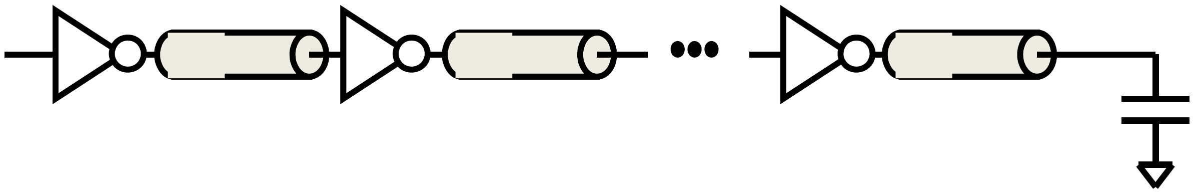
Transmission line design review

Theory of lossy line
IBM model
Bus system
Current driver
Pre-emphasis

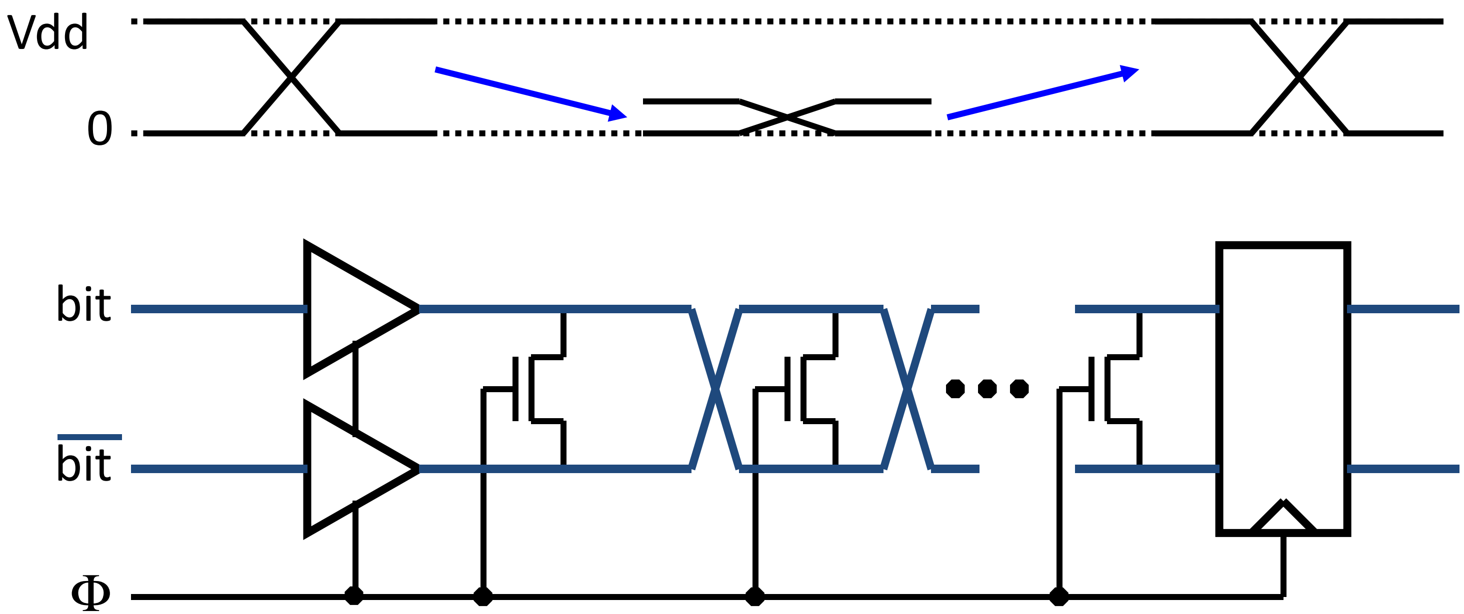
Fast signaling Repeated wires

- Traditional solution for long wires
  - CMOS inverters as repeater stages



- Makes delay linear with wire length
- No static power consumption
- CMOS voltage swing is an issue
  - Not feasible here

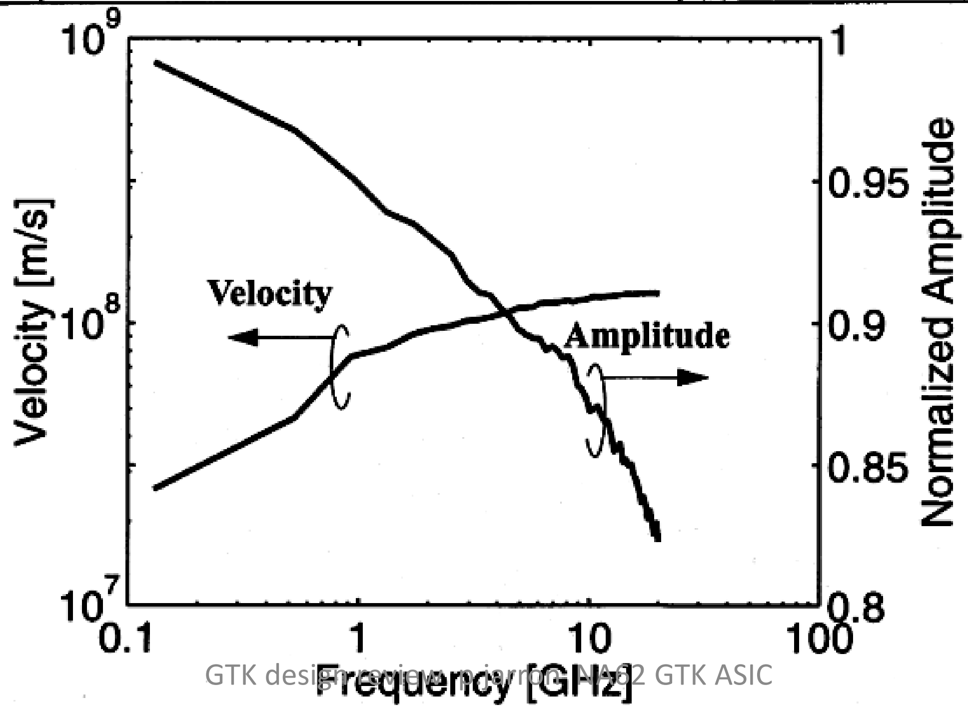
Low swing wires: architecture in R&D phase in industry



1. This bus architecture is synchronous
   Not possible here
   Voltage signal not possible on multi driver bus system

Wave propagation equations

	Low Frequency regime (R>>ωL)	High Frequency regime (R<<ωL)
Propagation Equation	$\frac{\partial^2 V}{\partial x^2} = RC\frac{\partial V}{\partial t}$	$\frac{\partial^2 V}{\partial x^2} = LC\frac{\partial^2 V}{\partial t^2}$
Phase Velocity	$v = \sqrt{\frac{\omega}{2RC}}$	$v = \frac{1}{\sqrt{LC}}$

