HOW TO MINIMIZE SCOPE/PROBE COMBINATION ERRORS
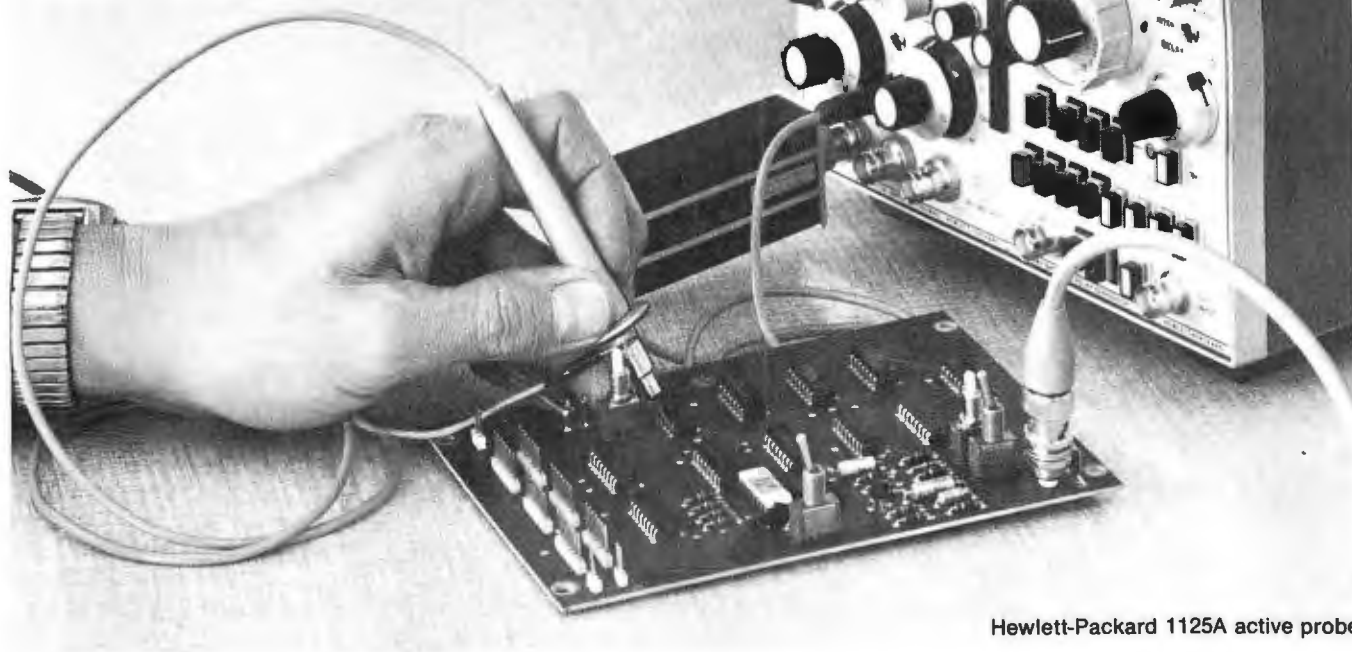
Hewlett-Packard 1125A active probe.

*Choosing the right probe for a particular application
can reduce measurement errors 50% or more.*

BY THOMAS R. SEAR

MOST of us tend to assume that an oscilloscope display is a "perfect" representation of what is occurring in a given circuit. Actually, when you apply a signal to the input of a scope, you can lose a large percentage of what is really there if the signal source is not carefully matched to the scope's input impedance. Since the main reason for paying big money for

a wideband scope is that you need the bandwidth, it is important that nothing be allowed to compromise its performance—least of all something as "simple" as a probe connected to the input.

If you select the wrong type of probe for a given measurement, the signal that reaches the scope may not have some of the characteristics that are of

interest to you. Unless certain precautions are observed, especially at high frequencies, getting the signal to the input of the scope may become the most critical part of any measurement you are making.

There are times when a plain piece of wire will suffice for coupling a signal to a scope. Also, the passive types of attenuator probes that are sold with

The Tektronix P6045 probe, with FET isolation stage, provides signal attenuation of 1:1, 10:1, or 100:1 with 1.5-ns rise time.

most new scopes do a fine job most of the time. However, the broad bandwidths of modern scopes and the sophisticated uses to which they are put make it absolutely necessary to match scope to probe if you want accurate and meaningful measurements. Failure to match probe and scope can result in measurement errors of 50% or more.

Impedance Effects. The scope vertical input to which you connect the probe will have either a high impedance or an impedance of 50 ohms (Fig. 1A). In either case, the impedance is a resistance in parallel with a capacitance (values approximately those in the diagram). Any probe can also be represented by a parallel RC circuit (Fig. 1B).

To estimate the effects that a given scope/probe combination will have on the signal, the combination can be simplified schematically as shown in Fig. 1C. Note that the values here are those that would be "seen" from the probe tip. That is, the series resistance of R_P and R_S is typically about 10 megohms (R_{IN}); and the series equivalent of C_P and C_S is about 6.7pF.

