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PDA for SI Analysis in LTI Systems

A VHDL-AMS Test Case

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IBIS Summit
Tokyo, Japan
October 31, 2006

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Background

The IBIS Advanced Technology Modeling Group is now discussing adding channel analysis support to IBIS

Key points of the discussion include:

- Is a model API needed to support today's data processing designs?
- If so, for which language? *-AMS? C? Other?

http://www.vhdl.org/pub/ibis/summits/jul06/wang.pdf

This experiment attempts to show channel analysis using VHDL-AMS

- Channel analysis & LTI theory summarized by Bryan Casper of Intel

http://download.intel.com/education/highered/signal/ELCT865/Class2_15_16_Peak_Distortion_Analysis.ppt

Simulation setup

A simple circuit was used to generate a reasonable pulse response

The “channel” consists of

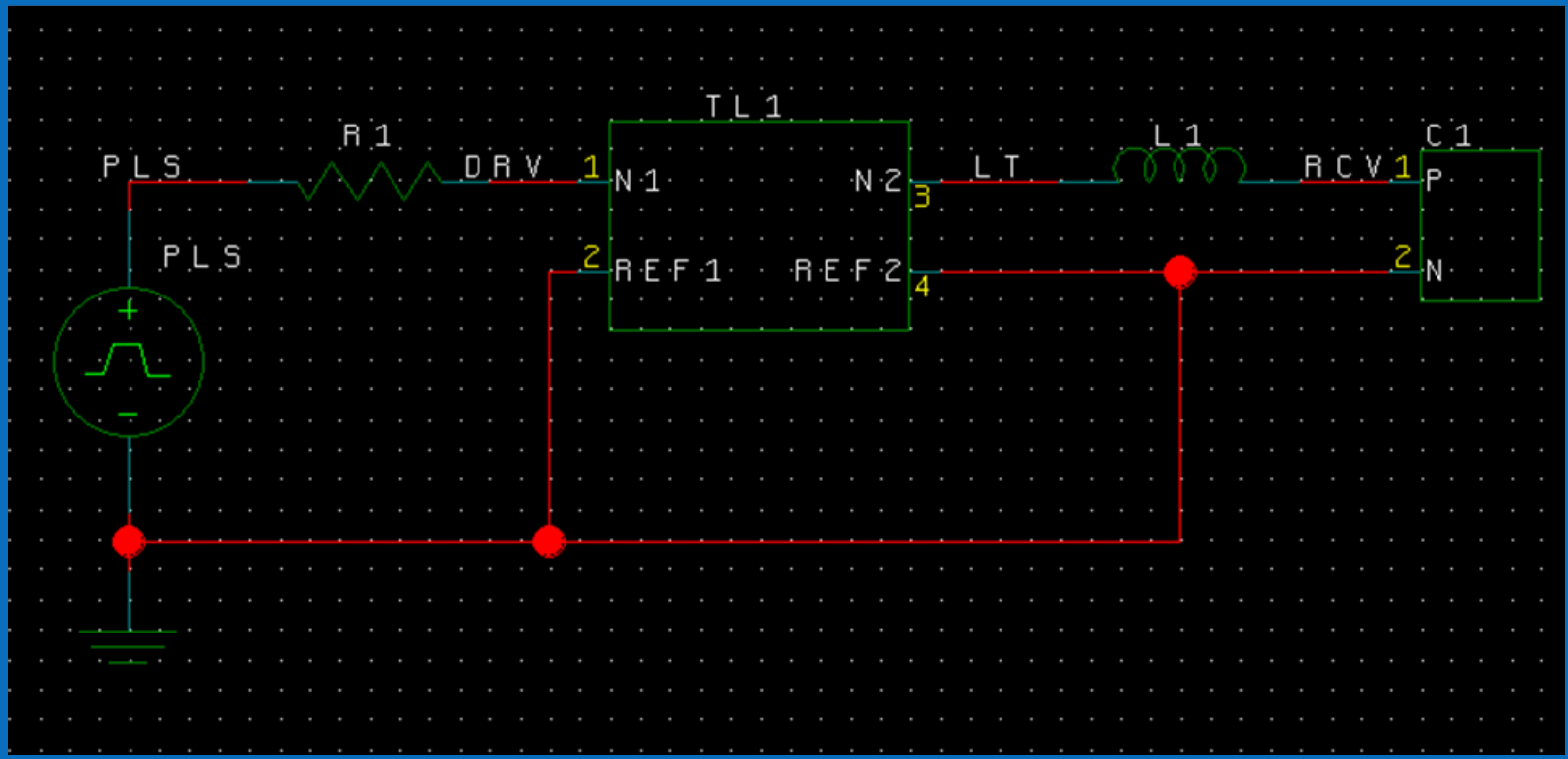
- A Thevenin driver using a pulse voltage source and a resistor,
- An ideal T-line
- An inductor and capacitor as the “receiver”

The channel was not meant to be realistic

The capacitor model has two “architectures”

- A normal capacitor
- A normal capacitor plus the PDA algorithm

Schematic of the simulated circuit



Pulse: 1 V, 200 ps wide, 1 ps edge
R1: 100 Ω
T-line: 100 Ω, 0.5 ns, lossless
L1: 10 nH
C1: 1 pF

Overview of the operation of the model

A normal time domain simulation is started

- Here, the first 3 ns of the simulation generate the pulse response
- The points of the pulse response waveform are stored in a “real_vector” (3000 points in this example)
- A 1 ps fixed time step is used for simplicity