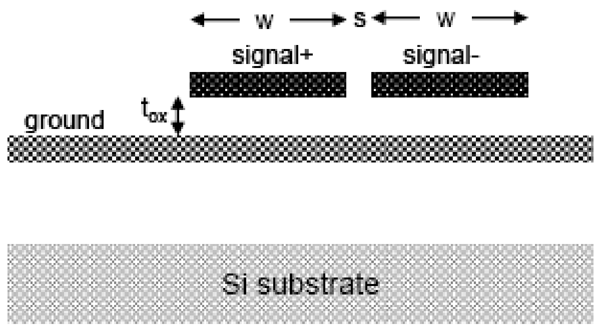


• Lossy Microstrip line issue

Lossy microstrip lines

•ISSUES

- •Pulse traveling down the line loses energy through resistive loss it becomes attenuated.
- •resistance leads to dispersion. The high frequency components of the signal travel more quickly than the low frequency content, since the low frequency content now becomes RC limited.
- • wave attenuation

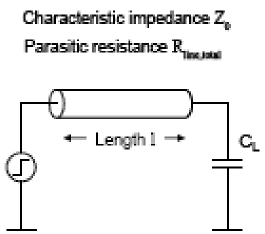


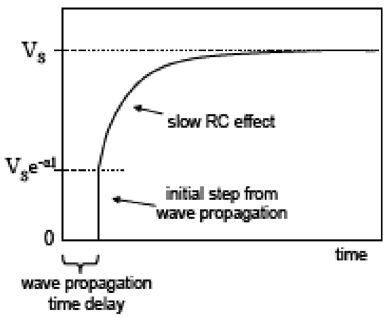
•with

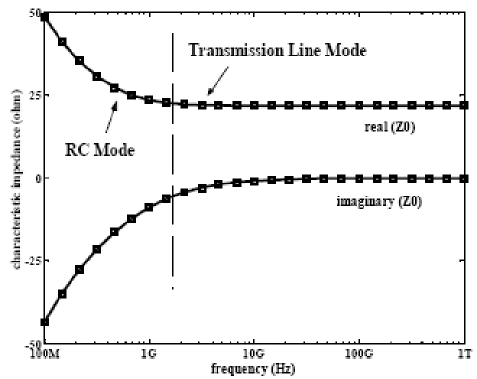
$$V(l) = V_S \cdot e^{-\alpha \cdot l}.$$

•*attenuation is* $e^{-\alpha l}$

$$\alpha \approx \frac{R_{line,unitlength}}{2 \cdot Z_O} \; (m^{-1}).$$







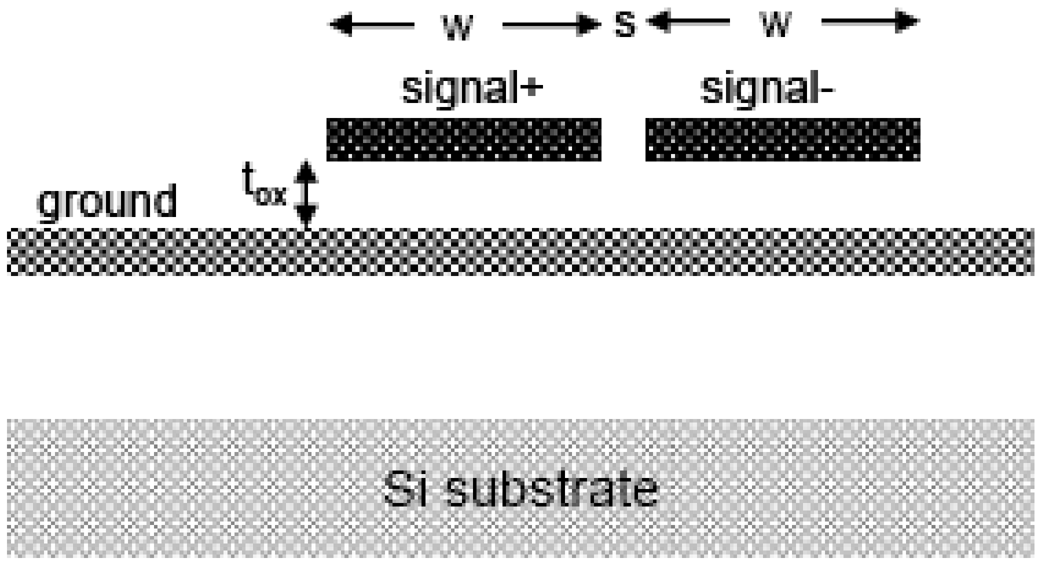
Line: Z_{CO}=40 Ω , R_{line}=450 Ω
Driver ΔI_B = ±30 µA,
Receiver: R_{IN}=200 Ω

Line transmission dominated by dispersion and not wave propagation
Improvement: pre-emphasis filter

Lossy Microstrip line

Dispersive transmission line

- Pulse traveling down the line loses energy through resistive loss it becomes attenuated.
- resistance leads to dispersion. The high frequency components of the signal travel more quickly than the low frequency content, since the low frequency content now becomes RC limited.
- wave attenuation



$$V(l) = V_S \cdot e^{-\alpha \cdot l}. \quad \alpha \approx \frac{R_{line,unitlength}}{2 \cdot Z_O} \; (m^{-1}).$$

