Voltage Overstress Protection in CMOS ICs

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Overview

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- Overview of technologies
- Problem description
- Schematic approaches
- Proposed solutions
- Level shifter design
- USB Full-Speed driver architecture
- Lifetime calculations
- Conclusion

Introduction

- Continuing technological shrinkage brings to lowering allowed maximum voltages applied to MOS devices and IC supply voltages
- High voltages applied to CMOS devices:
  - devices' failures
  - parametrical degradation over the time
- Physical phenomenon causing MOS degradation/failure
  - HCI – Hot Carrier Injection
  - NBTI – Negative Bias Temperature Instability
  - TDDB – Time Dependent Dielectric Breakdown
  - SILC – Stress Induced Leakage Current
- Device performance time can be increased either by improving technological processes or using newer approaches in circuit designs

Overview of Technologies

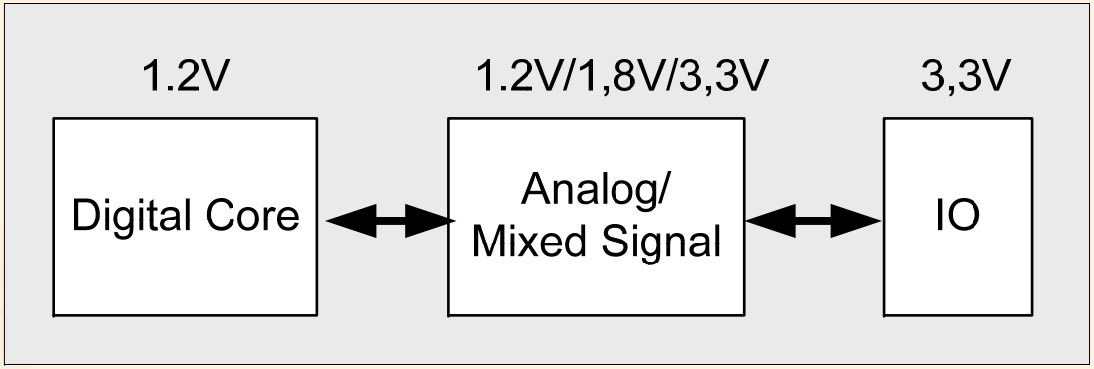
Technology	Thick oxide transistors		Thin oxide transistors	
	Supply Voltage (V)	T_{ox} (nm)	Supply Voltage (V)	T_{ox} (nm)
130nm	2,5 V	~5,8	1,5	~3,3
90nm	2,5	~5,7	1,2	~2,6
65nm	2,5/1,8	~5,6/~3,6	1..1,2	~2,4
45nm	2,5/1,8	~5,5/~3,4	0,9..1,1	~2..2,3
32nm(HK-MG)	2,5/1,8	~8,6/~5,9	0,9..1	~3,2

- **Usually max allowed voltage over MOS two different nodes is VDD+20%**

Problem Description

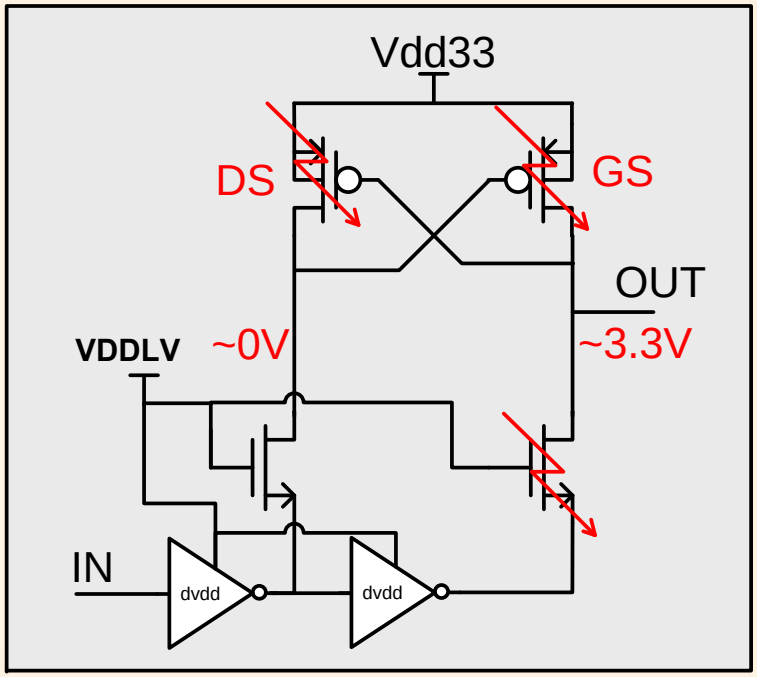
- Many widespread IO standards (USB, PCI, etc.) use 3,3V supply

