Lumped vs TLine Simulation Study

Interface Products
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This simulation study compares a LVCMOS output driving a lumped cap load vs. various length transmission lines. The goal of this study was to determine at what length does the line act as a distributed element vs. a lump load.

Simulation Setup

- DS91C176 LVCMOS output
- Output Load
  - No Load
  - Lumped Cap
    - 5, 15, 50 pF
  - 50 Ohm Transmission Line
    - 0.1” to 10” in length with 5pF at end
    - 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 10.0 (inches)

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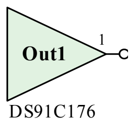
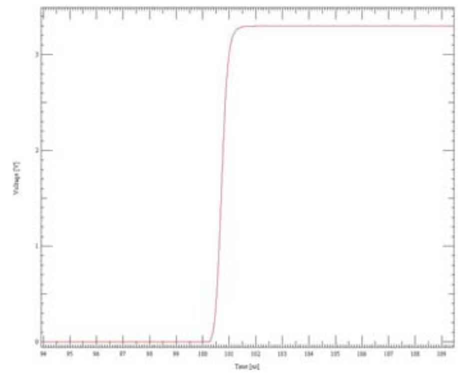
The simulation set up was done in the Innoveda (Now Mentor Graphics) XTK simulator under typical conditions. The LVCMOS output of the DS91C176 M-LVDS transceiver was used as the signal source.

The output’s rise time was measured for the load conditions stated above and the waveshape was studied.

Simulation 1 – No Load

- Simulate with no load
- 10/90 Rise Time = 470ps
- 20/80 Rise Time = 330ps





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SIM 1
Unloaded Output simulation – this simulation provides a reference point that the output is not expected to switch faster than 470ps. Note the rail-to-rail (RTR) swing and also the excellent signal waveshape (no overshoot or ringing) due to special GTO (Graduated Turn On) circuitry.

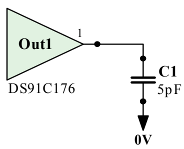
Calculating a slew rate yields:

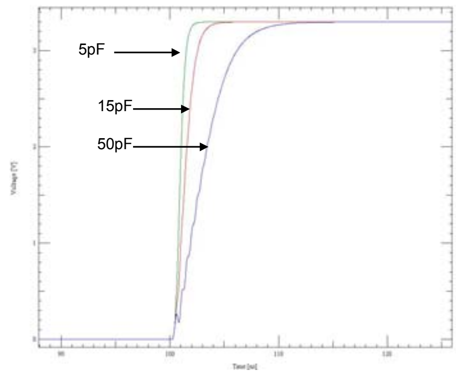
dv/dt => 2.64V / 0.47ns => 5.62 V/ns, based on the 10-90% measurement.
dv/dt => 1.98V / 0.33ns => 6.00 V/ns, based on the 20-80% measurement.

The two agree within 10% of each other and imply an approx. 5.8V/ns edge rate for an UNLOADED condition. Slew rate will slow as the output load is increased.

Simulation 2 – Lumped Load

- Simulate with Cap. Load
- Use different load values of 5/15/50 pF
- Rise Time of 5pF load = 610 ps (using 20/80)





SIM 2
Next we add a lumped load at the output pin of the device. As the CL is increased the output slows down as expected.

10-90% Rise time	20-80% Rise time	CL
980 ps	610 ps	5 pF
1.94 ns	1.23 ns	15 pF
4.74 ns	3.34 ns	50 pF

Note – 15pF is the specified datasheet load.

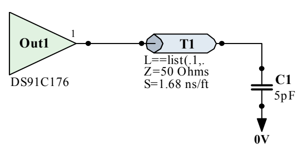
With a lumped load the “fastest” rise time can also be roughly calculated from the following equation:
I = C dV/dt where:

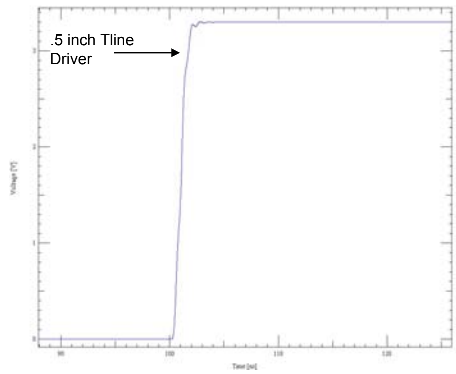
C = CL
I = IOS (Short circuit current of the output, approx 38mA)
dV = 60% of 3.3V for a 20-80% rise time, or 1.98V
dt = the rise time

Solving for dt we get C(dV) / I. 15pF(1.98V) / 38mA = 958 ps
Which agrees with (is faster than) the actual measured 1.23 ns. The error here is related to the fact that as the cap charges up, its output current is less than IOS, and the resulting rise time is actually longer.

