In particular, the fast edges on digital signals produce probing artifacts (ringing, and soft edges) when you try to use a standard 10× passive 'scope probe with its 6″ grounding lead.[14] Figure 12.30 shows how the same logic waveform looks when probed three different ways.

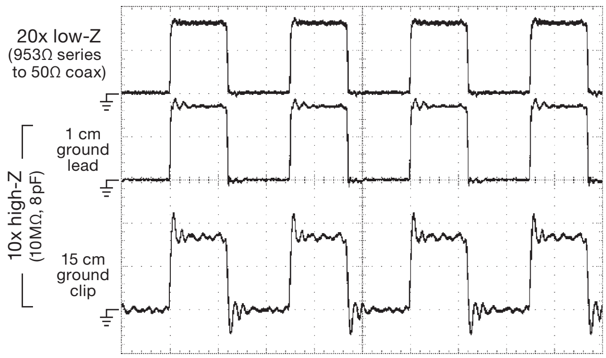

Figure 12.30. Logic waveform at 10 MHz from a 74AC14 inverter running at 3.3 V, as seen on a Tektronix TDS3044B 'scope when probed three different ways. Vertical: 2 V/div; horizontal: 40 ns/div.

This is a 10 MHz clock signal at the output of a 74AC14 inverter, wired up on a "solderless prototyping" board[15] (a dubious practice; but, hey, it works, most of the time anyway). We took the precaution of using an IC socket with integral SMT bypass capacitor, to put the best face on it. The bottom trace is business-as-usual, with a P6139A (500 MHz) 10× passive probe and 6″ ground lead. It's overshooting and ringing like crazy – can that be real, or is it an artifact of the probe's inductive ground path? You do considerably better by tossing the ground lead in the trash, removing the plastic sleeves, and using a little springy "ground tip contact." The middle trace shows the result: aha! Most of the ringing is gone. Better still, dump the 10× passive probe altogether (they don't come in speeds faster than 500 MHz anyway) and make your own by hooking a series resistor (we like 950 Ω) onto a length of skinny 50 Ω coax (we like RG-178); you temporarily solder the coax shield to a nearby ground, plug the other end into the 'scope (set for 50 Ω input) and voilà – a high-speed 20× probe![16]

[14] *Leads?* Yeah, sure. I'll just check with the boys down at the crime lab. . . they've got four more detectives working on the case. . . they got us working in *shifts!*

[15] For example, Global Specialties type UBS-100, or 3M type 923252.

[16] You can get these as a commercial product, the Keysight (Agilent) 54006A "6 GHz Passive Divider Probe Kit." It includes resistors for 10:1 and 20:1, and has a probe-tip capacitance of just 0.25 pF (as little as 0.1 pF, if you trim the tip). You can create greater ratios (thus higher loading resistance) by substituting other values of Caddock MG710-type resistors.

The top trace is about as clean as you can do, especially with through-hole (14-pin DIP) parts on a breadboard.

The homemade 50 Ω trick has the advantage of low cost, so you can do four traces easily; we used it for nearly all the digital 'scoping in this book. But because of its low input resistance, it is not useful for generalized circuit probing.

What happens with the more common configuration of surface-mount components on a printed-circuit board, and with much faster logic signals? Figure 12.31 shows what you see with four probing methods looking at the output of a 74AUC1G04 inverter, this time at 4 ns/div (and Figure 12.32 shows what the probes themselves look like).

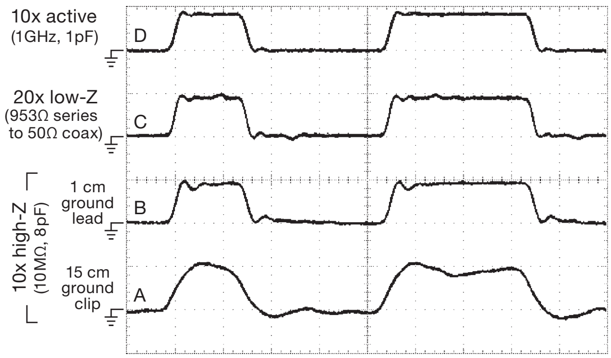

Figure 12.31. Logic waveform at a 6 ns clock rate from a 74AUC1G04 inverter running at 1.8 V, as seen on a Tektronix TDS3044B 'scope, when probed four different ways. The A–D labels match those in Figure 12.32. Vertical: 2 V/div; horizontal: 4 ns/div.

Here the passive-probe-with-ground-lead produces a mushy waveform (bottom trace) with moderate overshoot, considerably helped by using the shorter ground tip (next trace). The el-cheapo 20× trick looks better still. But best of all (if you've got the dough), is an "active probe" (an FET follower), with typical input capacitance less than 1 pF, and with speeds up into the high gigahertz (and prices to match). The top trace was made with a P6243 active probe (1 GHz bandwidth, less than – but not much less than – 1 kilodollar[17]).