USB/PCI PHY



- **Most susceptible blocks to overstress**
  - **Level Shifters. Transition from low voltage to high voltage domain**
  - **IO cells. Wide swing signaling with low voltage devices**
- **Benefits**
  - **Gain in area/performance – low cost/power**
  - **No need in additional mask – low cost**
- **Drawbacks**
  - **Reliability issues under high voltage operation**

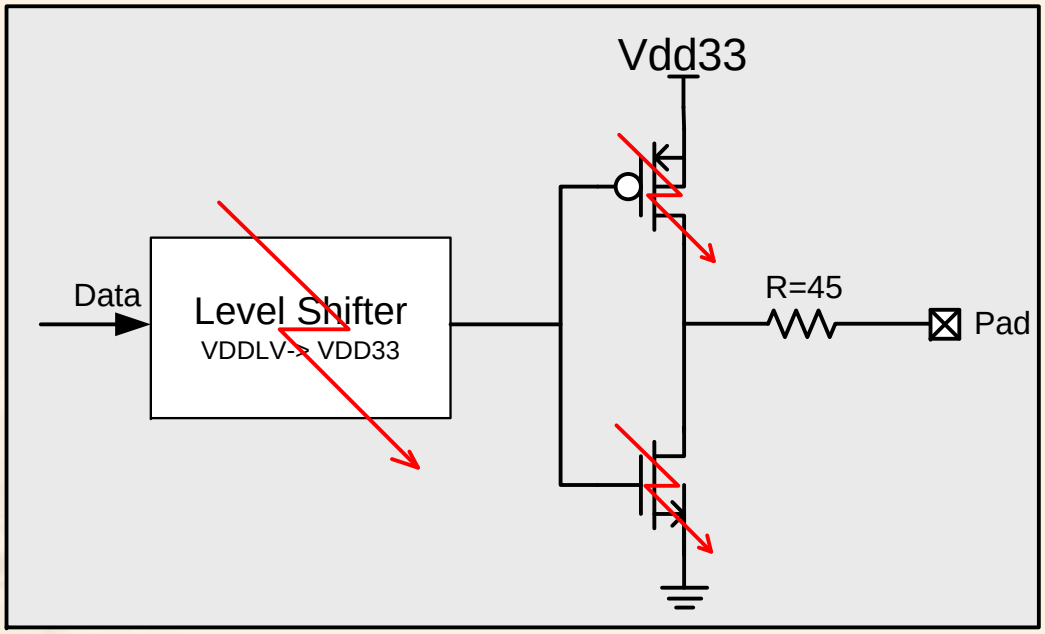
Overstress Issue
Conventional Level Shifter



- **Conventional Level-Shifter is appropriate with 3.3V devices**
- **Neither 2.5V nor1.8V devices can sustain overstresses with this schematic**

