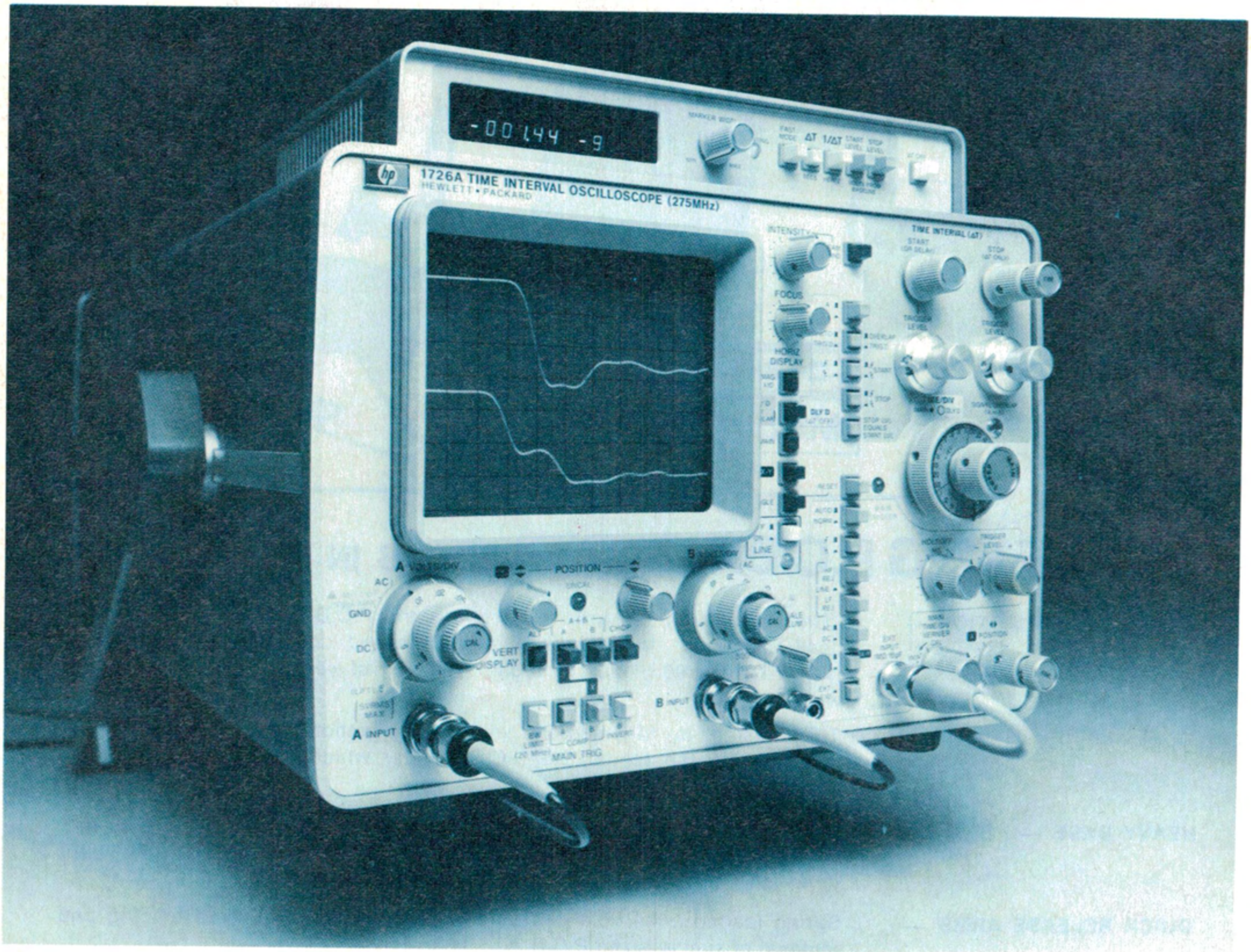
Bandwidth, probing and precise time interval measurements



Although some oscilloscopes are designed to make precise timing measurements, such as HP's new 1726A Time Interval Oscilloscope, a system's bandwidth and the probing techniques used can reduce an oscilloscope's accuracy making timing measurements less precise than they could be. This article discusses how bandwidth and probing can cause errors when an oscilloscope is used to measure time intervals and what can be done to minimize these errors.