- *attenuation is* $e^{-\alpha l}$

- Dispersive wave propagation

Some numbers

Line: Z_{CO}=40 Ω ,
R_{line}=280 Ω in DM,
450 Ω in LM

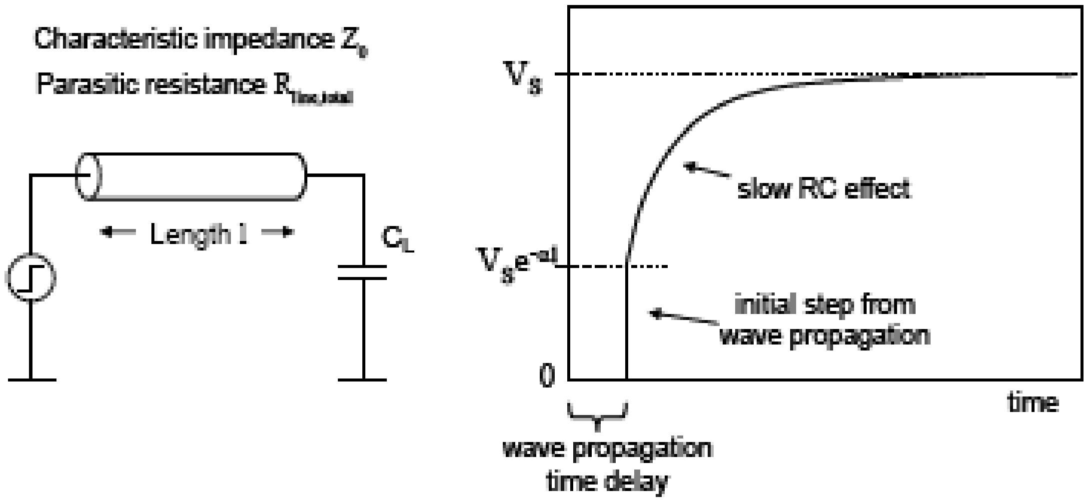
Driver ΔI_B = ±50 µA,

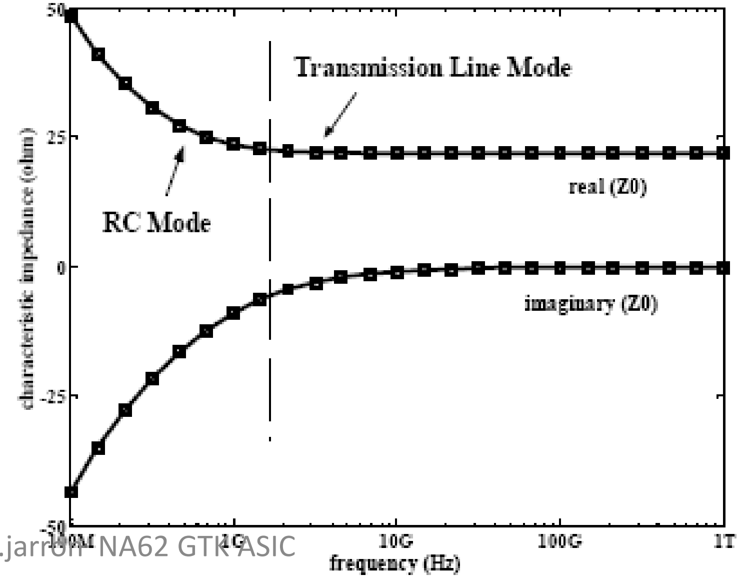
Receiver: R_{IN}=200 Ω

Transmission Line dominated by dispersion and not wave propagation

Improvement:

pre-emphasis at the input of the line embedded in line driver





Low swing bus

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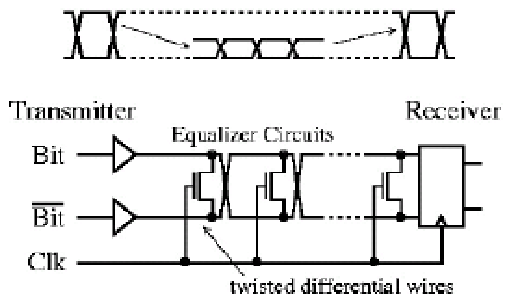
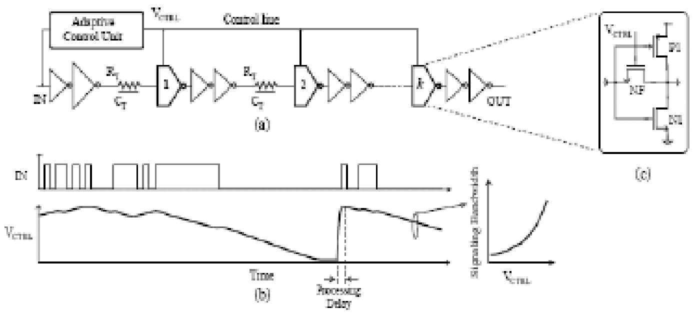
Other Demonstrated Solutions

- Low-swing differential buses



Source: R. Ho, "Efficient on-chip global interconnects," Symp. VLSI Circuits, Jun 2003.

- Current Mode Signalling



Source: R. Bashirullah, "A hybrid current/voltage mode on-chip signaling scheme with adaptive bandwidth capability," IEEE Trans. VLSI, Aug 2004.

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Voltage bus and equalization

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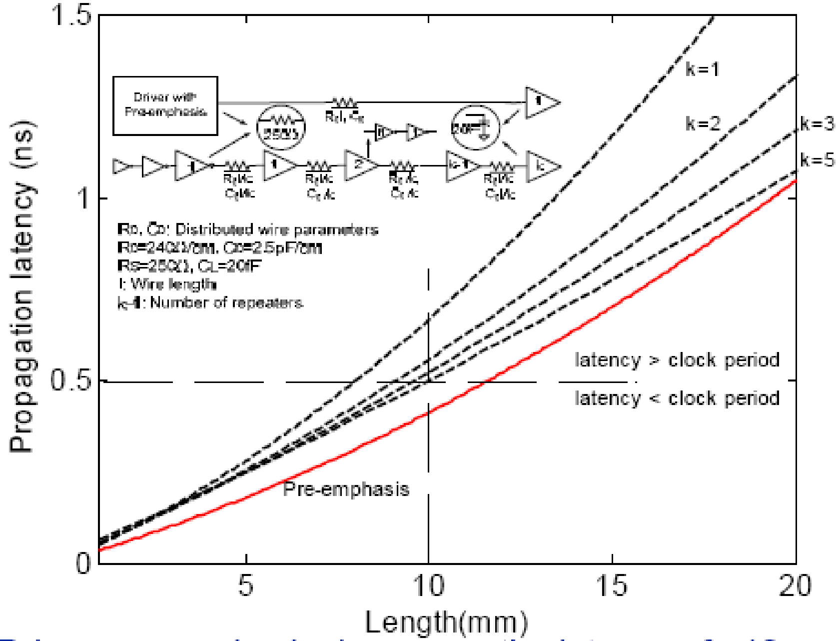
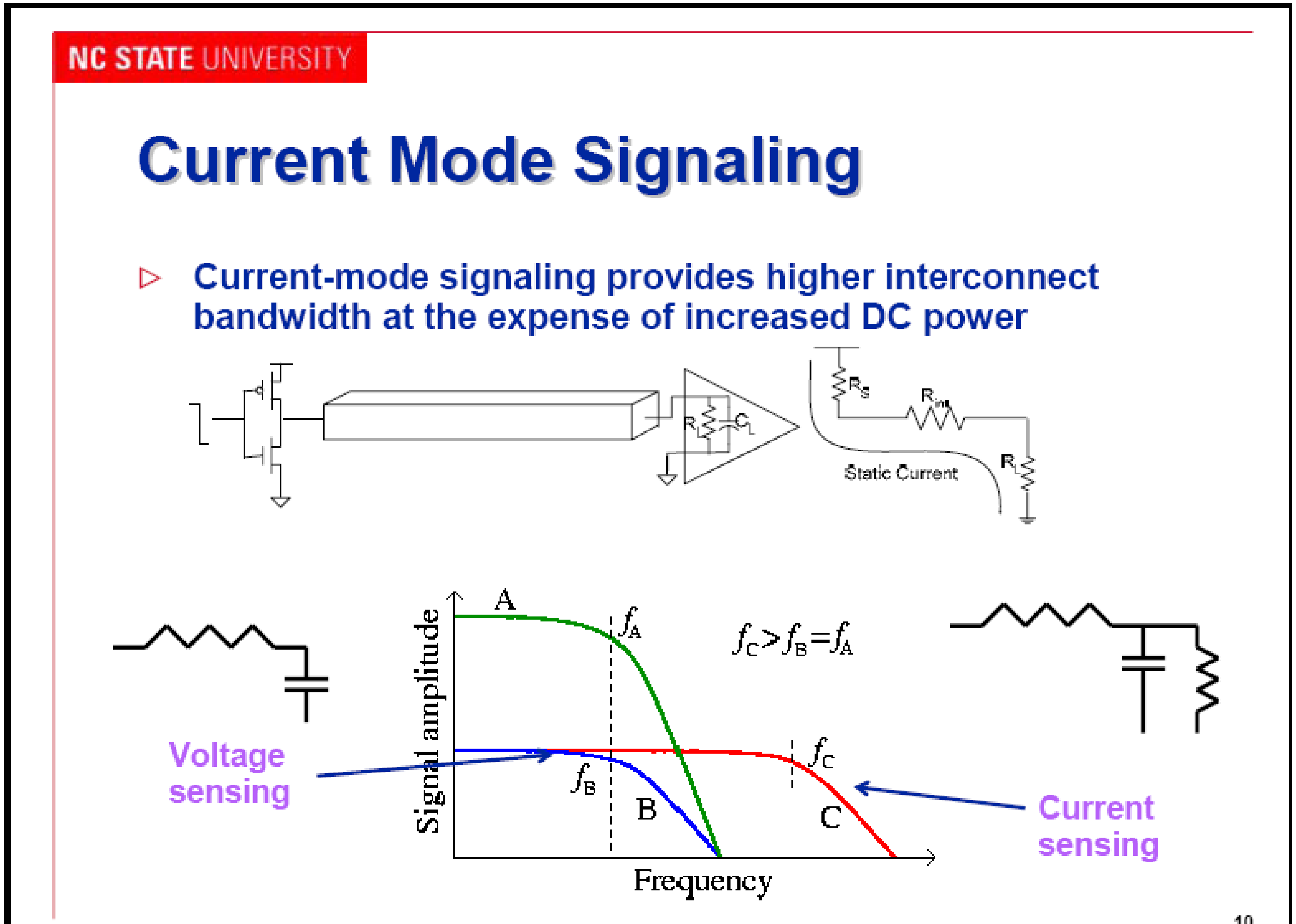
Comparison of Equalization and Repeater Insertion



