

## CONSTRUCTION OF A BROADBAND UNIVERSAL SAMPLING HEAD

James R. Andrews, PH.D.  
Picosecond Pulse Labs, Inc.  
P.O. Box 44  
Boulder, Colorado 80306  
(303) 494-0770

Gordon J. DeWitte  
EG&G, EM Inc.  
P.O. Box 809  
Los Alamos, New Mexico 87544  
(505) 667-6665

**ABSTRACT:** A broadband, feed-through, sampling head with a transition duration of 26 ps has been built using a wide-band, thin-film mixer from an Hewlett-Packard (H-P) frequency counter. This head can be used with both Hewlett-Packard (H-P) and Tektronix sampling oscilloscopes. Responses of this head, and other sampling heads, to a standard input step waveform are shown.

In the nuclear instrumentation area of fast single transient measurements, sampling oscilloscopes cannot be used for the actual measurement. However, because they have much faster transition durations (rise times), greater bandwidths, and are more sensi-

tive than real-time, traveling wave oscilloscopes<sup>1</sup>, they are widely used for evaluating the performance of fast transient measurement systems. They are often used as the performance standards to which other systems are adjusted.

Probably the best sampling oscilloscope ever built was the Hewlett-Packard model 1430.<sup>2,3,4</sup> The original H-P-1430A version had a transition duration of 28 ps and a corresponding bandwidth of 12 GHz. The more recent versions, the 1430B and 1430C, were the fastest at 20 ps (18 GHz). The H-P-1430 also had the cleanest overall transient response with a minimum of topline perturbations. Unfortunately, several years ago H-P discontinued building all sampling oscilloscopes. Personnel at EG&G were not satisfied with the performance of the remaining commercial, broadband sampling heads and began looking for a replacement to the H-P-1430.

We have used a wideband, thin-film sampler<sup>5</sup>, originally used as a dc- to 20-GHz harmonic mixer in the H-P model 5340A Microwave Frequency Counter, to build a broadband sampling head, Fig. 1. The head is a universal design that will interface directly to either H-P or Tektronix sampling oscilloscopes.

Figure 2 is the block diagram of the S-1430D Broadband Sampling Head. It consists of a two-diode sampling bridge (A1), a differential sampled data amplifier, feedback buffer amplifiers, signal pick-off and buffer amplifiers, sampling strobe pulse generator (A4 and A6), and a power supply (A5).

The basic purpose of a sampling head is to "sample" the amplitude of an input signal at a specific

instant in time.<sup>6</sup> The sampling time base controls the instant of sampling. A two-diode bridge is used to perform the actual sampling process. The diodes are normally reverse biased to a non-conducting state. Upon command from the time base, an extremely narrow sampling strobe pulse is generated. This strobe is applied to the sampling diode bridge and turns on the sampling diodes for a brief instant (a few ps). While

the sampling diodes are turned on, charge flows from the signal on the 50-ohm signal line to the sampling capacitors, Cs, and charges them to a level proportional to the signal voltage at the instant of sampling. The sampling capacitors are quite small (of the order of a few pF). Even though the time constant of the diode-capacitor circuit is quite short, the strobe duration is even less. Thus, the sampled voltage developed across Cs is only a small percentage of the actual signal voltage. This small voltage from Cs is then passed through the resistive arms of the sampling bridge to the positive input of the sampled data pre-amplifier. The output of the pre-amp. goes through the umbilical cable to the sampling vertical amplifier plug-in in the oscilloscope mainframe. There it is further amplified and held in a second sample/hold circuit. The dc output from the second sample/hold is then applied as the vertical deflection signal to the display CRT. This dc output is also brought back through the deflection sensitivity attenuators to the sampling head as a feedback signal and is used to charge the sampling capacitors, Cs, up to the actual value of the input signal at the previous instant of sampling. Thus, the next time the sampling bridge is strobed, the sampling capacitors will have to charge only towards a value proportional to the difference between the present signal,  $v(t_2)$ , and the previous signal  $v(t_1)$ . Therefore, the sampled data output is really an error or difference signal. If there is no change, i.e.  $v(t_2) = v(t_1)$ , then the error signal is 0.



Fig. 1 Model S-1430D Broadband Sampling Head.

