

**Comparison of Ultra-Fast Rise Sampling Oscilloscopes
(Update to Include New 50 GHz Scopes)**

James R. Andrews, Ph.D., IEEE Fellow

In 1989, Picosecond Pulse Labs (PSPL) published its application note AN-2a, "Comparison of Ultra-Fast Rise Sampling Oscilloscopes" [1]. AN-2a compared all of the then-commercially-available sampling oscilloscopes with risetimes of less than 35 ps. PSPL had performed an exhaustive set of tests upon all of these scopes. Their risetime and transient responses were measured and compared using the then-fastest-available, commercial tunnel diode pulse generator. Since 1989, several significant events have occurred that now need to be recognized and included in our survey of sampling scopes.

- (1) PSPL has developed a 12 ps, 9 V pulse generator.
- (2) Both Hewlett-Packard and Tektronix have continued their development of better sampling heads and have extended their bandwidths from 20 to 50 GHz
- (3) HYPRES has discontinued their 5 ps risetime, superconducting Josephson Junction oscilloscope.
- (4) PSPL has discontinued its 28 ps sampler.
- (5) A new company, HYPERLABS, has 20 GHz samplers.

PSPL 12 PS PULSE GENERATOR

In 1991, PSPL introduced its Model 4015B, which produces a -9 V step pulse with a typical 10%-90% falltime of 15 ps. PSPL has retained one of the faster units as its own internal lab standard for risetime (falltime). PSPL feels that the falltime for this particular instrument (s/n 12) is approximately 12.1 ps [2]. This specific instrument was recently sent by PSPL to NIST for calibration of its falltime. The value assigned to it by PSPL agrees with the NIST value within the limits of uncertainty quoted by NIST. This pulser was used to test the new TEK and HP scopes reported in this application note.

NEW HIGH BANDWIDTH SCOPE RISE TIME DATA

PSPL has recently performed a new set of risetime, transient response, and settling time tests on the HP and TEK 20 GHz to 50 GHz samplers. The 12.1 ps PSPL 4015B pulser with an HP-8490D-30dB, APC-2.4mm, 50 GHz attenuator was used as the test signal. The 30 dB attenuator had a 5 ps risetime. The falltime of the attenuated, 300 mV test pulse is estimated to be 13.1 ps. The results are shown in Figure 1 and tabulated in Table 1. The falltimes listed in Table 1 are the actual measured values. The automatic pulse parameter measurement feature on the HP and TEK scopes was used for this measurement. The 0% and 100% levels

chosen by the scopes are shown as cursors on the 10 ps/div. waveform plots. The calculated risetimes in Table 1 are from the root-difference-of-squares equation:

$$Tr(calc) = [Tf(meas)^2 - 13.1ps(gen)^2]^{1/2}$$

Table 1: Hi-Bandwidth Sampler Risetimes

Model	Bandwidth (spec)	Risetime (spec*)	Falltime (4015**) Tf (meas)	Risetime (calc)
HP 54121A	20 GHz	17.5 ps	20.80 ps	16.2 ps
HP 54123A	34 GHz	10.3 ps	17.22 ps	11.2 ps
HP 54124A	50 GHz	7 ps	16.14 ps	9.4 ps [3]
TEK SD-24	20 GHz	17.5 ps	22.10 ps	17.8 ps
TEK SD-32	50 GHz	7 ps	15.80 ps	8.8 ps

* Risetime estimated by manufacturer. $Tr = 0.35/BW(-3 \text{ dB})$

** Test pulse falltime estimated to be 13.1 ps [2]

A careful comparison of the measured waveforms at the slower sweep speed of 200 ps/div. shows close similarity between the five different samplers. The common features in all plots are the artifacts of the pulse generator's non-perfect waveform. The differences from one plot to another are the perturbations introduced by the various samplers.

SETTLING TIME TRANSIENT RESPONSE

In AN-2a, PSPL used a PSPL Model 6110 Reference Flat Pulse Generator (RFPG) to measure the settling time transient response of the various scopes tested. We have used the same identical generator (s/n 2) for the tests reported here. This generator produces a very flat, clean, step pulse from 500 mV to 0.0 mV. The step pulse has a 420 ps falltime and 1.5% overshoot. It then settles very rapidly to the 0.0 mV baseline. The settling time waveform of this generator has been mathematically modeled by PSPL using PSPICE. This generator has been recently sent by PSPL to NIST for a formal calibration of its settling time performance. The generator settles to within 0.2% in 3 ns, within 0.1% in 5 ns, within 0.02% in 10 ns, and within 0.01% in 100 ns. See the PSPL 6110D specification sheet for the PSPICE predicted settling waveform.