Driver pre-emphasis decreases the latency of a10mm-long line to 411ps, a 26% and 19% improvement over lines with one repeater and four repeaters, respectively.

Current mode



Differential current-mode sensing

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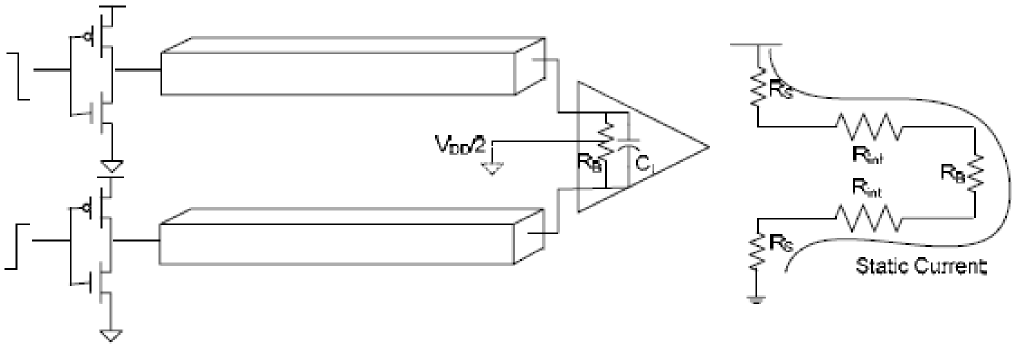
Differential Current-Mode Sensing

- A pair of differential interconnects with a bridge resistor termination are used to reduce the static current.



- RC time constant is the same because of the Vdd/2 virtual ground in the middle of RB.

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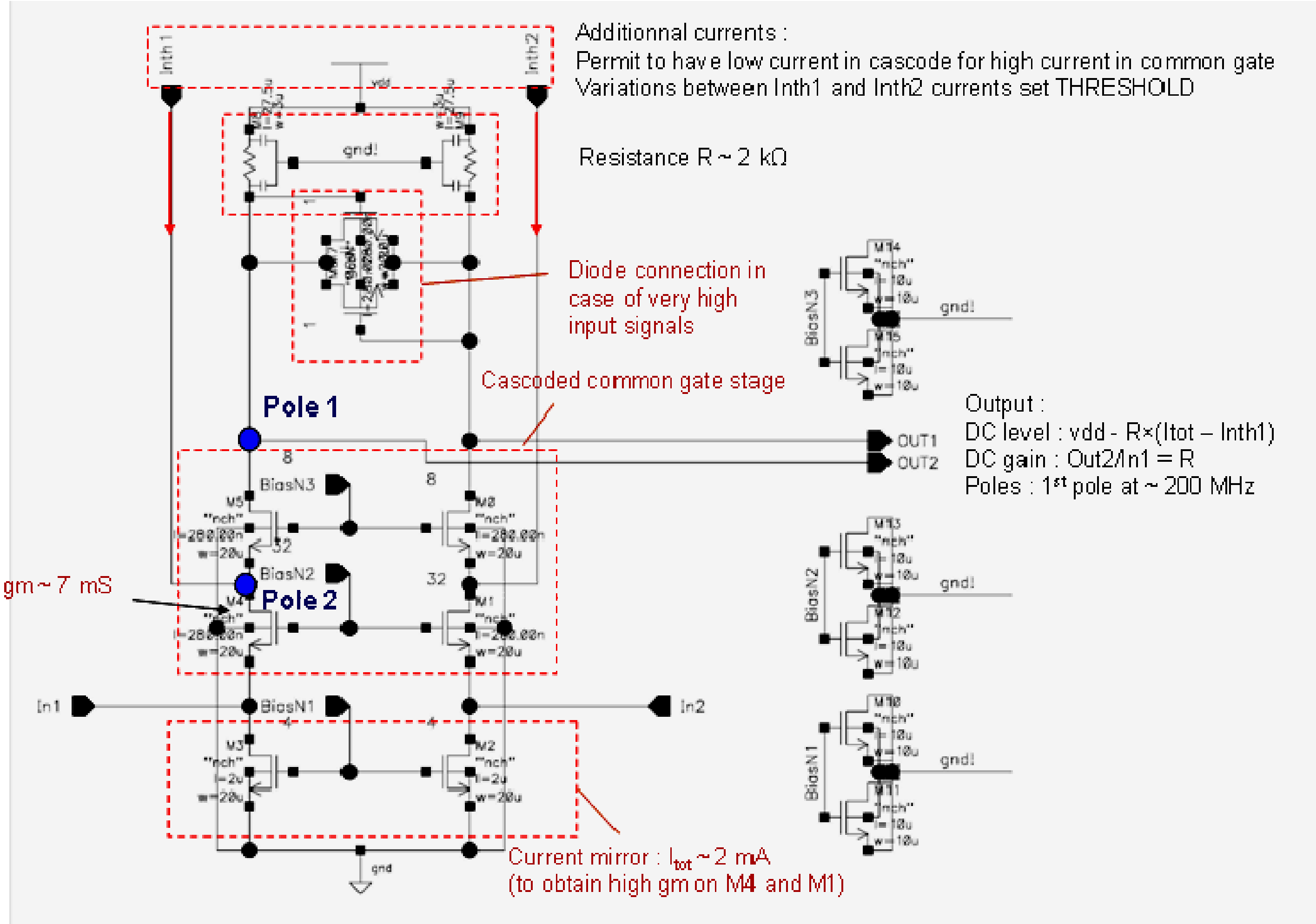
NINO input stage 130 nm revisited