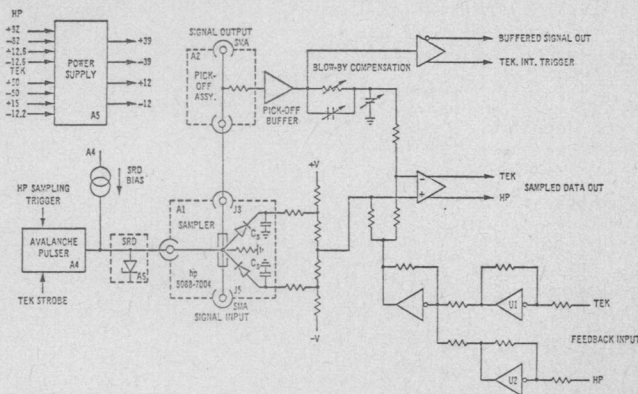


Fig. 2 Block diagram of S-1430D Sampling Head.

The sampling diode bridge is not a perfect sampler. It suffers from "blow-by".<sup>6</sup> Blow-by is a leakage phenomenon that appears primarily as a low-frequency distortion. The leading edge of pulses, and the first few ns, are reproduced faithfully on the display CRT, but, in the time frame of 10s of ns to several microseconds, considerable distortion in the displayed signal may be present. This is due to some of the input signal leaking around the "supposedly perfect, non-conducting diodes" and getting into the sampled data amplifier circuits. This leakage is primarily due to the junction capacitance of the reverse-biased sampling diodes. This capacitance is a small, but finite, value (typically 0.1 pF). If uncompensated, the blow-by can cause display errors of 100% or greater. To compensate for blow-by, another small signal is brought in and applied to the negative input of the sampled data pre-amp., thus cancelling the blow-by. To do this, the signal on the 50-ohm, feed-through signal line is picked off with a high-input impedance, active buffer amplifier. It is then passed through a passive network made up of variable resistors and capacitors. The purpose of this network is to simulate the reverse-biased characteristics of the sampling diode bridge. The output from the pick-off buffer is also used as an internal trigger signal for the time base.

To make the design compatible with both Tektronix and H-P sampling oscilloscopes required some additional circuitry. The power supply voltages available from these oscilloscopes are not the same, and the lower voltages were used in our design with Zeners being used as necessary. The sampling strobe trigger pulses are of different polarities also. The dc feedback voltage levels and the required impedances presented to the vertical scale factor feedback attenuators are different for the Tektronix and H-P oscilloscopes. The op. amps. U1 and U2 provide the necessary gain adjustment and input impedance loading. Complete circuit details are in Ref. 7.

Using the standard H-P mixer (P/N 5008-7004) as a sampler, we obtained a transition duration (rise time) of 35 ps. Figure 3 shows the transient response of this sampler when tested with a NBS 50-ps Transition Duration Standard. The standard H-P mixer used in the microwave frequency counter contains a 20-GHz, lowpass input filter network designed to minimize the VSWR below 18 GHz. Unfortunately, this filter distorts the step response when the mixer is used as a broadband sampler.

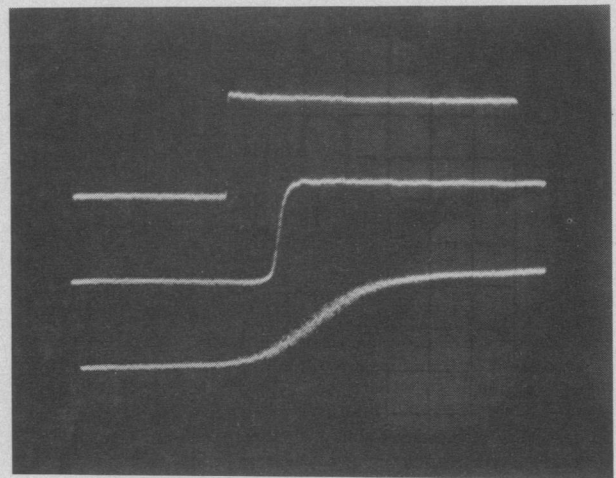


Figure 3. Transient response of standard mixer at 5 ns, 200 ps, and 20 ps/div.