Simulation 3 – TLine

- Simulate with TLine and Cap. load of 5pF at end
- Zo=50 TD=140ps/in
- Vary length of line from .1 to 10 inches
- Rise Time of .5 inch (Driver) tline = 730 ps (using 20/80)





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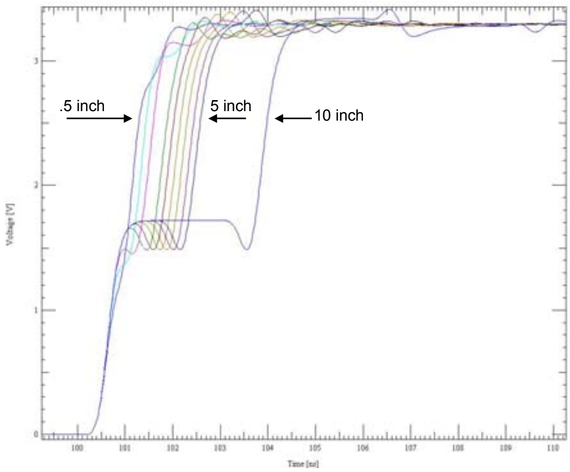
SIM 3
For the transmission line simulations, both driver output and receiver end signals were plotted and evaluated. A 50 Ohm lossy transmission line was used and its length stepped from 0.1” to 10” in length. At the load end was a bulk 5 pF load representing the Cin of the destination device.

With a 0.5” line, the driver’s rise time was monotonic and had a 20-80% rise time of 730 ps.

The Co of the line is 2.62 pF / inch, Ctotal seen by the driver is estimated at 6.3pF (5pF + 1.31pF).

Also note that no transmission line effects are observed (this plot is at the driver output).

Simulation 3 – Driver Results



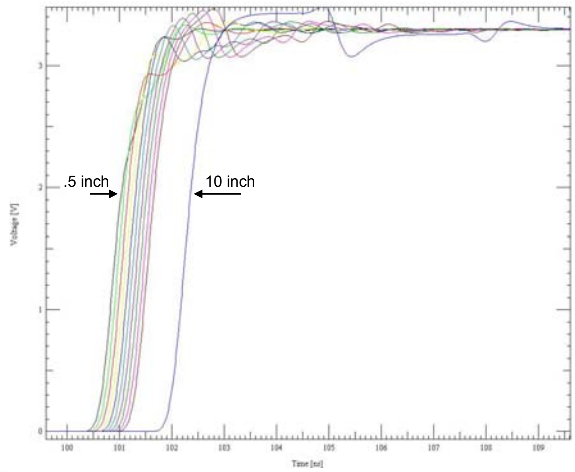
Here we see all the driver output waveforms. Note these are at the driver end. Three different lengths are noted. The first two lengths act as lumped loads and have a monotonic transition (no reversal of slope)

The other lines are acting like transmission lines and the round trip reflection must arrive back to pick up the signal to its final value.

The 10” line shows the round trip length delay: 2 X 10” X 140ps/in = 2.8ns.

Note also that the initial waveform step is related to the output current and the impedance of the line. 1.5V / 50 Ohms = 30mA drive. This initial porch is in the logic threshold region. In a point-to-point application (single load) this is typically not a concern – see load end waveshapes. If however this is a multi-drop line, this porch maybe of issue. To raise the location of the step, the driver’s output characteristics could be altered (more Iout or slower) or the transmission line’s impedance could be increased to increase the initial step size. However, the details of this application are outside the scope of the study and are not addressed/discussed further.