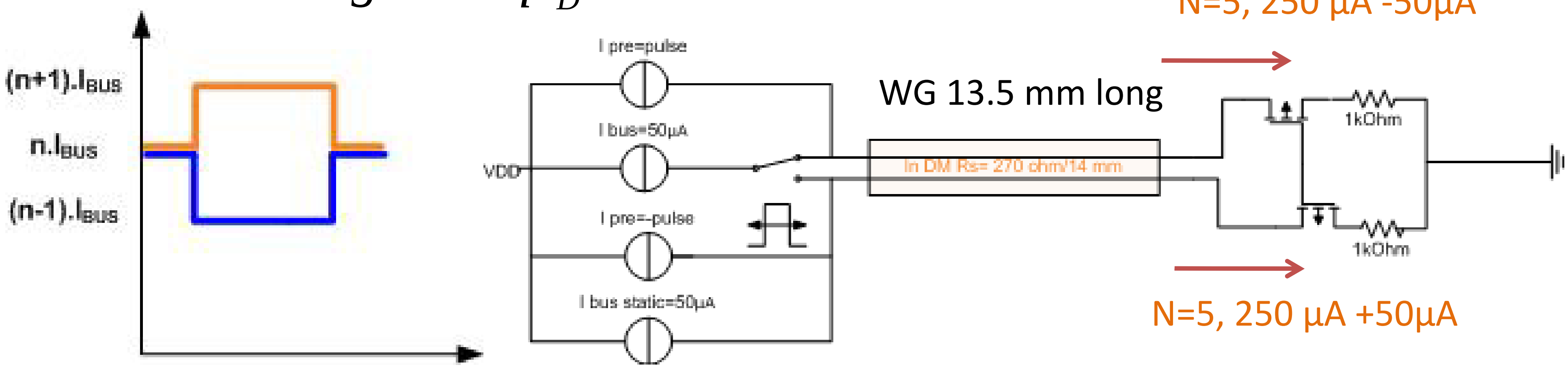
NINO Input stage below has been inverted and simplified to form the RF bus system



RF bus system principle

1. Circuit concept inspired from NINO configuration
   - NMOS input inverted to PMOS
   - Current source replaced by a switching current
   - Transmission line inserted between bias and input PMOS sources
   - Bus static current is balanced and provide receiver biasing
   - Transmission line terminated on one half of the series resistance, x4 odd impedance
   - Far end WG voltage constant, receiver output voltage ± 50 mV

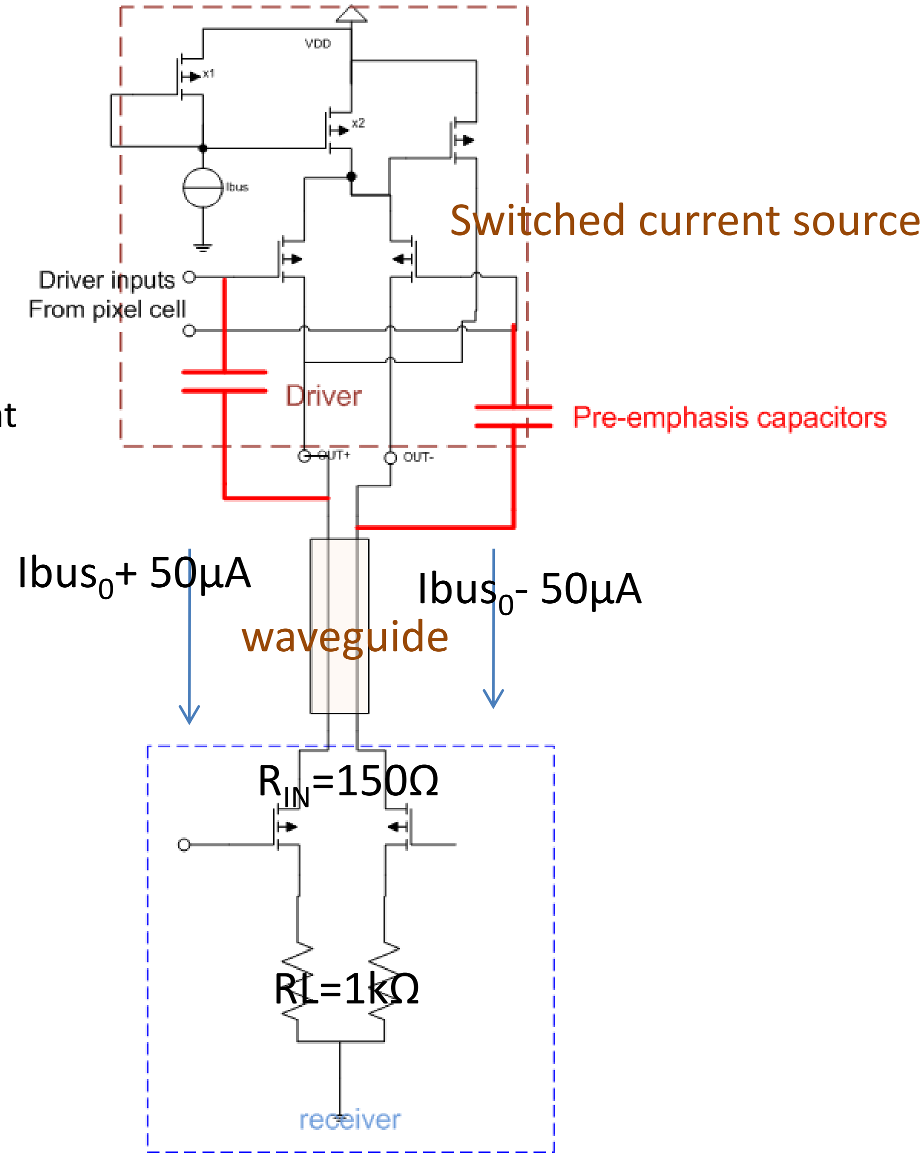
$$R_{IN}\min = \frac{1}{gms} \approx \frac{kT}{qI_D} \approx 160\Omega \;\; for\ I_D = 250\mu A$$