As R_{IN} decreases, more current is drawn from the circuit being tested. When R_{IN} approaches the impedance of the signal source, significant errors result because of resistive loading. The amount of error in per cent is $100Z_G/(Z_G+Z_{IN})$, where Z_{IN} is the parallel combination of R_{IN} and the impedance of C_{IN}.

Small amounts of loading decrease the signal amplitude only slightly.

Heavy loading, however, may draw so much current from the signal source that the circuit will saturate, become nonlinear, or stop operating completely.

So the first rule for selecting scope/probe combinations is:

Rule 1: To insure that resistive loading errors are less than 1%, select a scope/probe combination with R_{IN} at least 100 times greater than the source impedance.

The probe capacitor can be troublesome in two ways. First, if not properly adjusted to provide frequency compensation, slight errors will be introduced into your measurements. Second, consider the effects of the combined capacitance (C_{IN}) as a function of frequency. At 1000 Hz, C_{IN} (Fig. 1C) has an impedance of about 23.8 megohms, with no effect on signal measurement. But at 2375 Hz, its impedance will equal R_{IN} and have a definite effect on the signal. Down at 1 MHz, the impedance is only about 24,000 ohms and may load the circuit heavily.

The results of shunt capacitance variations can be amplitude attenuation and abnormal circuit operation. Furthermore, it can cause phase shift, excessive source loading, pulse perturbations, and errors in rise time and propagation-delay measurements.

The effects of shunt capacitance can become a factor almost before you know it. At 100 MHz, impedance of shunt capacitance can be less than 80 ohms for some scope/probe combinations—practically a short circuit in some cases. So, the second rule for probe selection is:

Rule 2: To minimize errors related to frequency, select a scope/probe combination with a shunt capacitance value that is as small as possible.

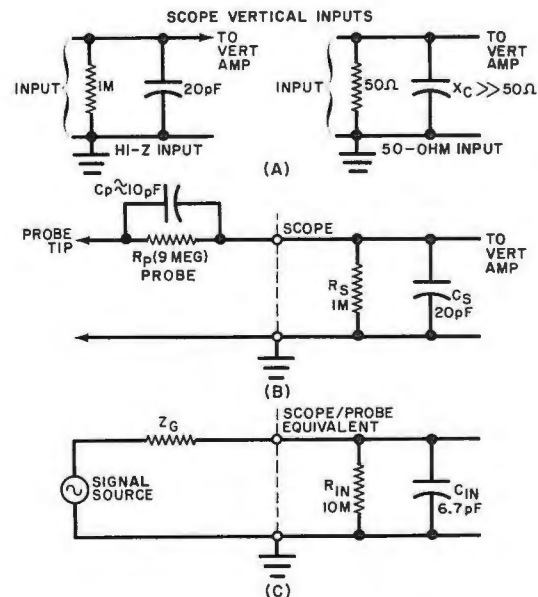**Rise-Time Error.** We have considered the effects of resistance and

Fig. 1. Typical scope inputs: (A) for high- and low-impedance scopes; (B) with a passive divider probe; (C) equivalent circuit of combination in (B).
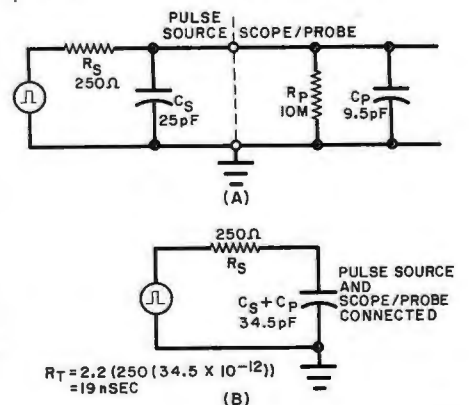

Fig. 2. A pulse source connected to the scope/probe combination in (A) results in equivalent at (B) for rise-time analysis.

capacitance. Now what is their combined effect? Figure 2A shows a typical pulse source, with an internal impedance of 250 ohms and shunt capacitance of 25 picofarads. Assuming a pulse signal with a rise time of zero, the source output rise time would be approximately $2.2R_SC_S$, or 13.8 nanoseconds. The equivalent circuit for the scope/probe and source combination is shown in Fig. 2B. Since R_P is so much larger than R_S, the former can be ignored. The rise time of the signal reaching the scope input will now be about 19 nanoseconds. The loading effect of the probe is the percentage change in rise time or about 37.7%. This is directly related to the difference in capacitance (9.5/25 or 38%) caused by the addition of the probe. So to determine how much error in rise time you are going to introduce by adding a probe, determine the ratio of the capacitances involved.
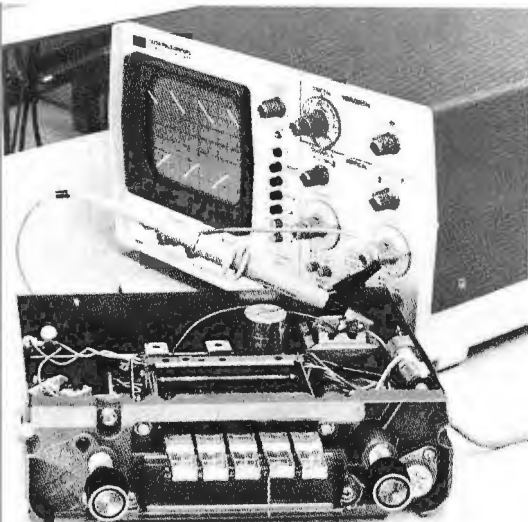
Hewlett-Packard's 10001A passive probe is rugged and easy to use.