A mixer was modified to eliminate the low-pass filter and provide a straight-through 50-ohm circuit. Figure 4 shows the response of a sampler using this modified mixer to the same NBS 50-ps Transition Duration Standard. The National Bureau of Standards in Boulder, Colorado calibrated this particular sampler and found its transition duration to be 26 ps and its -3dB bandwidth to be 17 GHz. Figure 5 shows the actual step response of this sampler as determined by NBS. For this figure, NBS deconvolved the waveform of the input test generator.

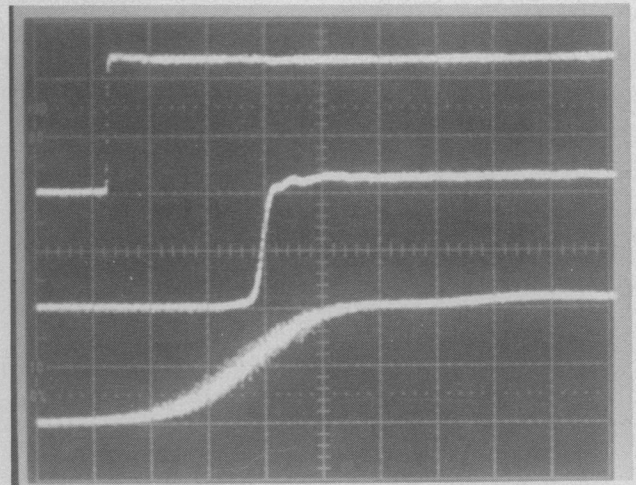


Figure 4. Transient response of modified mixer at 5 ns, 200 ps, and 20 ps/div.

For purposes of comparison, Figs. 6, 7, 8, and 9 show the responses of other commercial sampling oscilloscopes to the NBS standard at three sweep speeds. Figure 6 is a 28-ps head. Figure 7 is a 25-ps head. Figure 8 is a 30-ps head (after adjustment). Figure 9 is a 75-ps head.



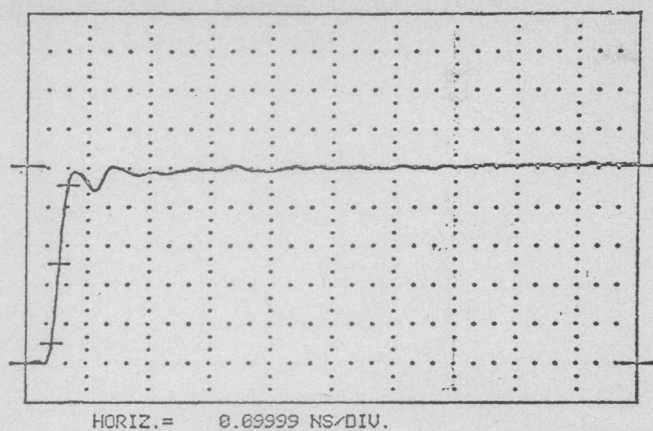


Figure 5. Deconvolved step response of modified mixer.

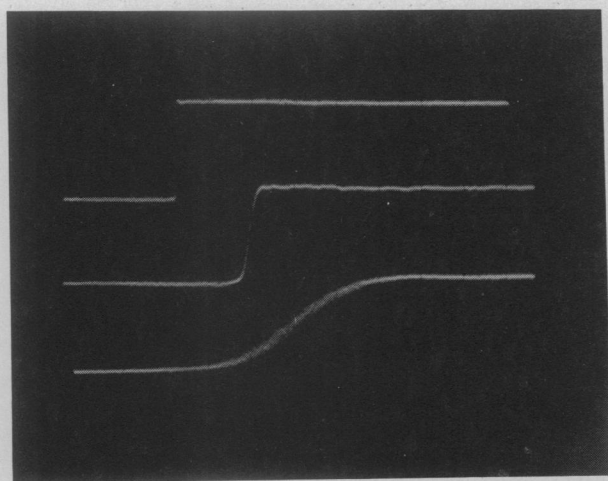


Figure 6. Transient response of commercial 28-ps head at 5 ns, 200 ps, and 20 ps/div.

