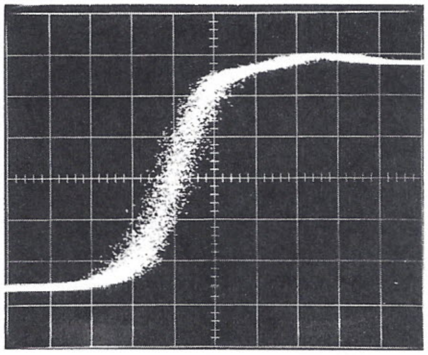


Fig 6. Type S-4 and Type S-50, 35 ps displayed risetime. Vert: 100 mV/cm. Horiz: 20 ps/cm.

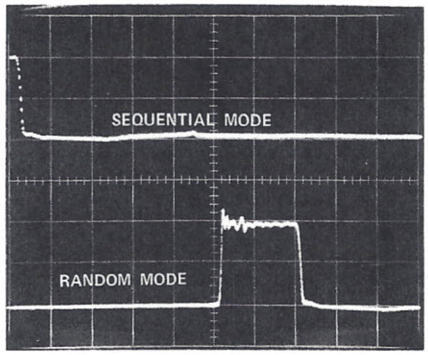


Fig 7. Multiple Exposure. The random mode allows observation of the leading edge without delay lines or pretriggers. Vert: 100 mV/cm. Horiz: 10 ns/cm.

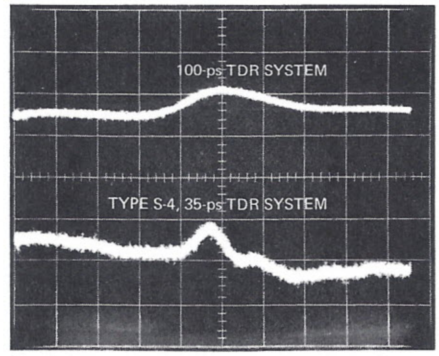


Fig 8. Multiple exposure of 100-ps and 35-ps TDR systems. Vert: 5% (ρ = 0.05)/cm. Horiz: 50-ps/cm.

impedance levels were restricted to a low impedance transmission-line approach since high-impedance delay lines are impractical. As a result, when using 100-kΩ sampling probes, there was no means of internal triggering. In addition, sampling oscilloscopes with risetimes faster than $\approx$350 ps did not offer internal triggering because of the absence of the signal delay line.

The availability of the Type 3T2 Random Sampling Sweep Unit has eliminated these restrictions. Its unique random-sampling circuitry *always* allows observation of points *prior to the triggering transition itself*. Depending on the sweep rate of the display, microseconds, or even milliseconds of time prior to the triggering event can be observed! This is an amount far greater than any conventional real-time oscilloscope can provide. With high-impedance probes, the advantages of internal triggering are present (although a separate trigger probe is required) since the user can monitor points in time before the trigger occurs. At the same time, it is possible to view 25-ps signals with the Type S-4 Sampling Head without pretriggers.

The development of the Type 3T2 Random Sampling Sweep Unit was a major factor in initiating development of the plug-in head concept. Once random sampling had been developed, it was *then* possible to consider a modular design approach without the use of delay lines, and still provide the advantages that internal triggering offers. Eliminating signal delay lines removed a major system bandwidth limitation and contributed markedly to size and weight reductions. At the same time, the problem of aberrations due to skin effect, dielectric losses of the delay lines, and compensation circuits were automatically eliminated.

Variable Interchannel Delay

Variable interchannel delay is a feature of the Type 3S2 Plug-In that has not before been available. The user now has the ability to vary the delay of one channel, ±5 ns, to ensure exact coincidence of time relationships. Minor manufacturing tolerances, probe differences, signal paths, transmission lines, etc., may now be exactly matched to allow more precise time comparisons.

This feature is of particular value when a high-impedance sampling head and a 50-Ω sampling head are used together (cable transit times are different), or when different length extender cables are required. In addition, it ensures optimum X-Y displays when the sampler is used in the A vertical, B horizontal mode.

Digital Sweep Delay

The development of digital delay in a sampling timebase unit, Type 3T5/3T6, offers a new versatility for oscilloscope users. It is now possible to dial in an exact delay over the range of 100 ps—999.9 μs (see fig 10). This delay is generated by incorporating a clock and digital counter to ensure a precise jitter-free display whose stability is not a function of the delay time. This technique allows the Type 3T5/3T6 to maintain its basic 30-ps jitter specification with delays of up to 1 μs.

Programmable Sampling Units

The availability of the Type 3S5 and Type 3S6 Programmable Sampling Units provide a new capability for use with the Type 568/230 Digital Readout System. Plug-in sampling heads present maximum interfacing flexibility when signal sources require a different sampling head. The systems user is assured of maintaining maximum versatility since the systems limitation is basically determined by the sampling head characteristics.

The Type 3S5 and Type 3S6 offer digitally programmable control of deflection factor, DC offset, polarity, and smoothing. 27 program lines using negative logic (true = ground or <2 V — false = open or >6 V) are required to program all measurement functions.