Figure 2 shows the settling time transient responses for the five HP and TEK samplers tested. The 0 V reference is

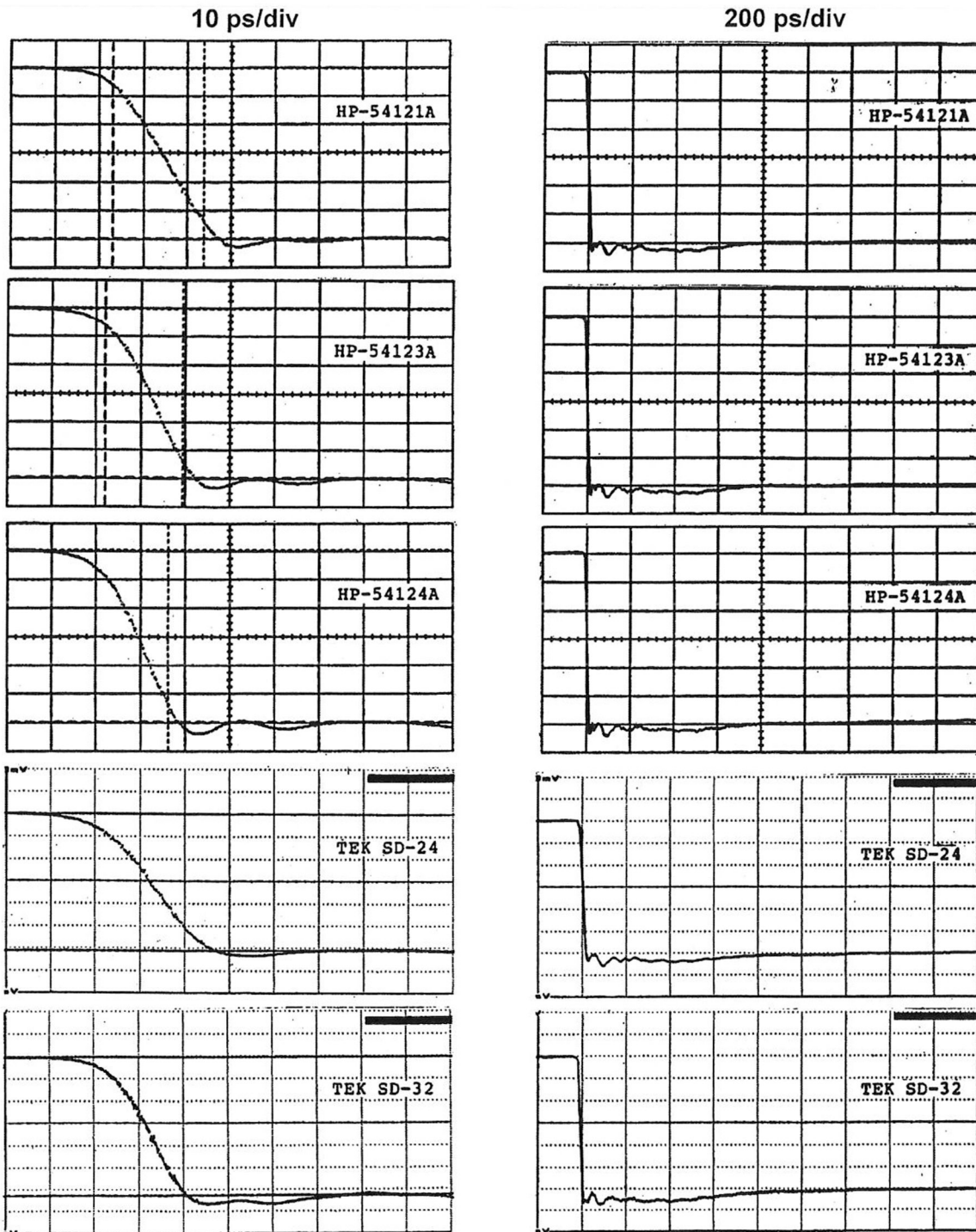


Figure 1: Picosecond Domain Transient Step Responses of HP and TEK Wideband Sampling Heads
Input was 13.1 ps falltime step from PSPL 4015B Pulse Generator. Horizontal = 10 ps/div (left) and 200 ps/div (right). Vertical = 50 mV/div. Samplers tested from top to bottom are: HP-54121A (20 GHz), HP-54123A (34 GHz), HP-54124A (50 GHz), TEK SD-24 (20 GHz) and TEK SD-32 (50 GHz).

