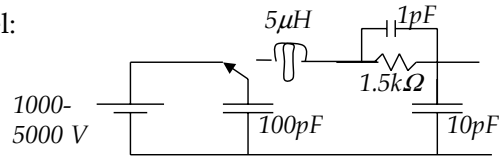


ESD Protection

Static electricity caused by human and machine handling of ICs

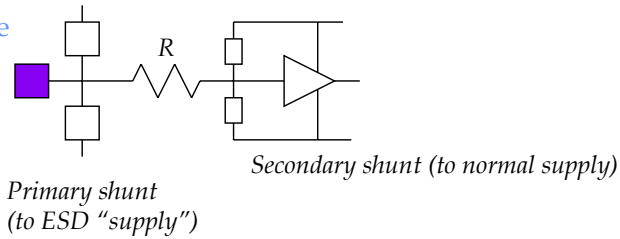
- Human body model:



- Effects of ESD
 - Breakdown of gate oxide (at 7×10^8 V/m)
 - ◆ “First breakdown” (not necessarily destructive)
 - ◆ 4.9 V for 7 nm thick gate oxide
 - ◆ 350 V for 0.5 μm thick field oxide
 - Thermal runaway due to high IDS
 - ◆ “second breakdown” (destructive)
 - Avalanche and Zener breakdown in parasitic diode

ESD Protection Circuits

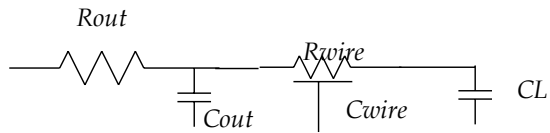
Overall structure



- Primary shunt
 - ◆ Goal: to drain current to neighboring input pad through ESD supply
 - ◆ Use parasitic diode, FET (using field oxide) or transistor
- R : Low-pass filter. Can be an L, at expense of increased area
 - ◆ Use poly or diffusion resistor
- Secondary shunt
 - ◆ Goal : Voltage clamping : diode-connected nFET
- Note : Adds ~1 pF of capacitance to input

On-chip Interconnect

Distributed RC lines



$$t_{rise} \approx 2.2 R_{out} (C_{out} + C_{wire} + CL) + 0.9 R_{wire} C_{wire} + 2.2 R_{wire} CL$$

$$T_{delay} \approx 0.7 R_{out}(C_{out}+C_{wire}+CL) + 0.4 R_{wire}C_{wire} + 0.7 R_{wire} CL$$

- For long wires, delay $\propto l^2$
 - ♦ \rightarrow Use repeaters to reduce delay as $2(1/2)^2 < l^2$
- Delay with repeater:

$$t_d = (l/l_s)(t_b + 0.4l_s^2 RC)$$
 where l = line length, l_s = segment length, RC = per unit length RC , t_b = buffer delay

RC lines

Optimal Repeater section length

$$l_s = (t_b / 0.4RC)^{1/2}$$

Gives delay per unit length

$$v = 1.3 (t_b RC)^{-1/2}$$

◆ For 0.35 μ m process

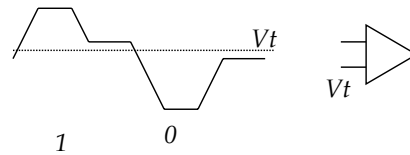
→ $l_s = 3.5$ mm, $v = 17.5$ mm/ns

Line geometry

- Increasing line width and spacing reduces RC per unit length
 - ◆ Until proximity effect kicks in

Can use overdrive to compensate for RC loss

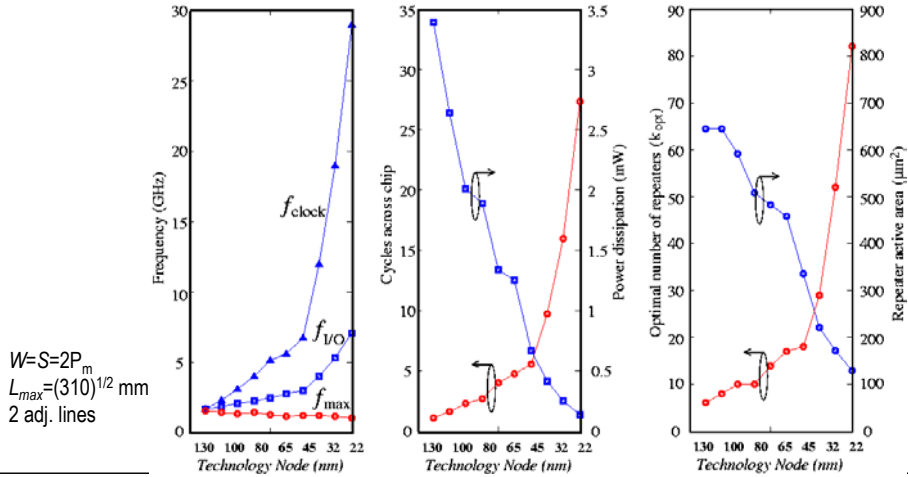
- I.e. Equalization through wave shaping
 - ◆ Requires small swing signalling
 - ◆ Gives ~ 10% delay improvement
 - ◆ Increases Xtalk
 - ◆ Ckt overhead