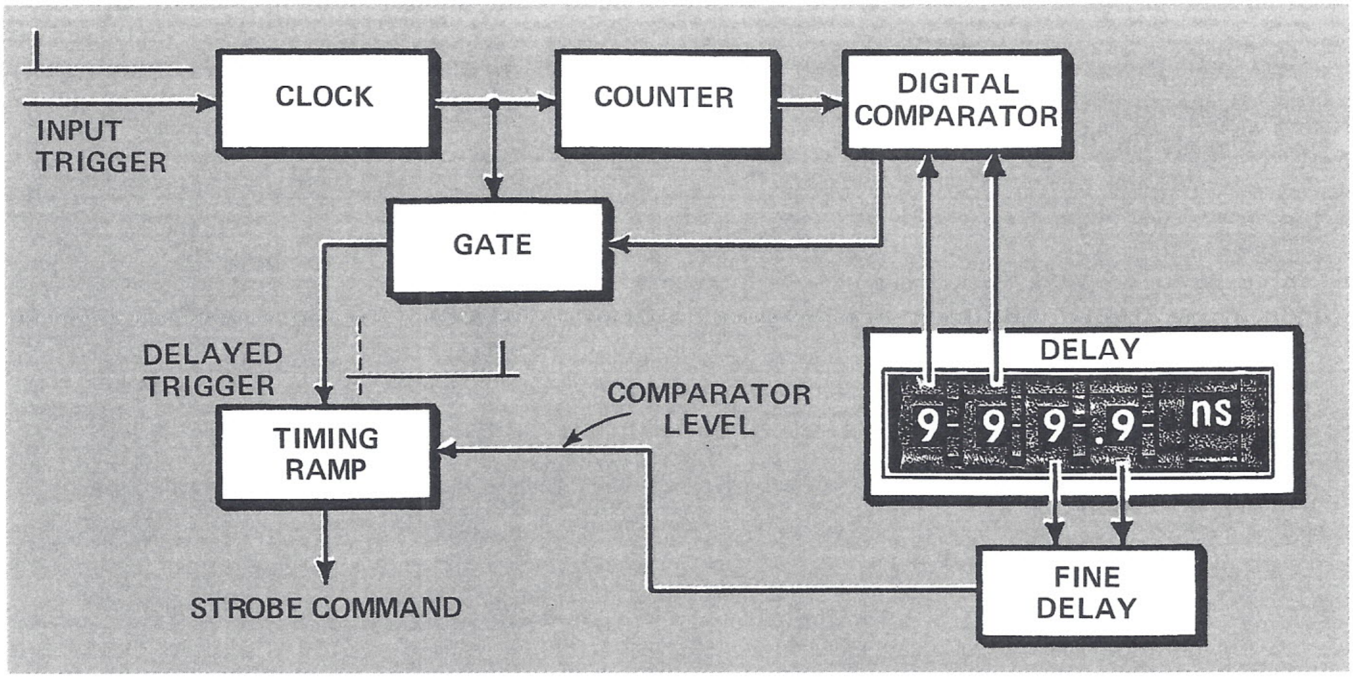


Fig 9. Simplified block diagram of digital delay circuitry.

DIGITAL DELAY RANGE		
Delay Range	Increments	Time/Div
999.9 ns	100-ps	100 ps/div to 500 ps/div
9.999 μs	1-ns	1 ns/div to 1 μs/div
999.9 μs	100-ns	2 μs/div to 500 μs/div

Fig 10.

The Type 3S5 and Type 3S6 have identical electrical characteristics. The Type 3S6 has all connections, including remote sampling heads on the rear panel, while the Type 3S5 provides all connectors on the front panel.

The Type 3T5 and Type 3T6 Programmable Sampling Sweep Units provide a wide range of digitally programmed functions. Time/div, delay time, and samples/sweep are remotely programmable (true = ground or < 2 V – false = open or > 6 V), or controllable from the front panel. The units are programmable over the wide range of 100 ps/div to 500 ms/div in 30 calibrated steps. Real-time sampling is used over the range of 1 ms/div to 500 ms/div.

A new automatic trigger mode has been included in the Type 3T5 and Type 3T6 to eliminate the need for trigger adjustments as trigger amplitudes, repetition rates, risetimes, and pulse widths vary.

The Type 3T5 and Type 3T6 have identical electrical characteristics. The Type 3T5 has a program connector and trigger input on the front panel while the Type 3T6 provides these connectors on the rear panel.

Real-Time Sampling

The Type 3S2 can provide 100 kHz pulses to each sampling head independent of the real-time time base unit. When the Vertical Sampling Unit is switched to the non-sampling position and a conventional time base unit inserted, real-time internal triggering is available. The real-time sampling mode is limited to approximately .1 ms/div since faster sweeps will begin to make the 10 μs clock segments objectionable. Thus, signals exceeding 20 kHz are seldom viewed in this mode.