12.3 Comparators

Comparators provide an important interface between analog (linear) input signals and the digital world, as we noted earlier in this chapter (§12.1.7A). In this section we would like to look at comparators in some detail, with emphasis on their output properties, their flexibility regarding power-supply voltages, and the care and feeding of input stages.

[17] But ∼8 dB less expensive on used auctions.

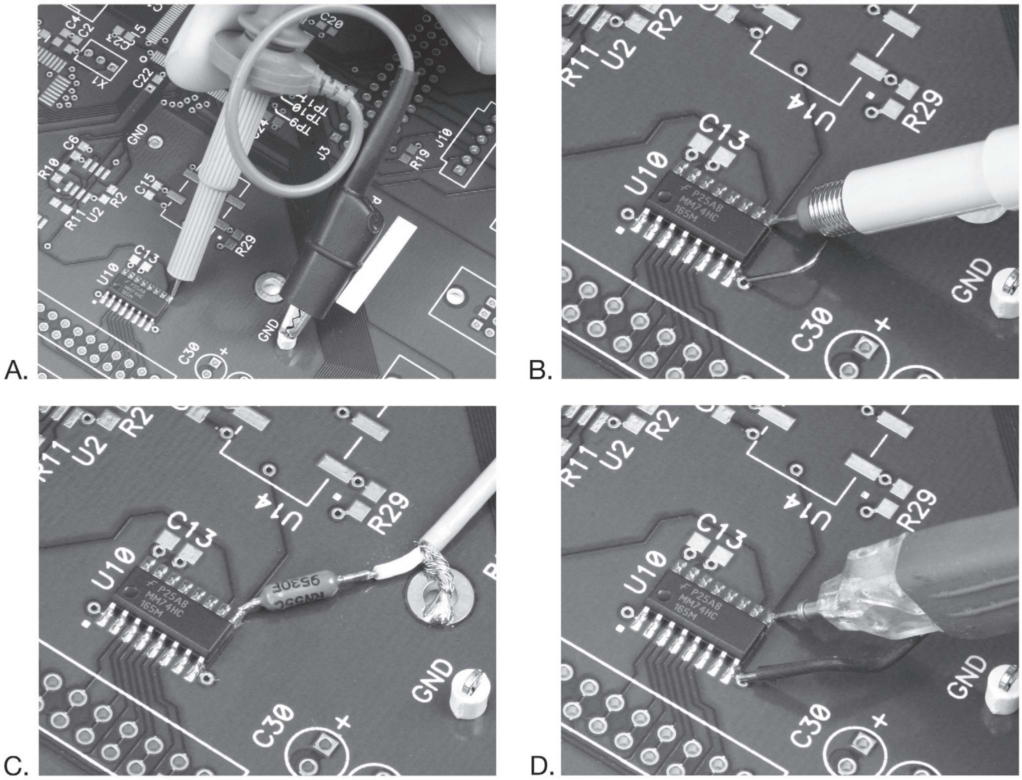

Figure 12.32. Probing digital signals: A. conventional 10× passive probe (Tektronix P6139A) with 6″ ground lead; B. short ground tip contact (Tek 016-1077-00) on 10× passive probe. C. Simple 20× passive "probe" for 50 Ω 'scope input: 953 Ω series resistor to coax; D. active probe (Tek P6243) with short ground tip. When probing fine-pitch ICs, it's a good idea to use a plastic guide (e.g., Tek "SureFoot" adapters) over the probe tip (not shown), so you don't short out adjacent contacts. The IC here is an SOIC-16, with 1.25 mm contact spacing.

Comparators were introduced briefly in §4.3.2A to illustrate the use of positive feedback (Schmitt trigger) and to show that special-purpose comparator ICs deliver considerably better performance than general-purpose op-amps used as comparators. These improvements (short delay times, high output slew rate, and relative immunity to large overdrive) come at the expense of the properties that make op-amps useful (in particular, careful control of phase shift versus frequency). Comparators are not frequency-compensated (§4.9) and cannot be used as linear amplifiers.

12.3.1 Outputs

We're used to op-amps, where the output can swing rail-to-rail (or nearly so), but where we usually stay in the linear region, deliberately avoiding saturation at the extremes of output swing. When the output is saturated, we're in trouble!

But comparators are different. Although the inputs are analog, the output is digital: it *lives* at the extremes. So what you care about is what the output does when LOW and when HIGH. As we've seen, the output may drive digital logic directly (Figure 12.25), in which case we need to bound its swing to that of the driven logic. Or we may want to drive an ON/OFF load, for example a relay (mechanical, or solid-state) or a bright LED, requiring plenty of output current, and perhaps powered from an external dc supply.

A. Output swing

Figure 12.33 shows the choices you've got to meet these various demands. In each case the comparator's analog circuitry is powered from a pair of supplies, V_+ and V_- (though for "single-supply" comparators, analogous to single-supply op-amps, the negative supply voltage V_- is ground). We'll have more to say soon about the input stage. What's interesting here are the output stages: one variety of comparators simply swing their output from rail to rail