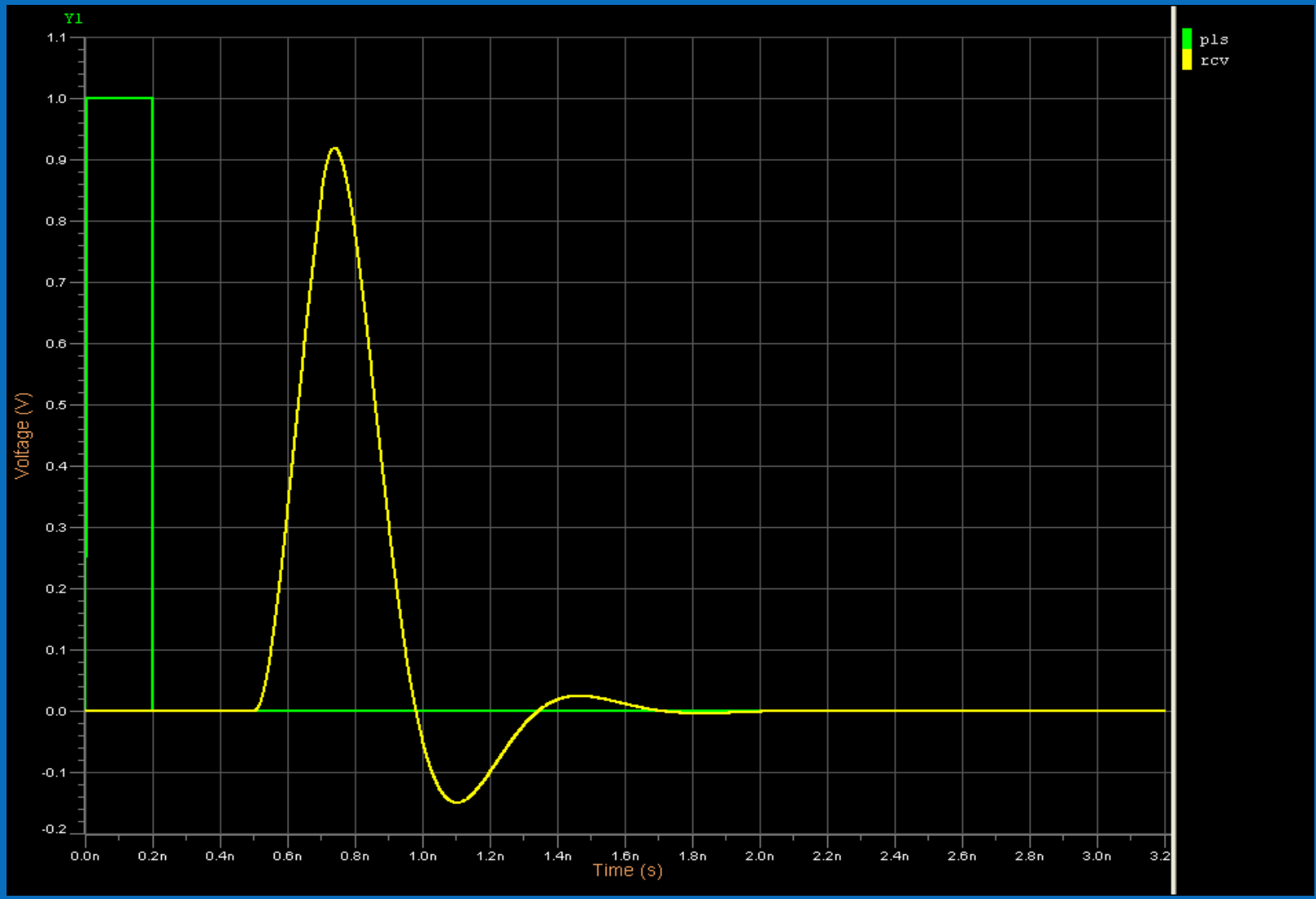
At the 3 ns time point of the simulation…

- A digital process begins (fast!)
- The process finds the peak of the pulse response, identifying the index of that point in the vector
- It finally generates an upper and lower eye contour using the methodology described in Bryan Casper’s presentation