Logic level n(5 /9) switched current cross coupled lines current receiver

Current mode driving and sensing

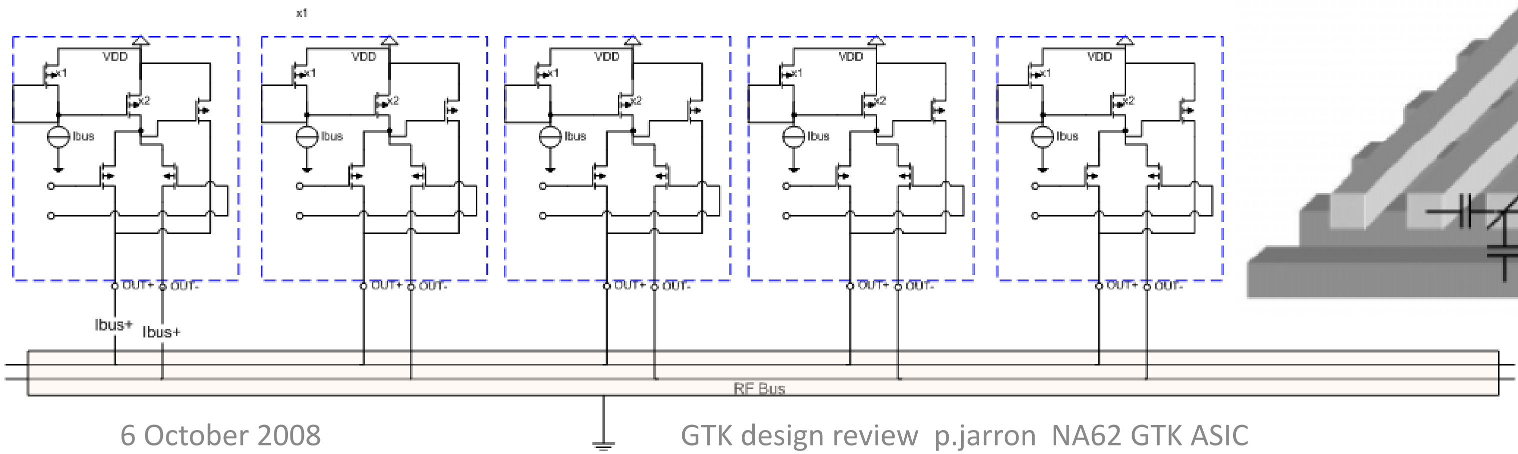
- Solution adopted for the GTK EOC bus
  - Switched current driver
    - DC balanced current
  - pre-emphasis
    - C_{PE}=100 fF,
    - current pre-emphasis can be very strong
    - Transfer function of the wave guide works at pre-emphasis shaper
  - Current mode receiver (cascode a la NINO)
  - Low swing current
    - 50µA
  - Receiver
    - Bias 5 x 50µA=250µA
    - Input resistance 150 to 300 Ω
  - Voltage signal at receiver
    - swing 10 mV single ended
    - Rise time 50 ps
  - Receiver output
    - Swing 100 mV
    - Rise time 250 ps

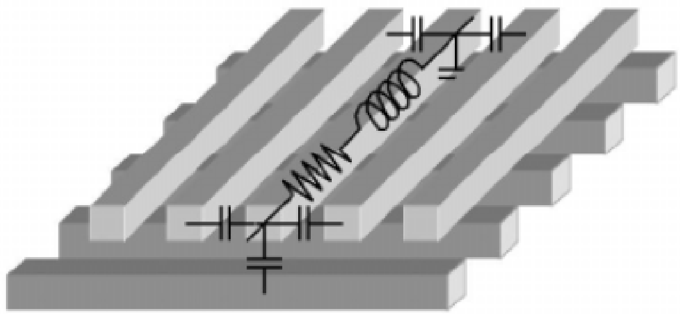


current sensing receiver

Bus architecture

- Adapted to 45 pixel column
  - Several drivers connected to the same line, 5 for data, 9 for address lines
  - Drivers consist of switching a current source when a hit occurs
  - Differential signal transported in the cross-coupled transmission line at near speed of light
  - Transmission line model defined by IBM
  - It is a non ideal transmission line, lossy, need pre-emphasis to correctly work
  - Receiver biasing is provided by the summing of driver current

