Fundamentals of Signal Integrity

ARTICLE #4

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Summary

LeCroy Corporation, in association with Signal Consulting, Inc., has prepared an eight-part series on the fundamentals of signal integrity. Authored by the world's foremost authority on signal integrity, Dr. Howard Johnson, the series is a "must read" for engineers who need a clear understanding of issues essential to high-speed performance.

Other papers in the series include Confirm The Diagnosis, Adequate Bandwidth, and Step Response Test. To read other parts in the series, please visit: http://www.lecroy.com

DC Loading

I just got a new differential probe.

Whether the probe accurately reports the voltages to which it is exposed, I do not doubt. I'm willing to assume a probe measures things the way its manufacturer says, unless broken. What I must always check, though, is the degree to which the probe loads down or distorts the signals in my system when applying the probe.

A trivial setup will suffice for this measurement. Take any driver and run its output directly into your scope with coaxial cables (no probes). Then, while observing the coaxial output, touch a probe onto the output pins of the driver. See what happens.

My setup incorporates an LVDS-style differential driver **(Figure 1)**. The driver feeds a short (1-in.) pair of microstrip traces. The traces go out through SMA connectors then through 24 inches of RG316 coaxial cables to a scope. At the scope, I connect DC blocking capacitors ahead of the 50-ohm scope inputs. Then I display the signal.

When doing this test, the expected result depends on the relation between the input impedance of the probe and the impedance of the circuit under test. Think of the circuit under test as a voltage generator with output voltage v[source] and output impedance Z1. When loaded with a probe having impedance, say, Z2, the expected value of the measured signal should be, according to the resistor-divider theorem:

$$V[\text{measured}] = V[\text{source}] * (Z2 / (Z2+Z1)) \qquad [1]$$

I'm using a LeCroy D600A-AT 7.5 GHz differential probe with a differential DC input impedance of Z2=4000 ohms,

http://www.lecroy.com/tm/products/Probes/Differential/WaveLink/default.asp .

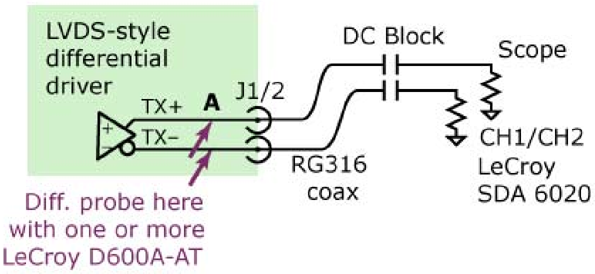

Fig. 1—Observe the CH1/CH2 outputs while touching one or more differential probes at **A**.

My 100-ohm differential circuit, terminated at both ends, has an effective differential driving-point impedance of 50 ohms. That happens because, from the perspective of the probe, it "sees" 100 ohms to the left, at the driver, in parallel with another 100 ohms to the right, at the scope. Two 100-ohm loads in parallel makes a 50-ohm differential driving point impedance.

Given those numbers, I expect this attenuation factor when connecting the probe:

$$A[\text{expected}] = (4000 / (4000+50)) = 0.988$$

The expected reduction should shrink the signal by only 1.2 percent, a tiny change. Let's try it.

Figure 2 plots the results when measuring a National Semiconductor DS25BR100 driver. This high-powered driver is designed for long-distance transmission applications. It incorporates transmit pre-emphasis, a feature that is turned off for this test. The figure shows the results of experiments conducted with zero, one and two LeCroy probes connected to the output terminals of the device. All measurements are made using the coaxial cable setup in **Figure 1**. The illustration shows both positive and negative signal edges.

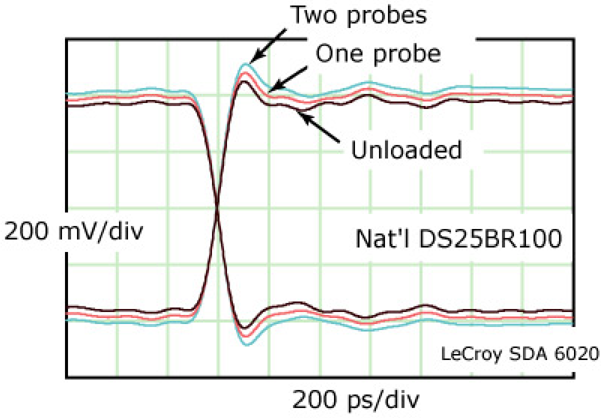

Fig. 2—The output of this differential driver *increases* when loaded with a differential probe.