The time domain simulation is continued for another 200 ps

- The upper and lower eye contour vectors are plotted

Pulse response of the circuit



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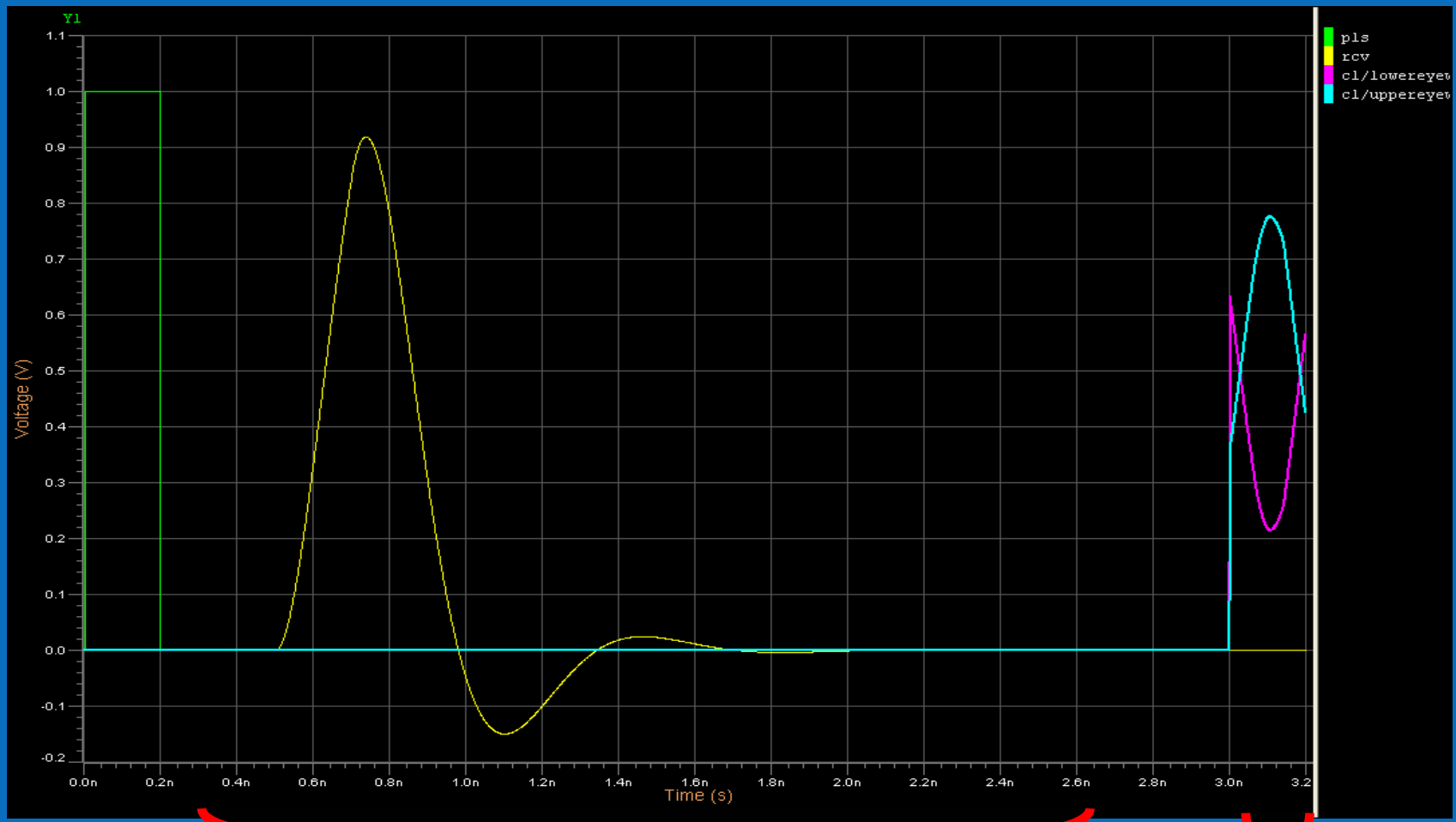
Adding PDA post processing



Pulse response TD simulation

PDA result "worst eye"

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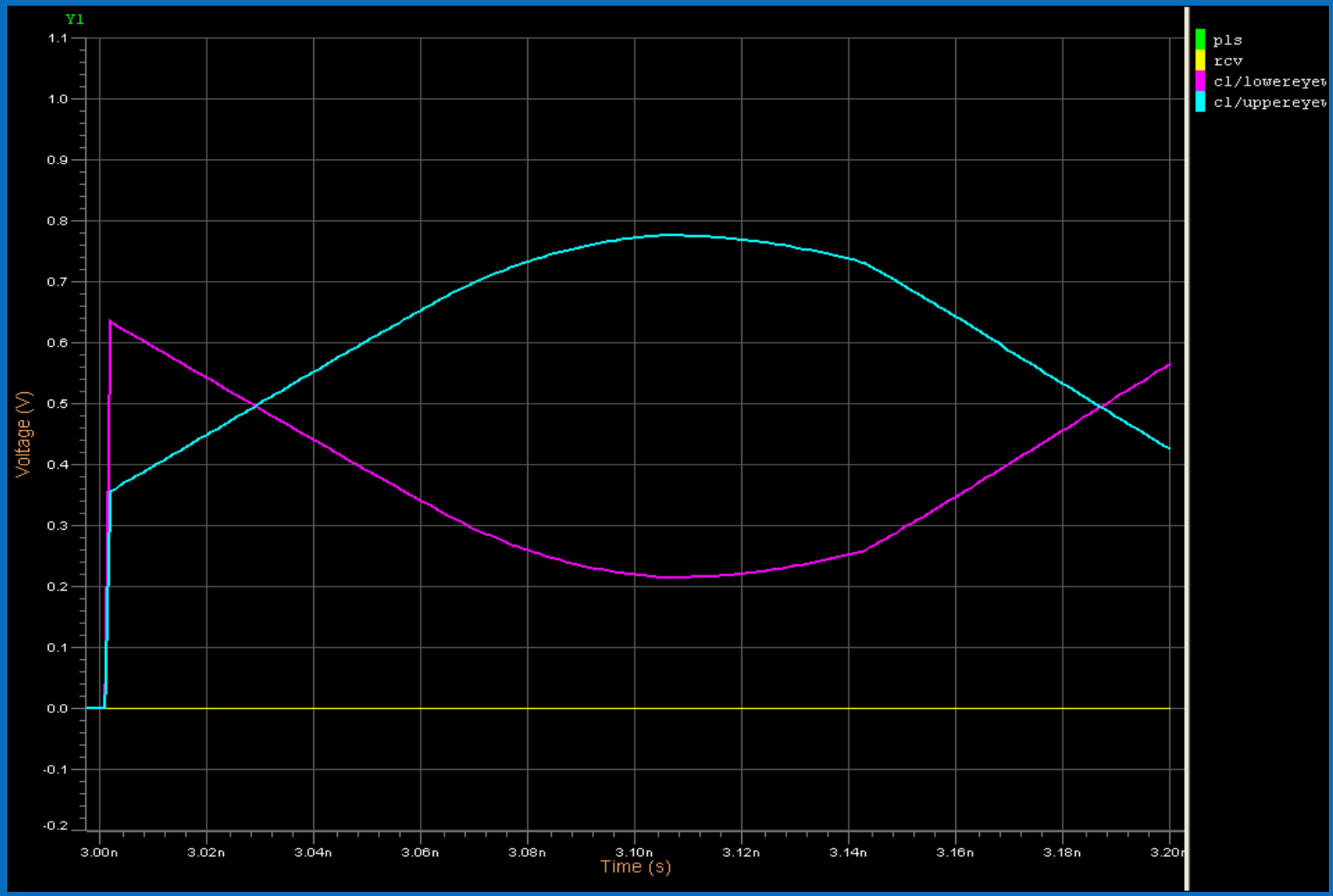
Zoom: Worst eye plot