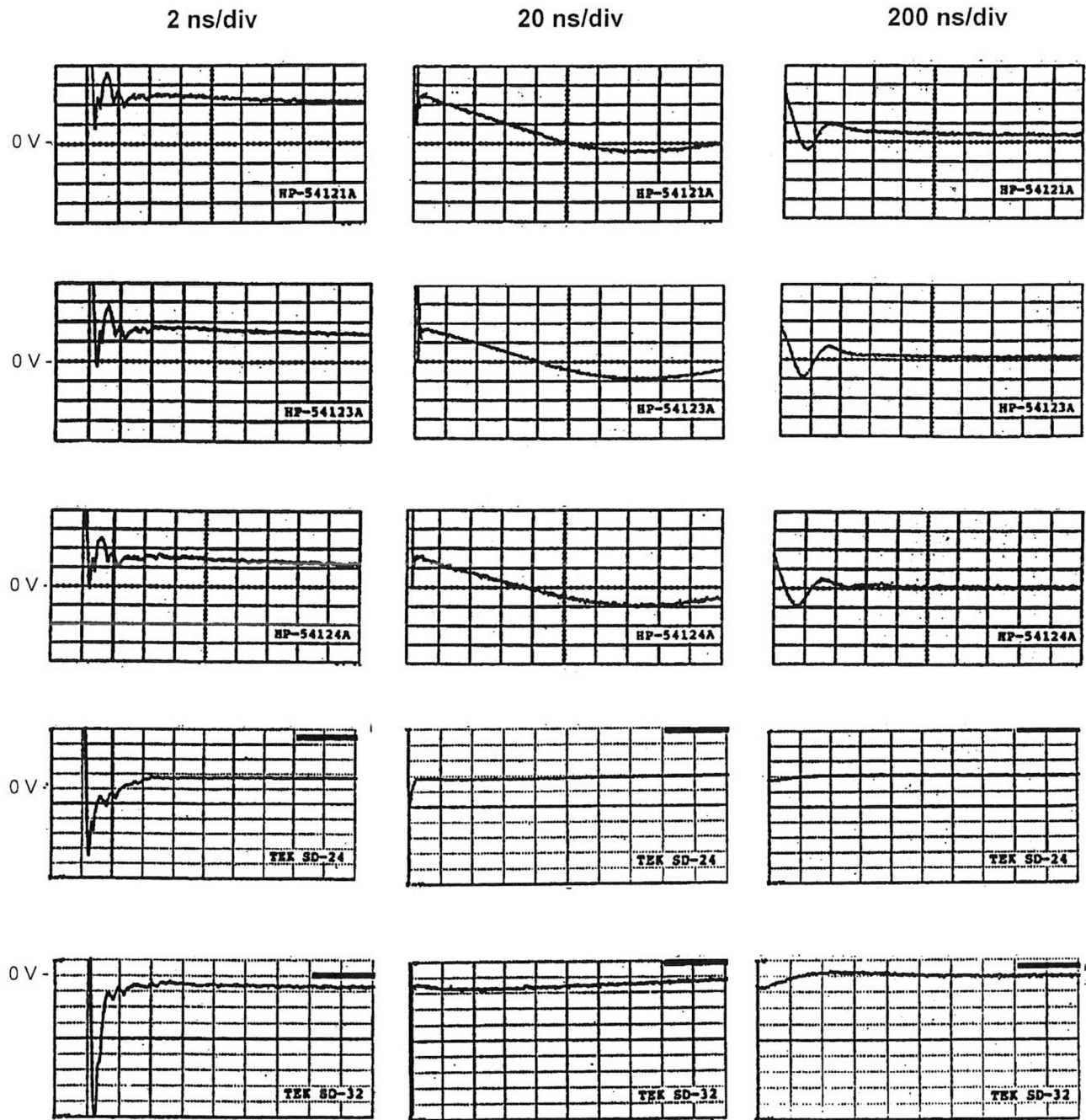


Figure 2: Nanosecond Domain Settling Time Responses of HP and TEK Wideband Sampling Heads
Input was 420 ps falltime step pulse from 500 mV to 0 V from PSPL 6110 Reference Flat Pulse Generator Horizontal = 2 ns/div (left), 20 ns/div (middle) and 200 ns/div (right). Vertical = 2 mV/div. = 0.4 %/div. Samplers tested from top to bottom are: HP-54121A (20 GHz), HP-54123A (34 GHz), HP-54124A (50 GHz), TEK SD-24 (20 GHz), and TEK SD-32 (50 GHz).

shown for all figures. Some DC offset error is noted for all samplers. The three HP samplers show almost identical responses and the same as reported in 1989 in AN-2a. The TEK samplers show better settling time responses. The TEK SD-32 seems to have too much short-time peaking. This effect in the SD-32 is also noted in the picosecond domain responses of Figure 1. In the short term 1-5 ns period, the SD-32 seems to most closely follow the PSPICE predicted 6110 RFPG waveform. As reported in AN-2a, the TEK SD-24 has the best overall settling time performance, and its waveforms shown in Figure 2 closely follow the predicted 6110 RFPG waveform.

HP-54120B SCOPE

HP has made some changes in its 54120 series of scopes since AN-2a in 1989. The most significant was adding 34 GHz and 50 GHz samplers. There was also an improvement in the trigger circuit. The original circuit triggered up to 500 MHz, and PSPL reported in AN-2a that we had measured the trigger timing jitter to be 1.6 ps rms. Current production HP scopes now trigger up to 2.5 GHz. We now have measured the trigger timing jitter to be improved to 1.0 ps rms.

HP has made a major contribution to improving pulse measurement standards by a very careful analysis, modeling, and measurement of the complete transient impulse and step response of its 50 GHz sampler, the HP-54124A. They have developed a very clever technique of using one 50 GHz sampler to generate a very narrow impulse which is then measured by a second 50 GHz sampler in a "nose-to-nose" measurement. They then