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A COMPREHENSIVE REVIEW of the variables affecting precision time interval measurements can be covered in three stages. The first step is to examine waveform distortions induced by probing or bandwidth limitations. Next, determine whether these distortions affect the measured time interval, and then discover whether measurement accuracy depends more on the time interval measurement technique or on the instrument's bandwidth.

Induced waveform distortions

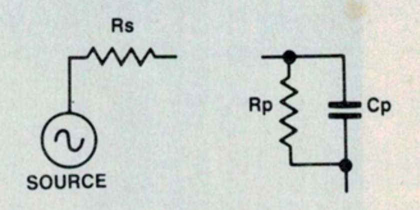
Before any instrument can measure a time interval, the signal must first be accessed, usually by a probe, and then delivered to the instrument's measurement circuitry. However, a signal's fidelity can be degraded by the probing process and/or by the bandwidth limitations of the instrument before the signal even reaches the instrument's measurement circuitry.

Probing — a critical connection

The perforance of a measurement system ultimately rests with the reliability and accuracy of its components. Although instrument specifications are usually considered to be extremely important, the probing system and its potential effects are often overlooked or ignored when evaluating performance. A poor probing system can degrade the performance of even the most sophisticated measurement system.

A poor probing system can degrade signal fidelity in a variety of ways. Resistive loading can attenuate pulse amplitude; excessive loading, resistive or capacitive, can change a circuit's operating point or stop circuit operation altogether; and continuous waveforms are attenuated as a function of a frequency-dependent loading equation. For precision time interval measurements in the picosecond region it is critical to understand how the source/probe input system can degrade rise time measurements and ultimately results in gross timing errors.

A basic model of a source/probe input system is outlined in Figure 1. Simplifying this model further, the source and probe resistances are combined in parallel forming an equivalent resistor that charges the input capacitance of the probe (Figure 2). The rise time (10%-90%) of this simple R-C network can be approximated by 2.2 ReqCp. Rise times of source/probe input systems can be calculated using this formula. Table 1 provides some sample calculations.



Rs = SOURCE RESISTANCE
Rp = INPUT RESISTANCE OF THE PROBE.
Cp = INPUT CAPACITANCE OF THE PROBE.

Figure 1. The source/probe input system.

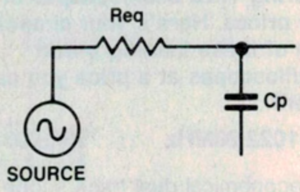


Figure 2. A simplified version of Figure 1. The source and probe resistances are combined in parallel forming one equivalent resistor (Req) that charges the input capitance of the probe. Note: the rise time (10%-90%) of this simple RC network can be approximated by 2.2 x R x C (rise time of source/probe).

SOURCE/PROBE INPUT SYSTEM	PROBE INPUT R	PROBE INPUT C	R SOURCE	Req	2.2 RC
HP 10018A	1M	9.5 pF	50	49.99	1.05 ns
HP 10018A	1M	9.5 pF	500	514.73	10.8 ns
HP 10018A	1M	9.5 pF	2000	2015.92	42.1 ns
HP 10020A	2k5	0.7 pF	100	96.0	0.06 ns

TABLE 1.

The following example illustrates a practical application where the rise time of the source/probe input system can create a problem. A one nanosecond (1 ns) rise time signal with an amplitude of one volt (1 V) is probed at two different points in a system — check clock skewing. One point has a 50 ohm source impedance, and the other a 100 ohm source impedance. Using an HP 10018A miniature probe, Figure 3 shows how the source/probe input system distorts the rise time of the signal under two different conditions. Obviously, these time differences between waveforms translate directly into time interval measurement errors. ▶