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Summary, benchmarks and future work

This experiment implemented the basic equations of PDA only

- No crosstalk
- No jitter
- No BER or more complex analyses included

Benchmarks with a 3000 point pulse response

- Approximately 230 ms CPU time without PDA algorithm
- Approximately 240 ms CPU time with PDA algorithm

Future work

- Show that more computationally intensive statistical analyses can also be implemented
- Implement same algorithm in Verilog-A(MS)

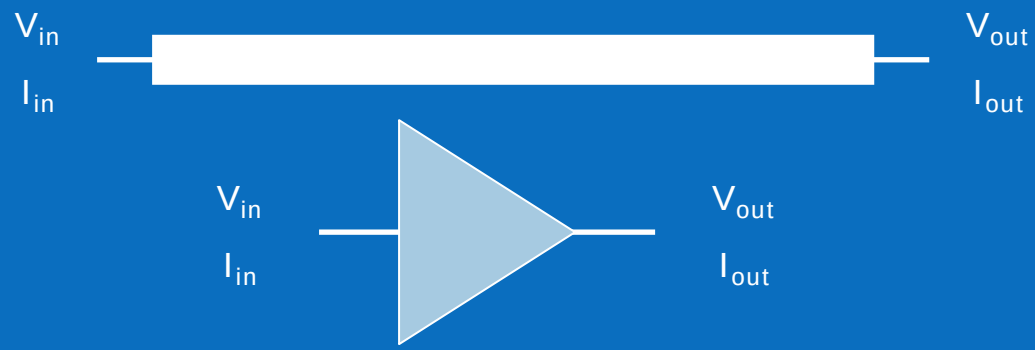
This experiment illustrates that a *-AMS language can be used for “signal processing” algorithms

Key questions remain…

PDA methods require “LTI” (linear time-invariant) systems.

How can we check buffer LTI?
Are common buffer designs truly LTI?

What is input and response?

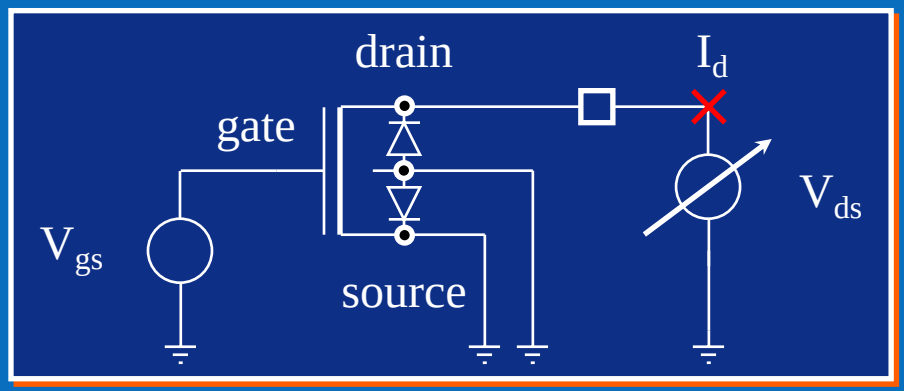


For S_{11} (Z_{11}, Y_{11}, etc…)

- if input is V_{in}, the response I_{in},
- if input is V_{out}, the response is I_{out},
- if input is I_{in}, the response is V_{in},
- if input is V_{out}, the response is I_{out}.