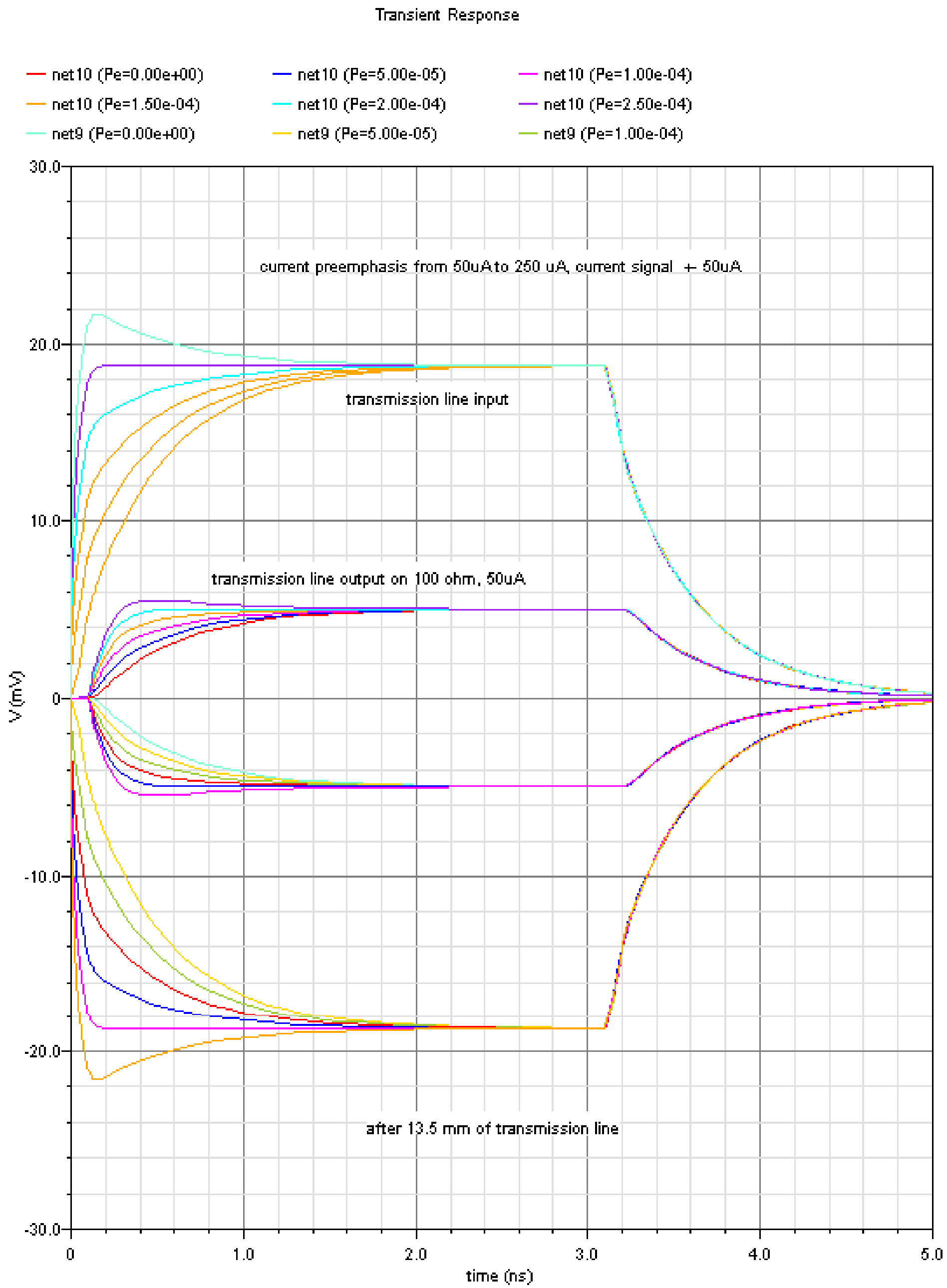




Pre-emphasis study done in LM, should be better in DM

On the full line bus length of 13.5 mm

- Terminated to 100 ohm SE.
- Emphasis time constant
  - 10 ps, rise time, 100ps fall time
- Optimum current emphasis looks to be 200 μA
  - Current emphasis tuned with the capacitor value

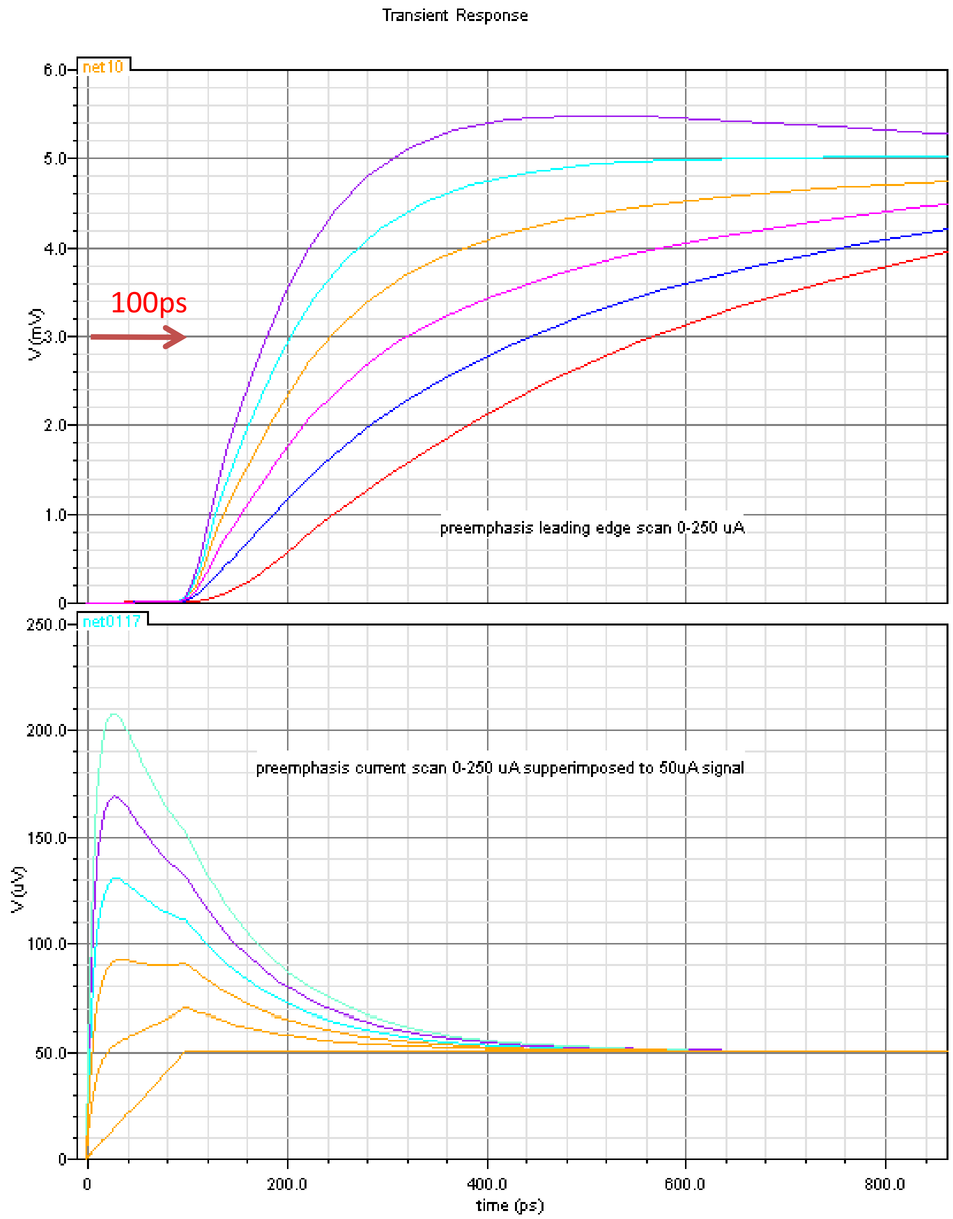


Pre-emphasis study 13.5 mm waveguide

- Leading edge details, full length bus
- Input rise time constant: 100ns
- Transient time: 100 ps
  - near speed of light
- Rise time with pre-emphasis
  - 130 ps
- In silicon oxide