Simulation 3 – Receiver Results



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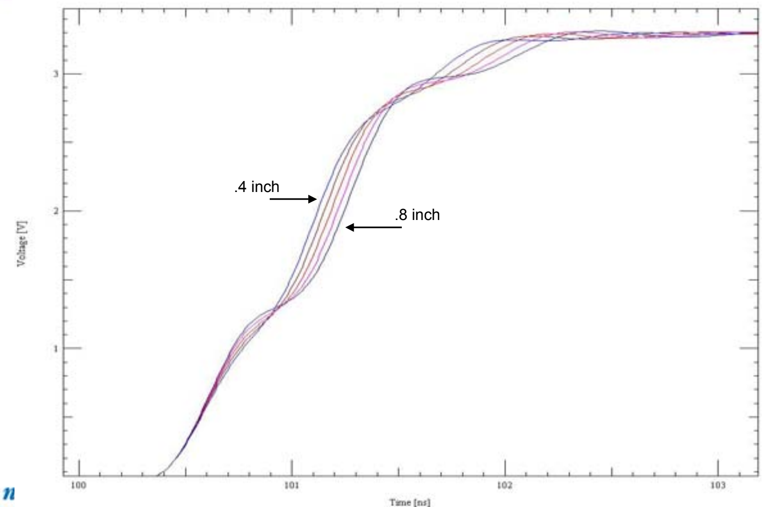
Here are the waveshapes at the load (receiver) end of the line. The signals arrive at different times due to the length of the line. The signal hits the high impedance of the load and a positive reflection steps the waveshape up on the lines that are acting like transmission lines.

Note that on the short lines, the waveshape at the driver output and receiver input are very similar. This is where the interconnect is acting purely as a lumped load. Where the line is acting as a transmission line we start to get the overshoot and damping effects.

T-Line Effects



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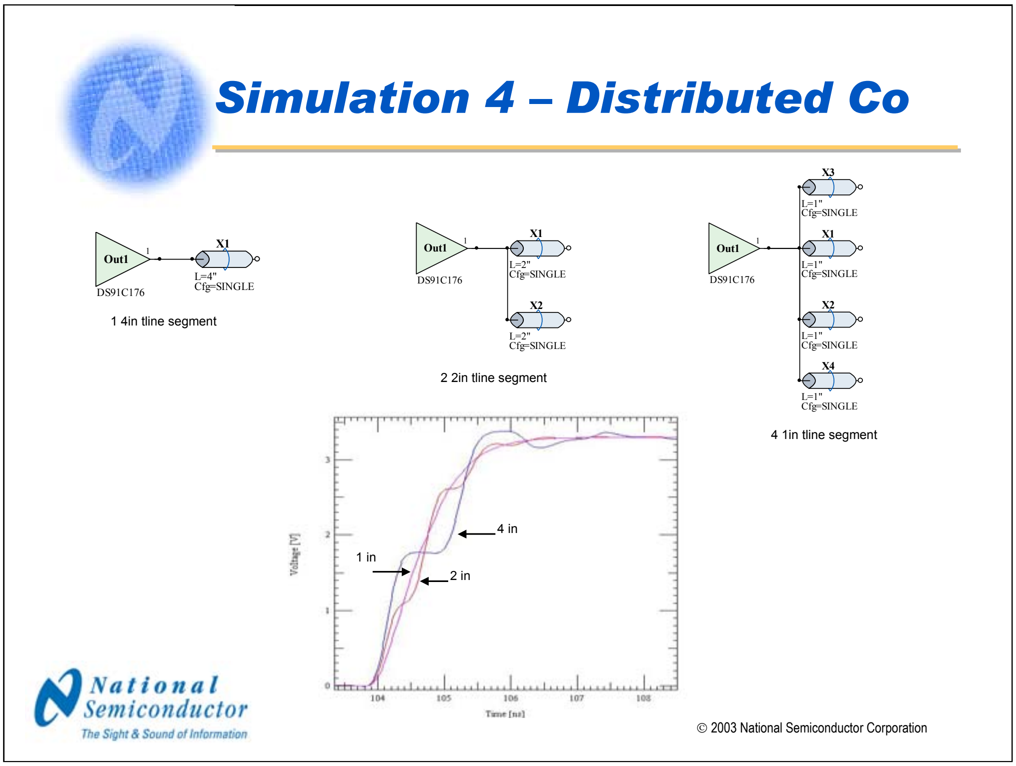
Here are more driver output waveforms (at the source end) for line lengths of 0.4, 0.5, 0.6, 0.7, and 0.8 inches. At 0.4 inches, the ‘step’ in the driver output waveform starts to be seen. By 0.8 inches, the ‘step’ in the waveform is apparent and the line is starting to act like a transmission line.