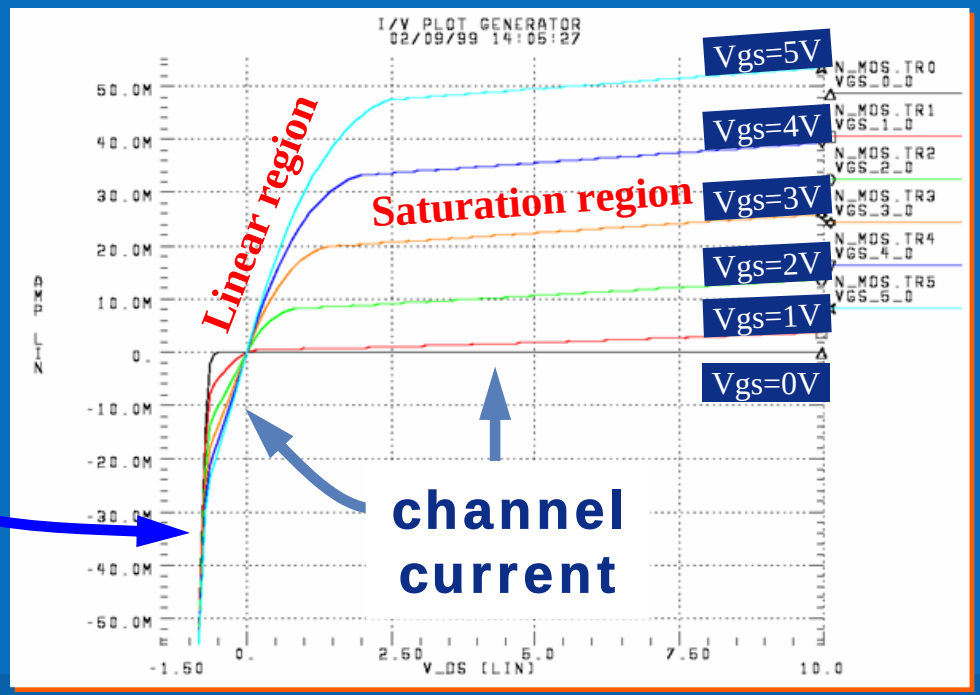
When we analyze a T-line with a driver and receiver for ISI effects, we must use the “11” parameters of the driver and receiver (V_{out}/I_{out}, I_{out}/V_{out}, or V_{in}/I_{in}, I_{in}/V_{in}, respectively) in response/input = transfer_function.

What is a non-linear driver (or receiver)?



If the input is V_{ds} and the response is I_d, we can see that the relationship is not linear.

diode current



Even the so-called "linear region" is not perfectly linear.

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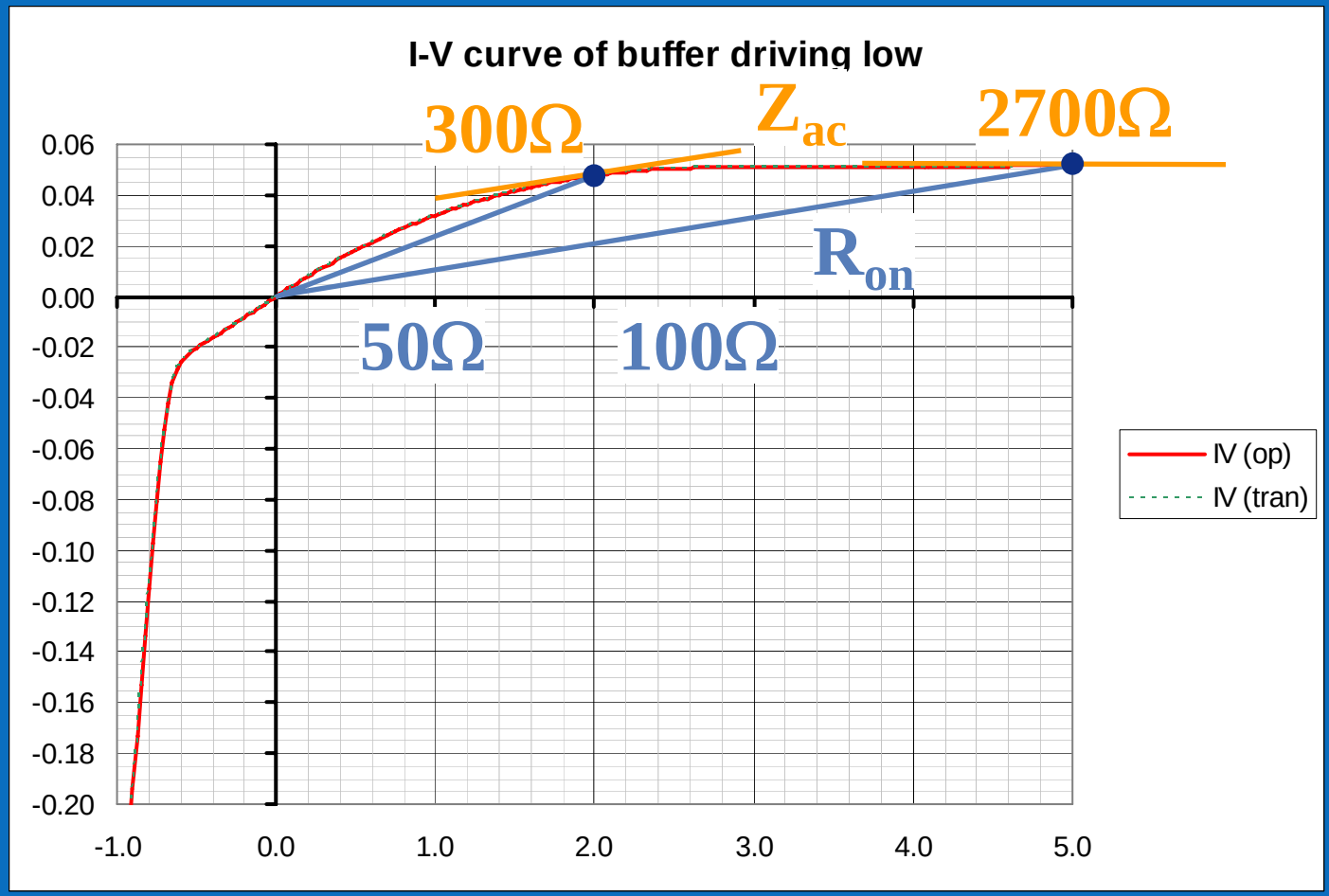
Reflections and FD analysis determined by Z_{ac} (not R_{on})



$dR_{on} \neq Z_{ac}$!!!