$$v = \frac{c}{n} = \frac{c}{1.46} = \frac{3.10^8}{1.46} = 5\,ps/mm$$

- For 13.5 mm 67.5 ps
- Simulation gives 100 ps



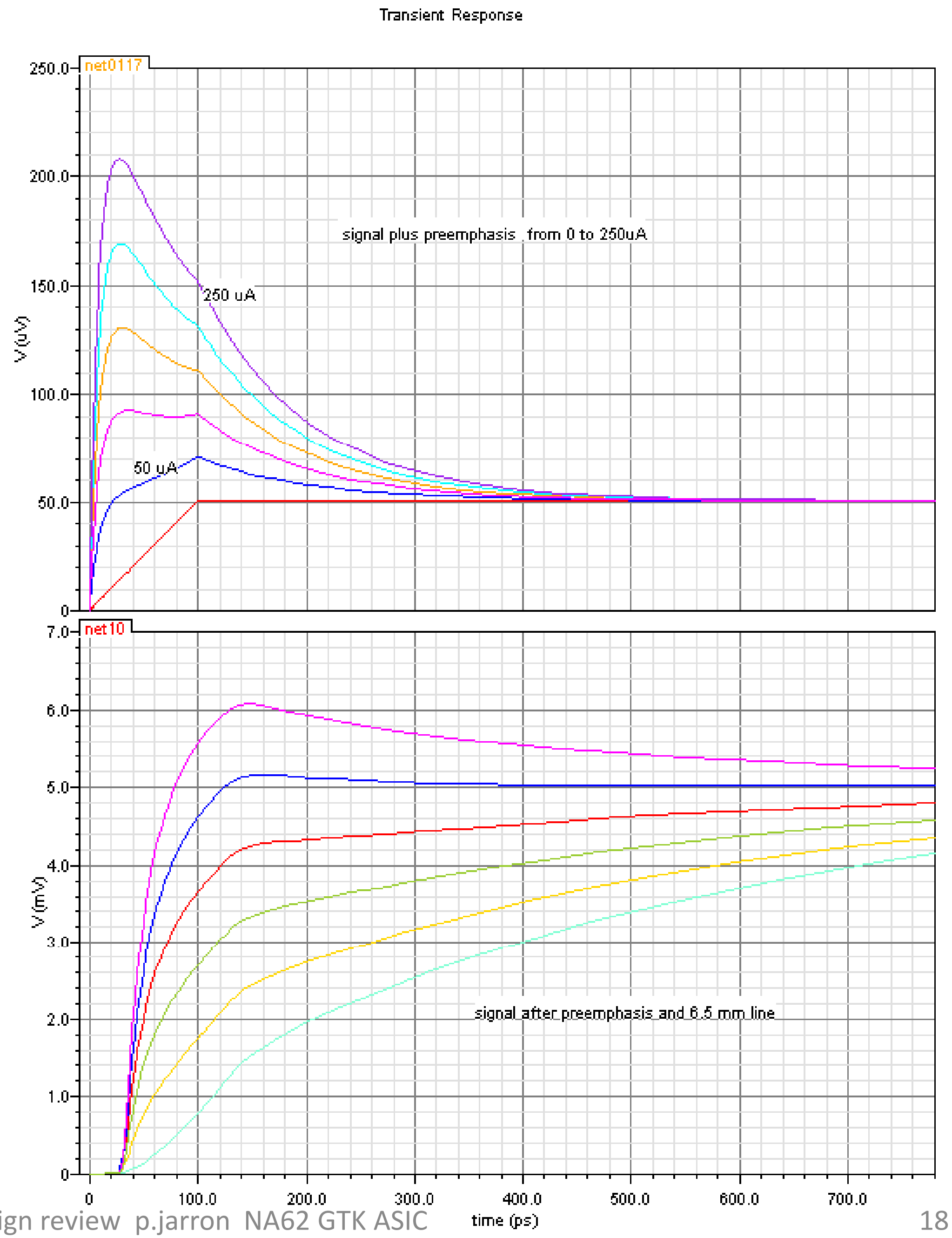
Pre-emphasis study

On ½ bus length 6.5 mm

- Propagation time 50 ps
- Risetime constant 60 ps
- looks proportional to WG length

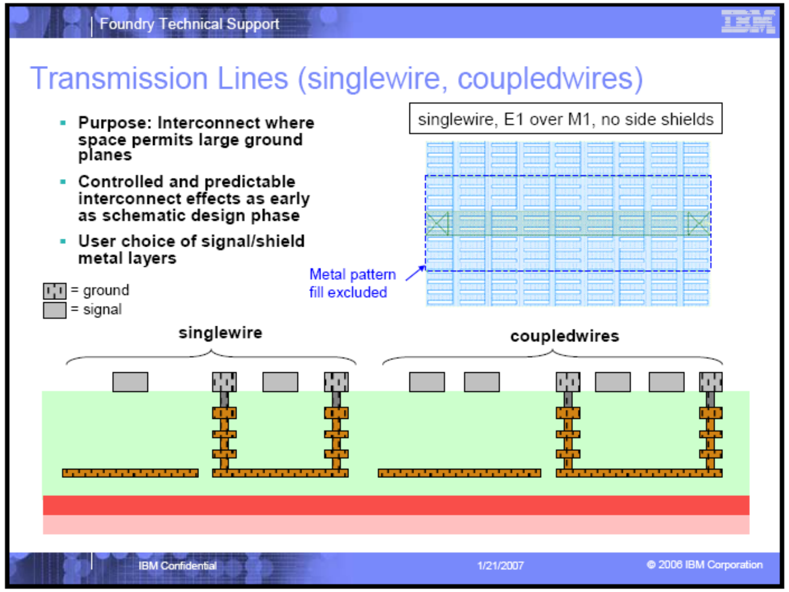
•Comments

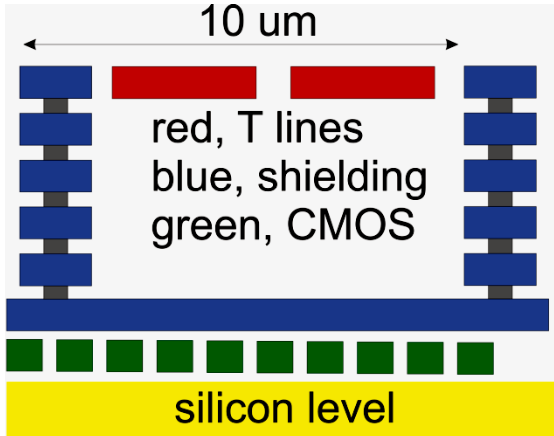
  - •The current is forced in the line
  - •The far end voltage is the convolution of the injected current with waveguide transfer function

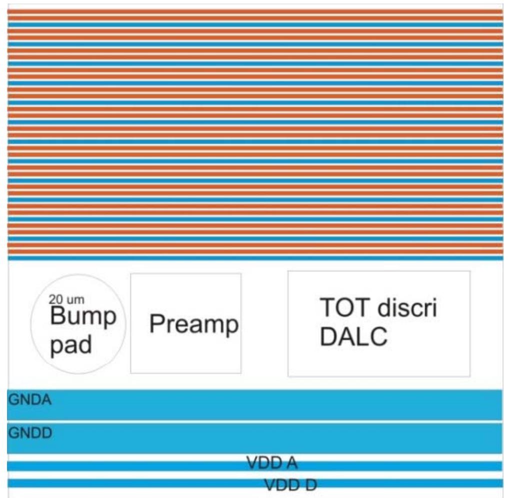


IBM transmission line model

- The elements *singlewire and coupledwires are microstrip transmission line structures that* incorporate one or two wires, a metal ground plane, and optional side shields. Microstrip transmission lines are most appropriate for applications where precise impedance and phase characteristics are desired, and where defined ground planes may be placed in the layout, such as for routing of RF signals between RF circuit blocks. These devices offer controlled and predictable transmission line effects to be included in simulations as early as the schematic design phase.
- The line and ground plane are on the levels chosen by the designer. The ground plane and signal lines on 1X and 2X levels are slotted lengthwise to enable BEOL polish processes. Optional side shields are composed of a wire on each side of the transmission line(s) that is connected to the ground plane every 50 microns by stacked vias.
- In order to assure repeatable electrical characteristics, automatic metal fill shapes are excluded on the wire layer, and layers between the wire and the ground plane. This is accomplished by the shapes on “Mx” “TRANS.” Device recognition is accomplished through the dummy shape on“OUTLINE” “TRANS.” M1 is shield, MQ is signal lines.







Summary

- Bus system based on transmission line
  - Low swing current driving and sensing O.K
  - Works correctly, depends on the precision of the IBM model
- Low swing Current pre-emphasis
  - Works fine push signal propagation to physical limit
- Issue: this technique has never been validated!