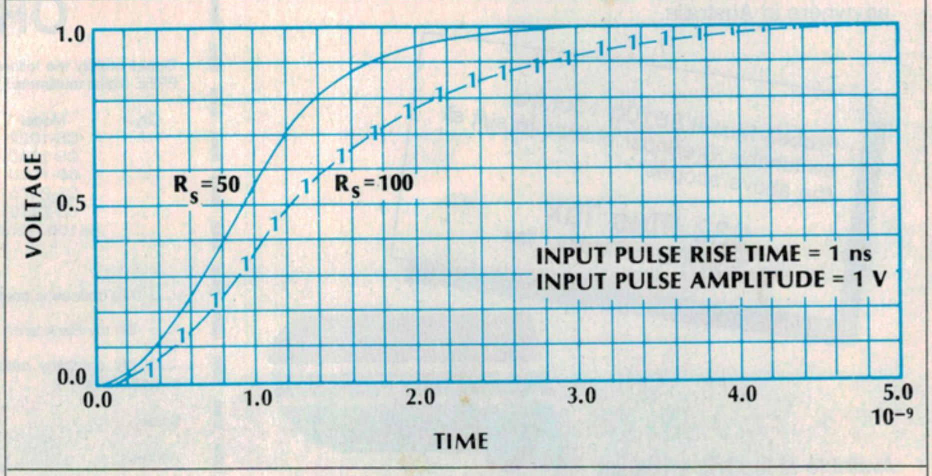


Figure 3. HP Mini-Probe (10018A): R_{in} = 1M, C_{in} = 10 pF.

To minimize the rise time degradation of the source/probe system in the example, the input capacitance and/or the equivalent resistance must be minimized. In Figure 4, a resistive divider probe, the HP 10020A, with a 10:1 division ratio, has been selected. It minimizes the input capacitance of the probe and eliminates most of the differential time interval measurement error.

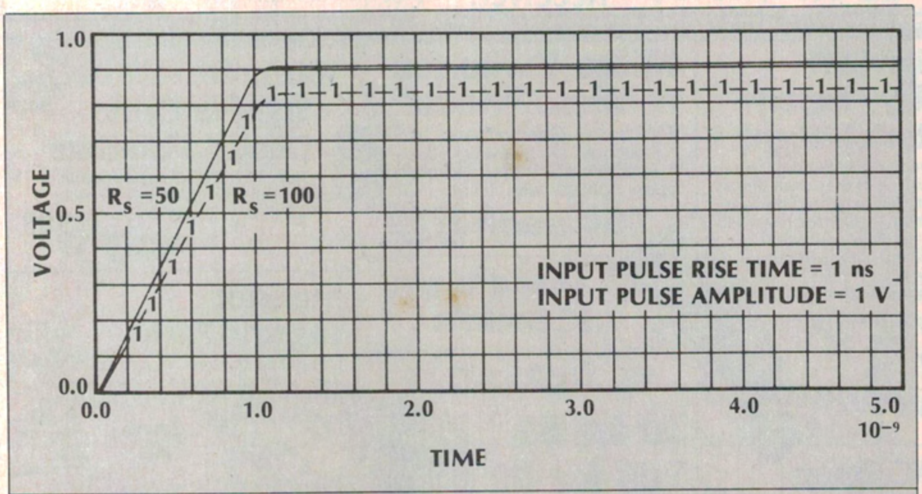


Figure 4. HP Resistive-Divider Probe (10020A): R_{in} = 500 ohms, C_{in} = 0.7 pF.

Instrument bandwidth limitations

An instrument's bandwidth can also significantly affect the fidelity of high speed signals. The easiest way to illustrate these limitations graphically, as they apply to precise time interval measurements, is to examine the rise time limitations of an instrument.

Distortion occurs as the edge speeds of a waveform approach the rise time limitations of the instrument. These distortions usually occur as shown in Figure 5. If a signal is close to the rise time of the instrument, the instrument slows down the signal. In an oscilloscope, the following formula is useful in determining the actual signal rise time based on the displayed rise time: T displayed = (Tr scope)^2 + (Tr signal)^2. The next section covers several measurement applications where these signal distortions affect time interval measurement accuracy.

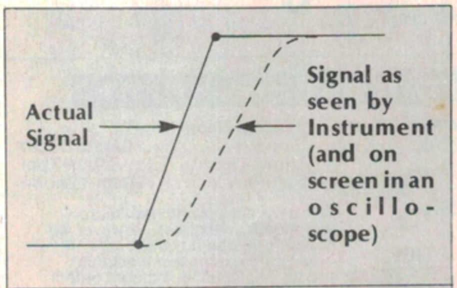


Figure 5. The general case.

Signal distortions and time interval measurement accuracy

The actual measurement application determines whether an instrument's rise time limitations affect time interval measurement accuracy. The following are several common measurement applications.

RISE TIME MEASUREMENTS:

To measure a signal's rise time accurately, the measurement system must offer a system rise time at least three times faster than the input signal's rise time. For example, what bandwidth is necessary to measure the rise time of an ECL signal with a one nanosecond rise time accurately? Table 2 shows the measurement errors associated with specific bandwidths.