Obviously, the probes affect the size of the signal. That's normal. But what totally, completely surprised me in this example is the direction of the change. Look closely. As you add probes the signal grows. With one probe, the signal gets 6.5% bigger. With two, it's 13% bigger.

What?? I can't believe it. I re-tried the experiment several times under different conditions. I double-checked the stored waveform file names to see if I had them reversed. My assistant looked over the setup. Everything appears right. As far as I can tell, this signal actually GROWS when loaded.

How can that be? The explanation involves a subtle interaction between the common-mode loading of the probe and the differential-mode gain of the driver. There is not a problem with either circuit; it's just how they happen, in this circumstance, to work together.

The DS25BR100 employs a feedback control loop to stabilize its common-mode output voltage (a good idea). The feedback loop reacts to changes in common-mode loading.

What changes might there be? Well, a simple 100-ohm resistor across the output terminals of the driver provides a 100-ohm termination for differential signals, but draws zero common-mode current. If you exercise such a load with a common-mode signal (same on both sides) no current flows through the resistor -- it's as if the resistor weren't there. The simple 100-ohm load draws no common-mode current.

Similarly, the scope in **Figure 1**, configured with DC-blocking capacitors, draws zero common-mode current at DC.

The LeCroy differential probe is different. It presents a load of 2K ohms to ground on each side. From a common-mode perspective, that's a 1K load to ground. This load draws a small amount (1.2 mA) of common-mode current from the driver. As differential probes go, that is pretty good. Some high-speed probes draw much more. I think the common-mode current drawn by this differential probe is causing the waveform amplitude artifacts in **Figure 2**.

To validate my thinking, I measured the common-mode output voltage from the driver when the probe was removed, using a high-impedance digital voltmeter, and again with the probe present. The DC droop under that condition amounted to only about 1 mV, indicating an effective common-mode output impedance from the driver of approximately 1 ohm. You can't get such a low output impedance without feedback regulation. So, I conclude that the DS25BR100 incorporates an internal feedback loop designed to regulate the common-mode output voltage. (Lee Sledjeski at National Semiconductor confirms my suspicions).

In practice, when you apply a differential probe to the driver, the feedback loop inside the driver raises the common-mode gain to make up for the DC droop caused by the common-mode loading of the probe. As a side effect, the act of raising the common-mode gain also raises the differential-mode gain, causing the signal growth reported here.

To check my assumptions, I loaded the DS25BR100 with a 2.2K-ohm passive metal-film resistor on each side to ground. Under that condition, the outputs GREW. Then I connected the same resistors from the outputs to VCC instead of ground (now sourcing common-mode current INTO the driver) and, guess what, the outputs SHRANK.

The DS25BR100 is the first case I can recall of a transceiver whose output gets bigger when loaded. Not all LVDS outputs do this. **Figure 3** shows the outputs of a TI DL100-44T. I captured these output waveforms with zero and one probes present (two wouldn't fit). This output, when loaded, shrinks as expected by 1.2 percent.

I do not mean to imply that one transceiver is better than the other; only that they are different, and that the difference affects your voltage margin budget. If you are trying to measure output levels with any accuracy it's worth knowing that the DS25BR100 outputs can GROW when probed. That affects your voltage margin budget calculations, and that's worth knowing.

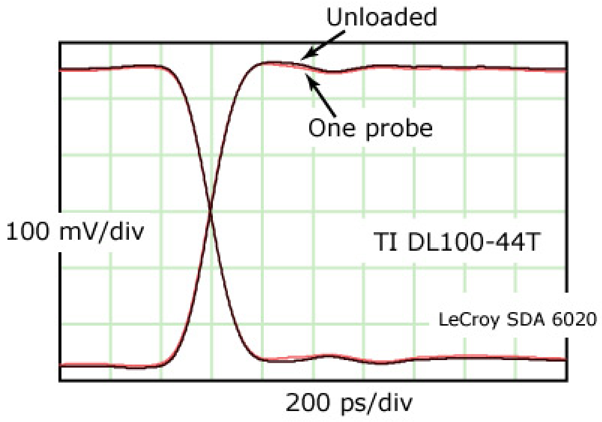

Fig. 3—The output of this differential driver is largely unaffected by common-mode loading.

Best Regards,
Dr. Howard Johnson