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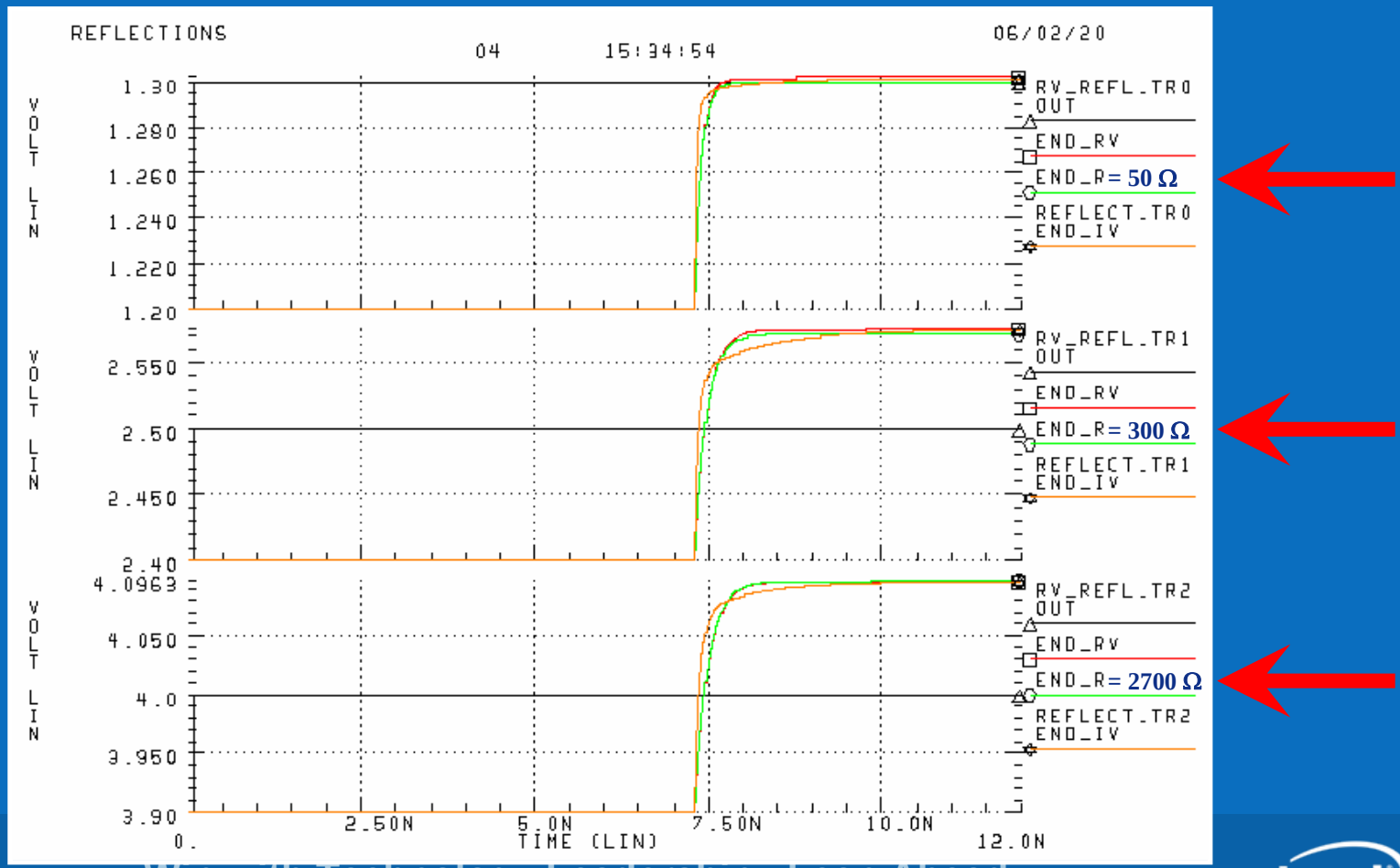
Proof with a time domain simulation