INSTRUMENT BANDWIDTH	INSTRUMENT RISE TIME	MEASURED RISE TIME	PER CENT ERROR
275 MHz	1.27 ns	1.61 ns	61%
400 MHz	0.875 ns	1.33 ns	33%
1 GHz	0.35 ns	1.06 ns	5.9%

TABLE 2. Errors associated with a 1 nanosecond rise time measurement.

A similar table can be developed for a 4 nanosecond rise time measurement (Table 3).

INSTRUMENT BANDWIDTH	INSTRUMENT RISE TIME	MEASURED RISE TIME	PER CENT ERROR
275 MHz	1.27 ns	4.20 ns	5.0%
100 MHz	0.875 ns	4.09 ns	2.3%
1 HGz	0.35 ns	4.015 ns	0.4%

TABLE 3. Errors associated with a 4 ns rise time measurement.

MEASUREMENTS BETWEEN "LIKE-EDGE" SIGNALS:

Time intervals measurements between signals with similar edges are a very common application. Examples include measurements within a logic family and propagation delay measurements on the same signal at two different points. In these measurement applications, both "like-edges" are distorted the same amount, and measurement errors do not occur. Figure 6 illustrates this case. ▶

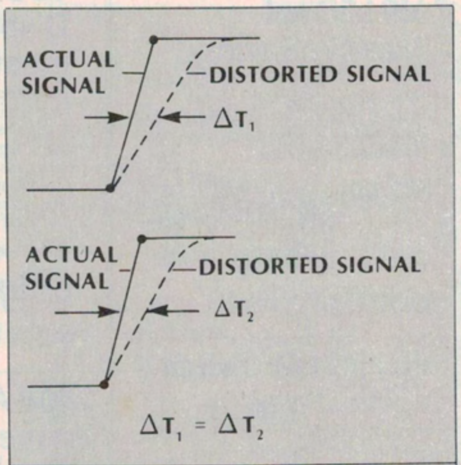


Figure 6. Time interval measurements between 'like-edge' signals will not result in errors due to instrument rise time limitations.

MEASUREMENTS BETWEEN "UNLIKE-EDGE" SIGNALS

Time interval measurements between signals with "unlike-edges" (e.g: rise time = 2 ns, fall time = 4 ns) can result in time interval measurement errors because of instrument rise time limitations. In these situations, the oscilloscope's rise time limitations affect each edge by a different amount, resulting in differential timing errors. An example of this situation is illustrated in Figure 7.

High bandwidth vs measurement technique

When evaluating precise time interval measurements, it is important to consider the accuracy of the measurement technique in light of how bandwidth limitations may affect a particular time interval measurement. Although a high bandwidth may reduce signal distortion, the errors resulting from traditional oscilloscope measurement techniques, based on analogue voltage comparisons, may add more error than the amount saved by the higher bandwidth. ●

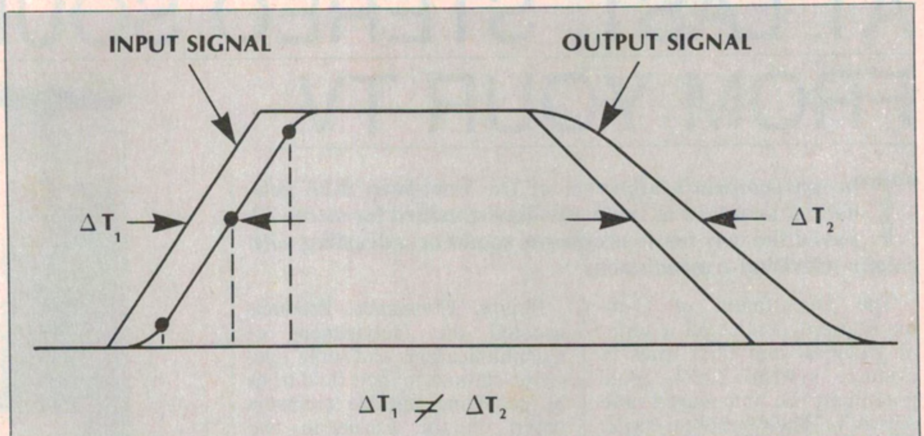


Figure 7. System bandwidth considerations; time interval measurements between 'unlike-edges' can result in differential errors due to instrument rise time limitations.

THE AUTHOR

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