Real-time Sampling offers slower sweep rates with the full bandwidth of plug-in sampling heads. The characteristics of interest this mode offers are:

(1) Slow sweeps with full bandwith

(2) Reduction of random noise through smoothing

(3) DC offset capability with excellent overload recovery

Conclusion

The sampling head concept has brought a shift in design effort toward the front end of the sampler, where it really belongs. In addition, there has been a reduction in the total number of sampling plug-in units required for the designer to be attentive to the instrumentation needs of tomorrow.

These developments, combined with the options of digital readout, high resolution low-cost storage, random sampling and programmable units, offer the user more versatility at lower cost than ever before.

SERVICE SCOPE

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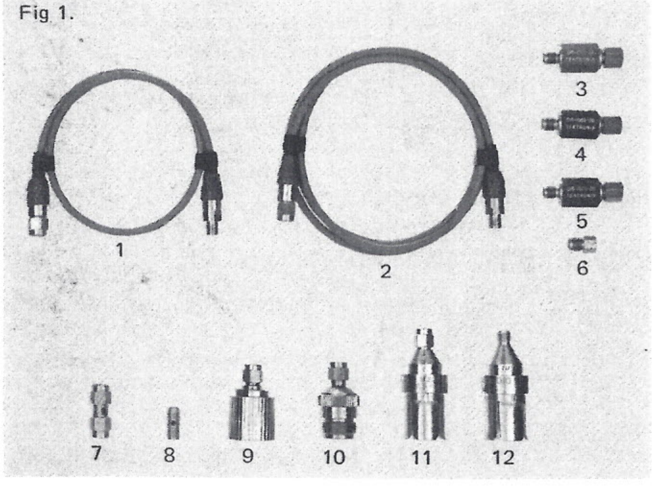
Editor: R. Kehrli Artist: J. Gorman

This issue of SERVICE SCOPE discusses some of the state-of-the-art developments in sampling technology. Since the development of sampling by Janssen and Michels in 1950, Tektronix engineers have made a number of significant contributions to sampling technology. Listed below are some of the more important developments and the year in which they occurred.

1960	Plug-in sampling unit converts conventional oscilloscope to sampling oscilloscope at modest cost.
1962	High-quality delay lines allow internal triggering and the observation of signal leading edges. Miniature low capacitance, passive probes developed.
1962	Digital readout introduced.
1963	100-ps sampling introduced.
1964	Low-cost, high-resolution storage combined with sampling.
1965	Miniature high-impedance sampling probes introduced.
1966	Wide-range sampling time base introduced, 10 ps/cm to 5 s/cm.
1967	Random sampling eliminates need for signal delay lines. Allows viewing of up to 5 cm before trigger.
1968	New sampling concept developed. 6 plug-in heads introduced. 25-ps sampling with 35-ps TDR. Programmable sampling units, digital delay, and 3 mm connectors.
1969	MORE TO COME!

SOMETHING NEW IN OSCILLOSCOPE CONNECTORS

Fig 1.



NO	ITEM	PN
1	Cable, 2 ns	015-1005-00
2	Cable, 5 ns	015-1006-00
3	Attenuator, 2X	015-1001-00
4	Attenuator, 5X	015-1002-00
5	Attenuator, 10X	015-1003-00
6	Termination, 50 Ω	015-1004-00
7	Adapter, M to M	015-1011-00
8	Adapter, F to F	015-1012-00
9	Adapter, M to 7 mm	015-1010-00
10	Adapter, M to N(F)	015-1009-00
11	Adapter, M to GR	015-1007-00
12	Adapter, F to GR	015-1008-00

A 3-mm (mates with OSM®)* line of connectors is currently stocked by Tektronix. When development of the 50-ps (7-GHz) Type S-2 Sampling Head was completed, studies were undertaken to determine the best connector for higher-frequency sampling oscilloscope designs. As a result, Tektronix has standardized on the 3-mm miniature connector line for higher-frequency developments.

This line of connectors offers the following advantages to the customer: (1) Operation at all frequencies up to 26 GHz. Since the 25-ps S-4 Sampling Head represents 14-GHz response, there is sufficient additional performance so the connector does not present a design limitation. (2) Availability of a full range of adapters and accessories from a number of manufacturers at competitive prices. Adapters are commercially available to adapt to Type N, TNC, BNC, GR, ARC, and OSSM. (3) It is a high-reliability connector because of the following considerations: (a) It is self cleaning, thus it is difficult for gradual signal degradation to occur. At the same time, a time-consuming cleaning process is not required. (b) There are fewer moving parts, so the surface-to-surface contact is better than other connectors available. (4) The VSWR of the 3-mm line is quite good, although not as good as some of the more precise, larger diameter lines. The high-speed sampling gate inherently produces discontinuities that negates much of the value of an expensive, high-precision connector. Therefore, the less expensive, medium precision 3-mm connector seems a good choice. In addition, the VSWR can be improved by inserting a high-quality attenuator, with very little sacrifice to the user. (5) Minimum front-panel space is required.

These considerations represent an excellent value connector for the customer. Fig 1 shows the 3-mm accessories currently being stocked by Tektronix.

*OSM is a registered trademark of Omni Spectra, Inc.