V_{in} = 100 mV step centered around 1.25, 2.45, 3.95 V_{dc}



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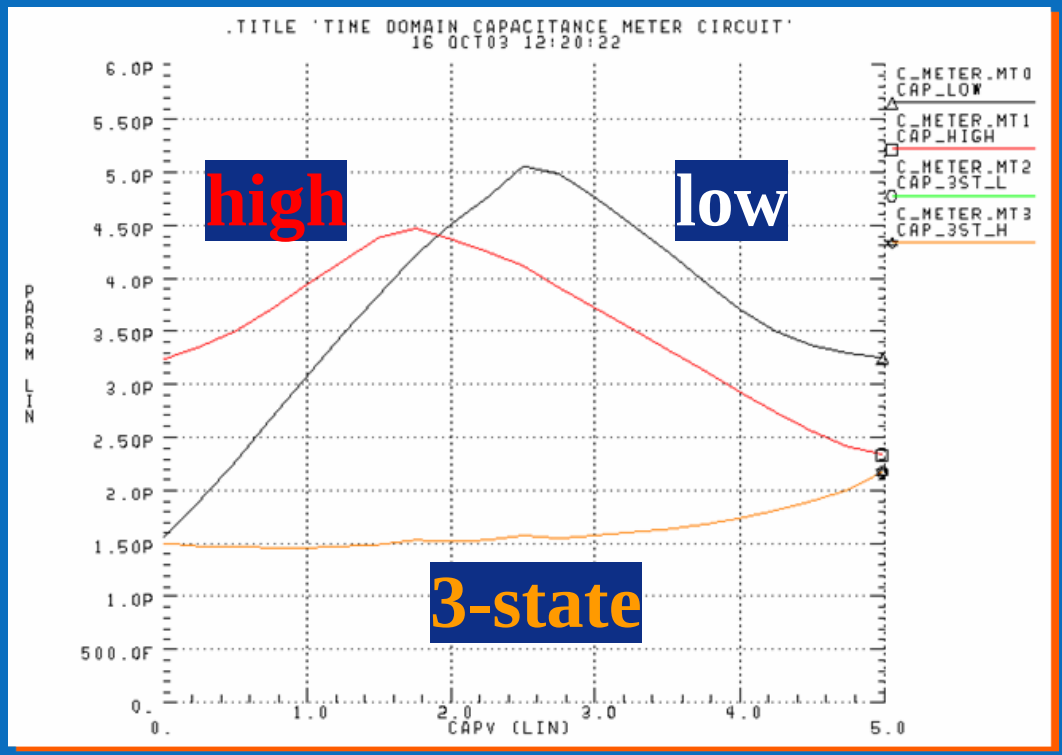
Capacitance can be non-linear and state dependent



C(V) means non-linear
C(state) means state dependent or time-variant

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Buffers and LTI Requirements

Our VHDL-AMS model driver was LTI:

- Resistive
- Same impedance across all times and states

Realistic drivers tend not to be LTI, without special design:

- Transistors usually have non linear IV curves
- High and low states may have different impedances
- Impedance may not be constant during transitions
- Impedance may change from bit to bit (data pattern dependence)

Therefore, toggling the driver to generate the pulse response may make the system non-LTI

Is it possible to generate a pulse (or step) response with a time domain simulation without violating the LTI requirement?

Backup

VHDL-AMS code

Code - processes (digital equations)

```
begin
    ------------------------------------------------------------------------
    GetCursorIndex : process is
    begin
      wait for 3.0e-9;
      CursorIndex <= FindCursorIndex(Wfm);
      wait;
    end process GetCursorIndex;

    GetEye : process is
    begin
      wait on CursorIndex;
      --report "Cursor index is: " & integer'image(CursorIndex);
      UpperEye <= EyeContour(Wfm, CursorIndex, BitWidthPts, "U");
      LowerEye <= EyeContour(Wfm, CursorIndex, BitWidthPts, "L");
    end process GetEye;

    Ticker : process is
    begin
      wait for 1.0e-12;
      if (Count < WfmPts) then
        Wfm(Count) <= Vout;
        Count      <= Count + 1;
      elsif (EyeIndex < BitWidthPts) then
        EyeIndex <= EyeIndex + 1;
      end if;
    end process Ticker;
    ------------------------------------------------------------------------
```

Code - analog equations

```
-------------------------------------------------------------------------
    break on Count, EyeIndex;

    if (domain = quiescent_domain) use
      Vout == V0;
    else
      Iout == Scale * Cval * Vout'dot;
    end use;

    if (now > 3.0e-9) use
      UpperEyeV == UpperEye(EyeIndex);
      LowerEyeV == LowerEye(EyeIndex);
    else
      UpperEyeV == 0.0;
      LowerEyeV == 0.0;
    end use;

  end architecture PDA_on;
-------------------------------------------------------------------------
```

Code - function FindCursorIndex

```
------------------------------------------------------------------------------
function FindCursorIndex (Wfm : real_vector) return integer is
------------------------------------------------------------------------------
  variable Index : integer := 0;
  variable Value : real    := 0.0;
------------------------------------------------------------------------------
begin
  for i in Wfm'range loop
    if i = 0 then
      Value := Wfm(i);
    else
      if Wfm(i) > Value then
        Value := Wfm(i);
        Index := i;
      end if;
    end if;
  end loop;
--  report "Index: " & integer'image(Index);

  return Index;
------------------------------------------------------------------------------
end function FindCursorIndex;
------------------------------------------------------------------------------
```