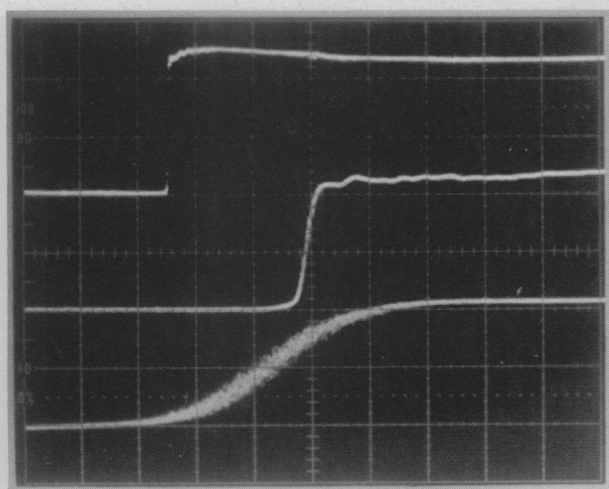


Figure 7. Transient response of commercial 25-ps head at 5 ns, 200 ps, and 20 ps/div.

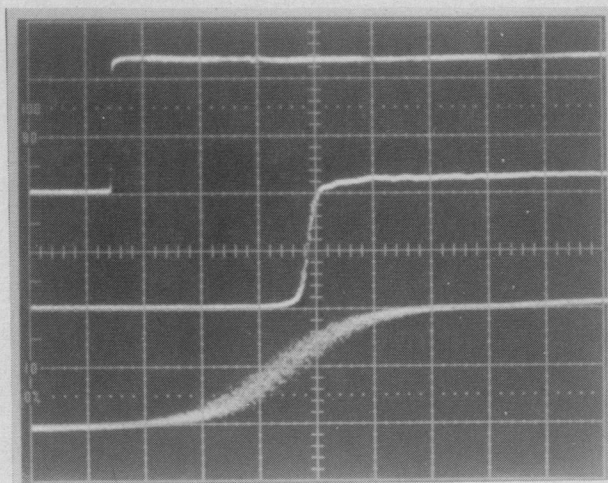


Figure 8. Transient response of commercial 30-ps head at 5 ns, 200 ps, and 20 ps/div.

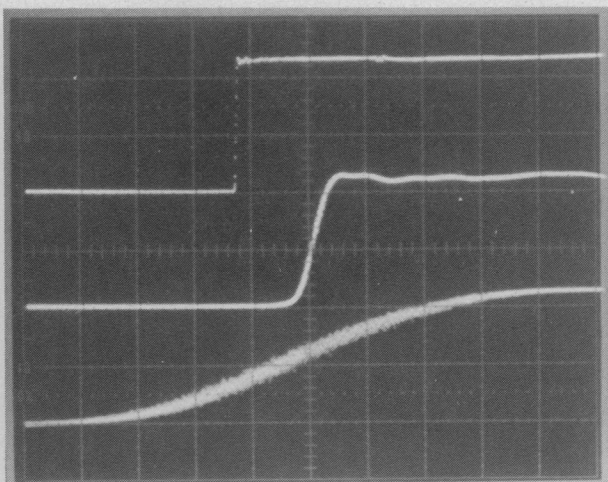


Figure 9. Transient response of commercial 75-ps head at 5 ns, 200 ps and 20 ps/div.

#### REFERENCES

1. Campbell, Donald E., "A Review of Single Transient Oscillographic Recorders with Gigahertz Bandwidth", IEEE Trans, Nuc. Sci., Vol. NS-30, no 1, Feb. 1983, pp. 267-271.
2. Grove, W., "A dc to 12.4 GHz Feedthrough Sampler for Oscilloscopes and Other RF systems, Hewlett-Packard Journal, Oct. 1966.
3. Grove, W., "Sampling for Oscilloscopes and Other RF Systems, DC Through X-Band", IEEE Trans. Microwave Theory and Tech., Vol. MTT-14, no. 12, Dec. 1966, pp. 629-635.
4. Riad, S.M., "Modeling of the HP-1430A Feedthrough Wideband (28ps) Sampling Head", IEEE Trans, Inst. and Meas., Vol. IM-31, No. 2, June 1982, pp. 110-115.
5. Merkelo, Jerry, "A DC-to-20 GHz Thin-Film Signal Sampler for Microwave Instrumentation", Hewlett-Packard Journal, April 1973, pp. 10-13.

6. Mulvey, John, "Sampling Oscilloscope Circuits", Tektronix, Beaverton, Oregon, 1970.
7. "Model S-1430D Broadband Sampling Head Instruction Manual", Picosecond Pulse Labs, Boulder, Colorado, March 1983. Final report to EG&G, Inc., Los Alamos, New Mexico on contract # N4629.