Phase-Shift Error. In making measurements, source impedance is the key parameter. Accuracy requires that the source impedances of the two points being measured be on the same order of magnitude. For example, referring to Fig. 3, consider the effects of various probes on phase measurements between the input and output of the amplifier. The source impedance of the input is 50 ohms; while, for the output, it is 2000 ohms.

If 10-megohm, 10-picofarad scope/probe combinations are connected to the input and output of the amplifier, the source impedances will not be changed and a phase measurement error of about 49 degrees will result.

However, if 1000-ohm, 1-picofarad scope/probe combinations are connected to the input and output, the source impedances will become 47.5 and 667 ohms, and the phase measurement error will be only about 2 degrees. Thus, by loading the input and output circuits of the amplifier, the phase error has been almost eliminated; but the resistive loading error is on the order of 67%.

When phase and amplitude are both of interest, it is necessary to perform two tests—one for phase (using low-impedance probes) and another for amplitude (using high-impedance probes). So the third rule is:

Rule 3: To minimize phase errors, use low-impedance scope/probe combinations.

Types of Probes. In general, there are three basic types of probes available commercially. The types and their characteristics are as follows:

- **High-Resistance Passive.**
  Minimum resistive loading.
  Subject to capacitive loading at frequencies above 200 kHz.
  High input impedance from dc to about 200 kHz.
  High dynamic range (500-600 V).
  Least expensive type.

- **Miniature Passive Divider.**
  Load source more than high-resistance types, but load remains constant to about 100 MHz so loading is easy to predict.
  Minimum capacitive loading.
  Most useful when resistive loading is not a consideration.
  Fastest rise time.
  Widest range of voltage division (to 100:1 with changeable divider tips).
  Maximum signal voltage less than high-resistance types.
  Best for measuring fast rise time, phase relationships, and high frequencies if resistive loading is not important.

- **Active Probes.**
  Very little resistive loading.
  Minimum capacitive loading.
  Limited dynamic range (50 V maximum signal).
  Highest input resistance of all types.
  Lowest input capacitance of all types.
  Excellent for high-frequency, low-level signals.
  Best general-purpose probe within its limited dynamic range.
  Slightly greater pulse perturbations than passive-type probes.
  Large physical size.
  Most expensive type.
  Requires some form of external power.
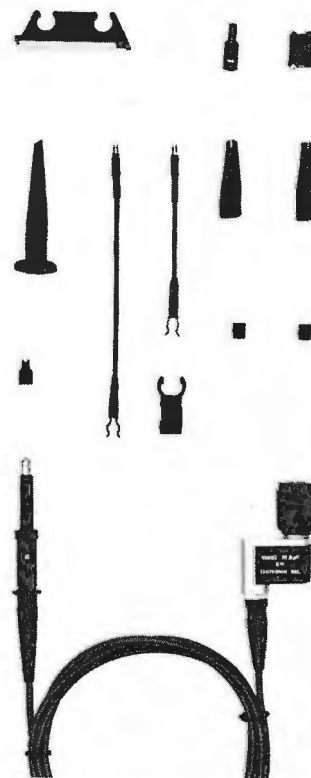
Tektronix active probe has switch to actuate trace-identity function on scope—good for dc to 250 MHz.

Of course the active probe is the "in thing" these days—primarily because it has the least possible effect on the test circuit. It is generally used with scopes having 50-ohm inputs; but it can't really be considered a general-purpose probe since it is expensive and is liable to damage from misuse.

There is a fourth type of probe that doesn't fit any of the other categories. Called a "current" probe, it is ideal for measurements involving very high source impedances, where other probes would put too much load on
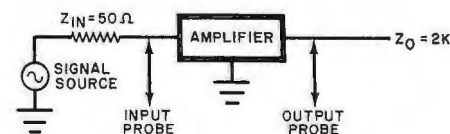

Fig. 3. Scope/probe combination can affect phase-error measurments.

the circuit. The current probe clips around the wire (or component) carrying a signal so that it does not actually contact the circuit. There is a small amount of insertion impedance (about 0.1 ohm) reflected into the circuit being tested, but this merely means that the source impedance must be at least 5 ohms to minimize errors in amplitude measurement. ◈