Code - (essentials of) function EyeContour

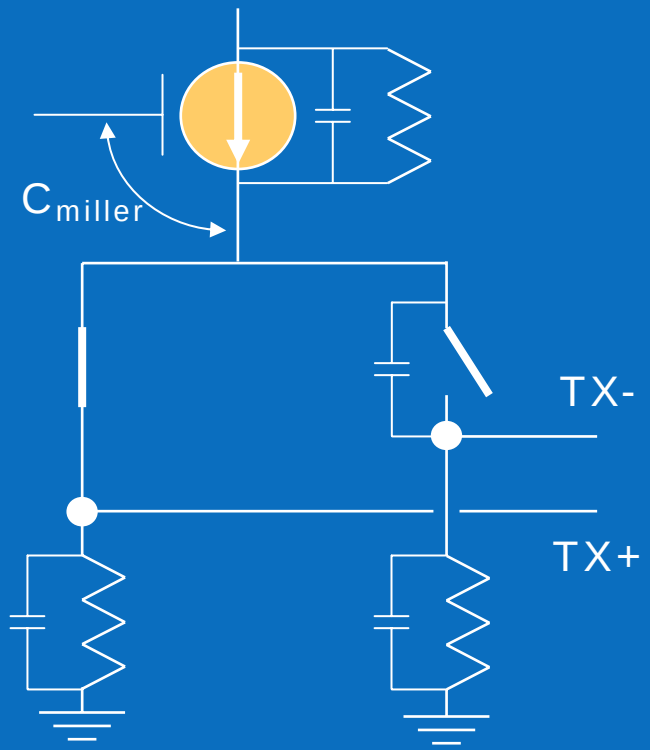
```
--------------------------------------------------------------------------------
function EyeContour (Wfm         : real_vector;
                     CursorIndex : integer;
                     BitWidth    : integer;
                     EyeSelector : string := "L") return real_vector is
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------
begin
  while (CursorIndex - BitWidth/2 - i*BitWidth) > 0 loop
    i := i + 1;
  end loop;
  StartIndex := CursorIndex - BitWidth/2 - (i-1)*BitWidth;

  i := 0;
  while (StartIndex + (i+1)*BitWidth) <= Wfm'right loop
    if StartIndex + i*BitWidth + BitWidth/2 = CursorIndex then
      if (EyeSelector = "U") then
        for j in EyeContour'range loop
          EyeContour(j) := EyeContour(j) + Wfm(StartIndex + j-1 + i*BitWidth);
        end loop;
      end if;
    else
      if (EyeSelector = "U") then
        for j in EyeContour'range loop
          EyeContour(j) := EyeContour(j) + realmin(0.0, Wfm(StartIndex + j-1 + i*BitWidth));
        end loop;
      else
        for j in EyeContour'range loop
          EyeContour(j) := EyeContour(j) + realmax(0.0, Wfm(StartIndex + j-1 + i*BitWidth));
        end loop;
      end if;
    end if;
    i := i + 1;
  end loop;

  return EyeContour;
--------------------------------------------------------------------------------
end function EyeContour;
--------------------------------------------------------------------------------
```

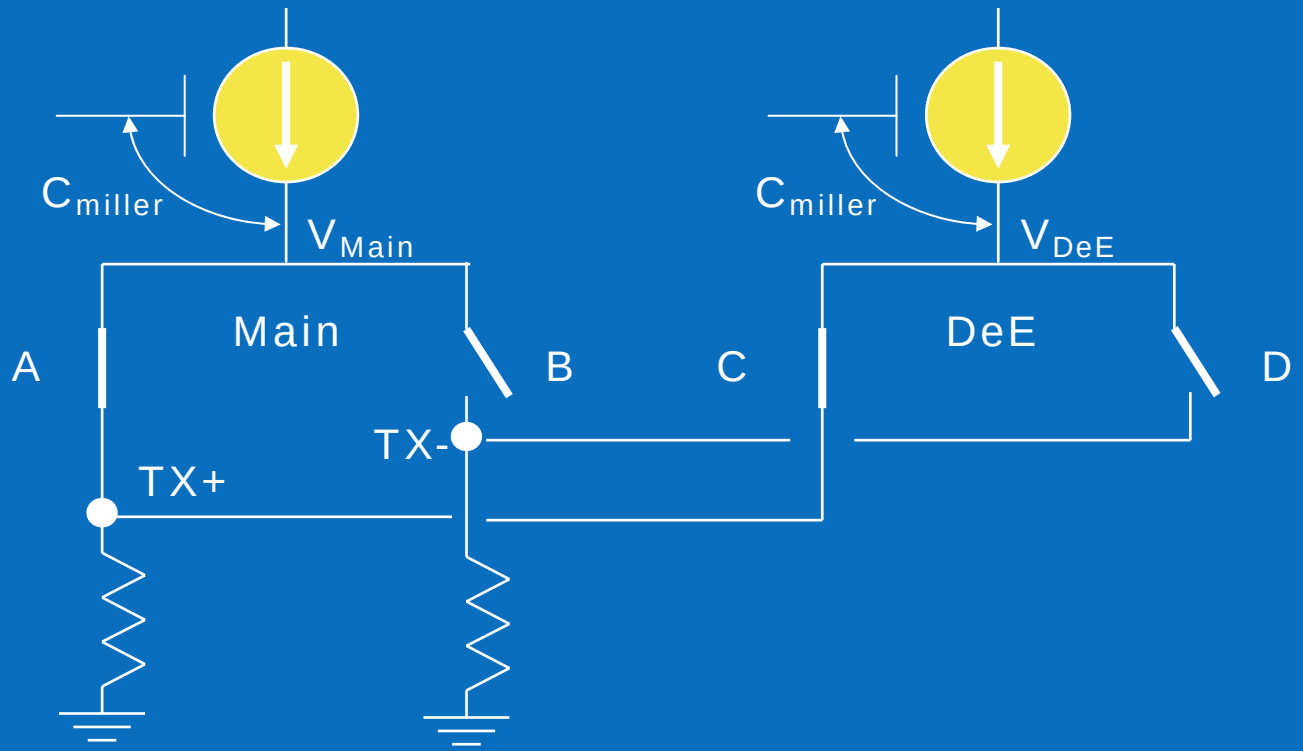
Buffer Variation Impact

State dependent driver impedance



The equivalent impedance looking into TX+ and TX- are not the same, i.e. a logic “1” has a different impedance from a logic “0”.

Buffer impedance may vary from bit-to-bit



Miller capacitance may modulate the bias circuit of the current source making it data pattern dependent (time-variant)

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