Repeater Explosion!

From ITRS:

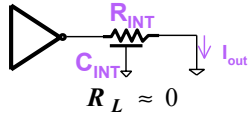
- In practice sub-optimal repeater insertion used



Voltage vs. Current Sensing

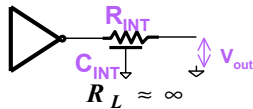
Current Sensing

- Low impedance termination



Voltage Sensing

- High impedance term. (i.e. capacitive)

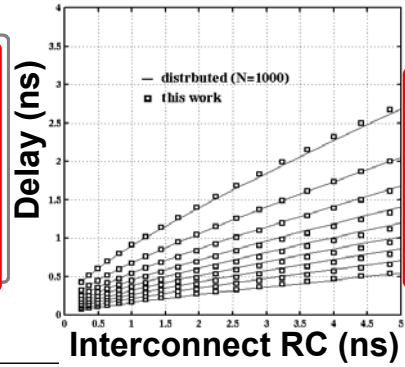
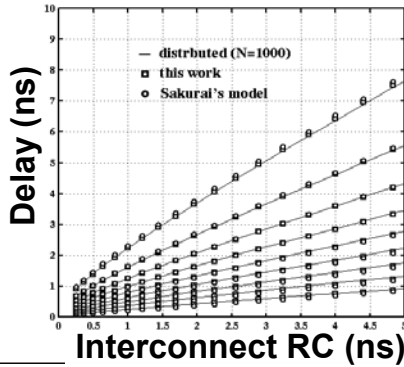
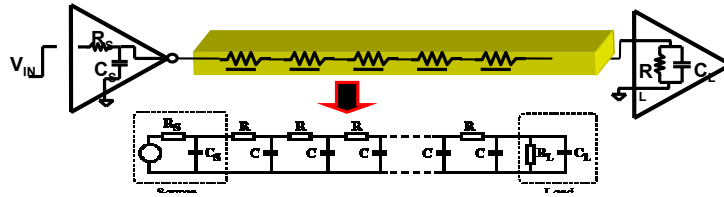


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Voltage-Mode Receiver	
	$Z_L = -j \frac{1}{\omega C_L}$
Current Mode Receivers	
	$Z_L = -j \frac{1}{\omega C_L} \parallel \frac{1}{gm_N + gm_P}$
	$Z_L = -j \frac{1}{\omega C_L} \parallel \frac{R_F}{1 + A_V \beta}$
	$Z_L = -j \frac{1}{\omega C_L} \parallel Z_o$

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Current Mode Delay Analysis

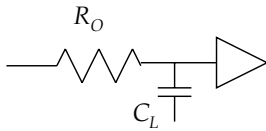


On-chip Current Mode Signalling

Decreased delay

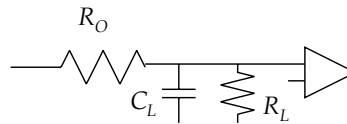
Why?

Voltage Mode



$$\tau = R_O C_L$$

Current Mode



$$\tau = R_L R_O C_L / (R_L + R_O)$$

Impact:

- Fewer repeaters
- Narrower wires

At expense of DC power consumption

LRC lines

Can "tune" line

- Critically damped (or slightly underdamped in practice) gives min delay, rise time

Again, can equalize line to get optimum response

- FIR
- Wave-shaping
- Key : Simple circuits

Summary

Drivers require large transistor. What is important to avoid?

Large drivers → large di/dt . How to reduce?

What are the advantages of current mode drivers?

What determines eye opening at Rx?

Summary

How can delay be minimized in on-chip lines?