performed software deconvolution processing of the measured waveform to obtain the impulse, step, and frequency responses of the 50 GHz sampler. The computed frequency response compared favorably with measured data. Based upon this work, HP assigns a risetime of 9.4 ps to its 50 GHz sampler. This work was reported in an article in the IEEE SPECTRUM [3].

TEK-11801B SCOPE

TEK has made several improvements in its sampling scope over the 11802 originally tested by PSPL in 1989. Like HP, it has added higher bandwidth samplers up to 50 GHz. The 11801B mainframe now has a color CRT display and several additional software features. The trigger timing jitter has been improved to 1.43 ps rms from the 2.5 ps rms measured by PSPL in 1989. On the new 11801B with the SD-24 TDR sampler we did, however, note a very objectionable 3 ps "hop" of the TDR waveform which occurred at about a 1 Hz rate. It should be noted that the 11801B mainframe calibrator output was used to trigger the PSPL 4015B pulser for the

measurements shown in Figure 1. The SD-24 TDR pulse was found unsuitable because of the 3 ps hop defect.

HYPERLABS

Hyperlabs, Beaverton, Oregon, is a new company started in 1993 by Dr. Agostan Agostan, a former TEK R&D engineer. They make replacement "S" series sampling heads for the discontinued Tek 560 and 7000 series sampling oscilloscopes. Their fastest head is the Model HL-13 with a claimed risetime of 20 ps and 17.5 GHz bandwidth. PSPL has been unable to obtain any evaluation samplers from Hyperlabs for testing and thus will not make any further statements regarding this company's products.

REFERENCES:

- [1] J.Andrews, "Comparison of Ultra-Fast Rise Sampling Oscilloscopes", Application Note AN-2a, Picosecond Pulse Labs, Boulder, Colo, USA, Feb. 1989.
- [2] J.Andrews, "PSPL Calibrations & NIST Traceability", Application Note AN-6, Picosecond Pulse Labs, Boulder, Colo, USA, April 1994.
- [3] K.Rush, S.Draving & J.Kerley, "Characterizing High-Speed Oscilloscopes", IEEE SPECTRUM, Sept., 1990, pp. 38-39.