The electrical length of the 0.8 inch line is 0.8in(140ps/in) = 112 ps
The total load presented by the line and load is 5pF + 0.8in(2.62pF/in) = 7.1 pF

The 20-80% rise time of the signal with a 7pF lumped load is 725 ps

At about 1/7 of the rise time, the line starts to act like a transmission line (112/725).



SIM4
This simulation shows the effect of the distributed capacitance. The driver output is plotted at the source end.

In this simulation, an open-ended transmission line was used. The bulk 5pF at the load end was removed. Note that the dip is removed. It is clear in this plot that a 2 2" segment or greater line is acting as a transmission line.

The T-Line was broken into equal length sections: 1 4in line, 2 2in lines, 4 1in lines, and 8 .5in lines. A lumped capacitive load of 10pF was plotted as well for reference.

It can be seen from the graph that after the 4 1" lines, the T-Line affects start to show up. Anything under this looks like a lumped load. The slew rates are calculated below for the given cases:

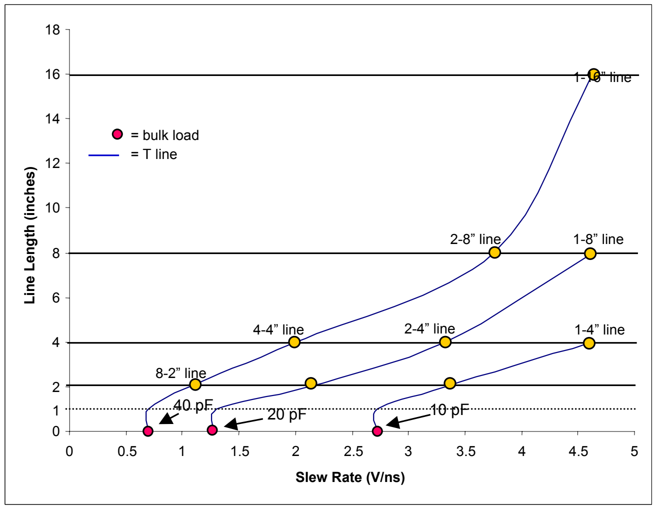
One 4 inch line: 1.062 V/ .230 ns => 4.62 V/ns

Two 2 inch lines: 0.60 V/ .180 ns => 3.33 V/ns

Four 1 inch lines: 0.60 V/ .220 ns => 2.72 V/ns

The slew rates were calculated by selecting a dv value that was not influenced by the transmission line affects. For the one 4in line, the 20/80% of the full signal swing was used. For the two 2in line, the 20/80% of 0 to 1V was used. For the four 1in line, the 20/80% of 0 to 1.7 V was used. Note that the longest line length (4 inch) actually has the fastest initial slew rate (blue line leads in graphic). The shorter lines were acting more lumped and slowed the initial edge.

Distributed Co Graph



For this graph, an open-ended 50 Ohm transmission line was used to show the effects of the distributed capacitance. A reference lumped capacitive load (with no transmission line) of 10pF, 20pF, and 40pF was used.

A 10pF load resulted in a Slew Rate of 2.72 V/ns. The Slew Rate was measured at the source. The transmission line was a 4 inch line, resulting in a Slew Rate of 4.62 V/ns. Then the transmission line was split into two 2 inch transmission lines, and the Slew Rate of the driver was measured again. As the transmission line was split into more elements (but keeping the overall 4 inch length the same) the Slew Rate of the driver got faster.

Below 1 inch transmission line segments, the Slew Rate of the driver looks lumped.

For the two 2 inch transmission line segments (and above), the Slew Rate was calculated based on 20/80 of the signal transitioning from 0 to 1V. (So as not to include the affect of the transmission line) For the transmission line segments smaller than the two 2 inch transmission line segments, the Slew Rate was calculated based on 20/80 of the total signal.

A reference load of 20pF with a 8 inch transmission line and a reference load of 40pF with a 16 inch transmission line are also plotted. This shows that the transmission line affects happen at 1”, no matter what the load is.

1 inch and below lines are show to act act as a lumped load.

Conclusions

- Multiple simulations with varying loads can be used to determine where a line starts to act as a transmission line.
- Before that point, the line can be approximated by a lumped cap load representing the total capacitance seen by the output.
- Transmission line effects start to occur at approx. 1/7 of the signal's rise time (20/80) in electrical length.

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NOTES