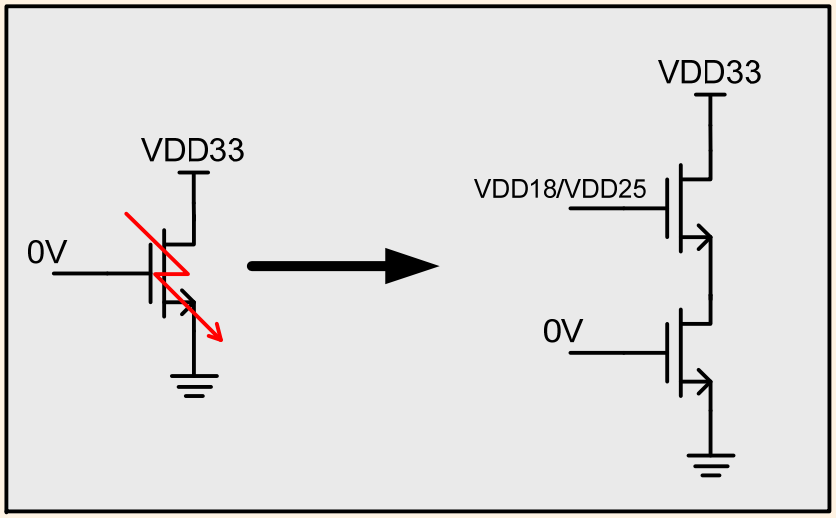
Overstress Issue
USB FS Driver

USB FS driver's conventional architecture



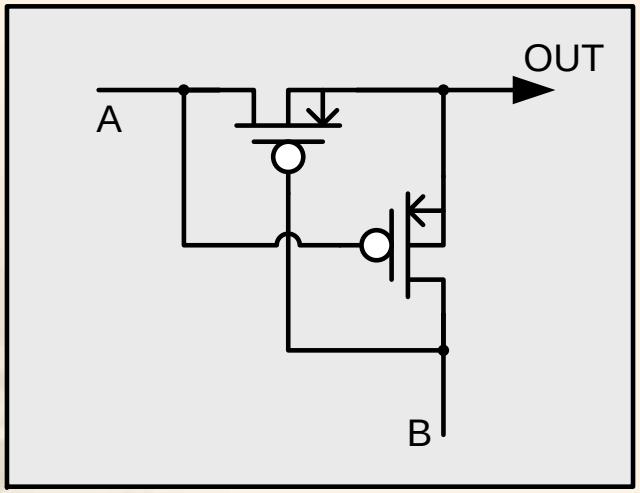
- **Conventional design is suitable for 3.3V devices**
- **Overstress issues with 2.5V nor1.8V devices**

Overstress Protection Techniques: Cascoding



- **Allows to redistribute large voltage over several series connected devices**
- **Costs area and performance**

Overstress Protection Techniques: Voltage Limitation

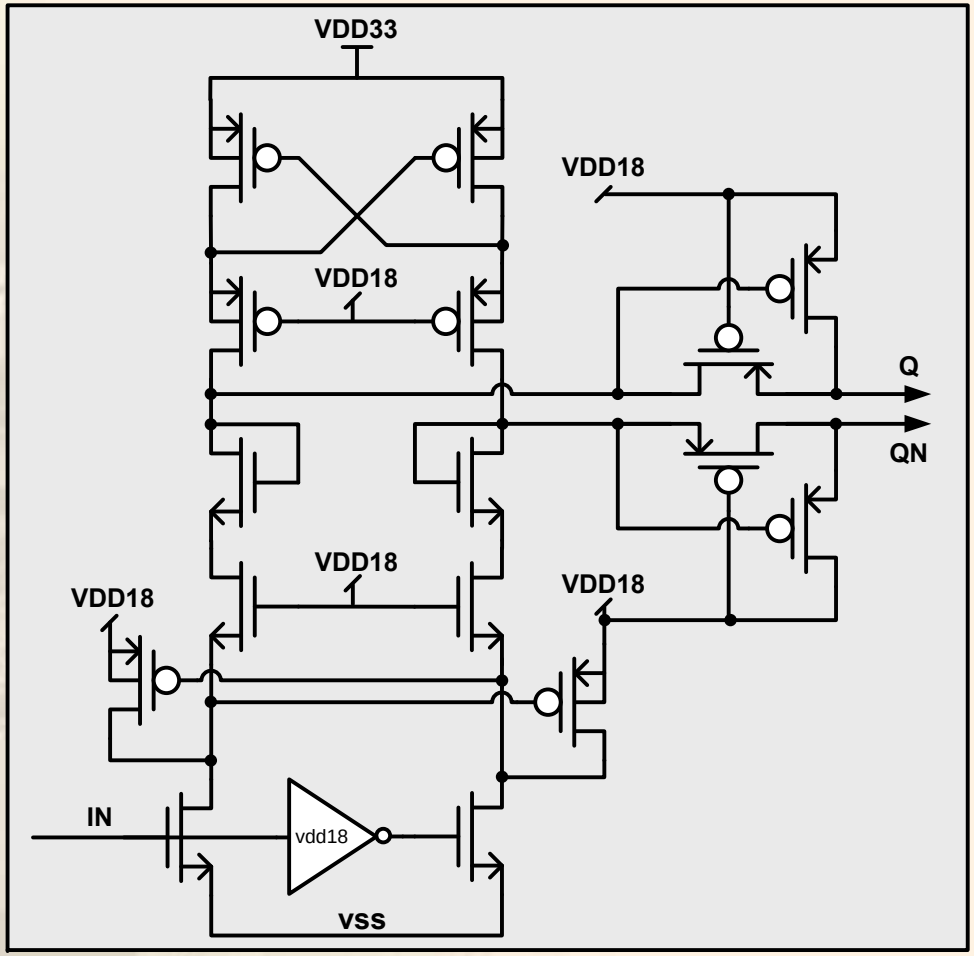


$$V(OUT) = \begin{cases} V(A), & \text{if } V(A) > V(B) \\ V(B), & \text{if } V(B) < V(A) \end{cases}$$

- V(OUT) chooses highest from two inputs

- Can be used as voltage limiter, if on of the inputs is set to desired minimal value
- High impedance when $|V(A)-V(B)|<V_{TH}$:
  - Floating node
  - Large rise/fall times

Proposed Solution
Level Shifter Based on 1.8V Devices

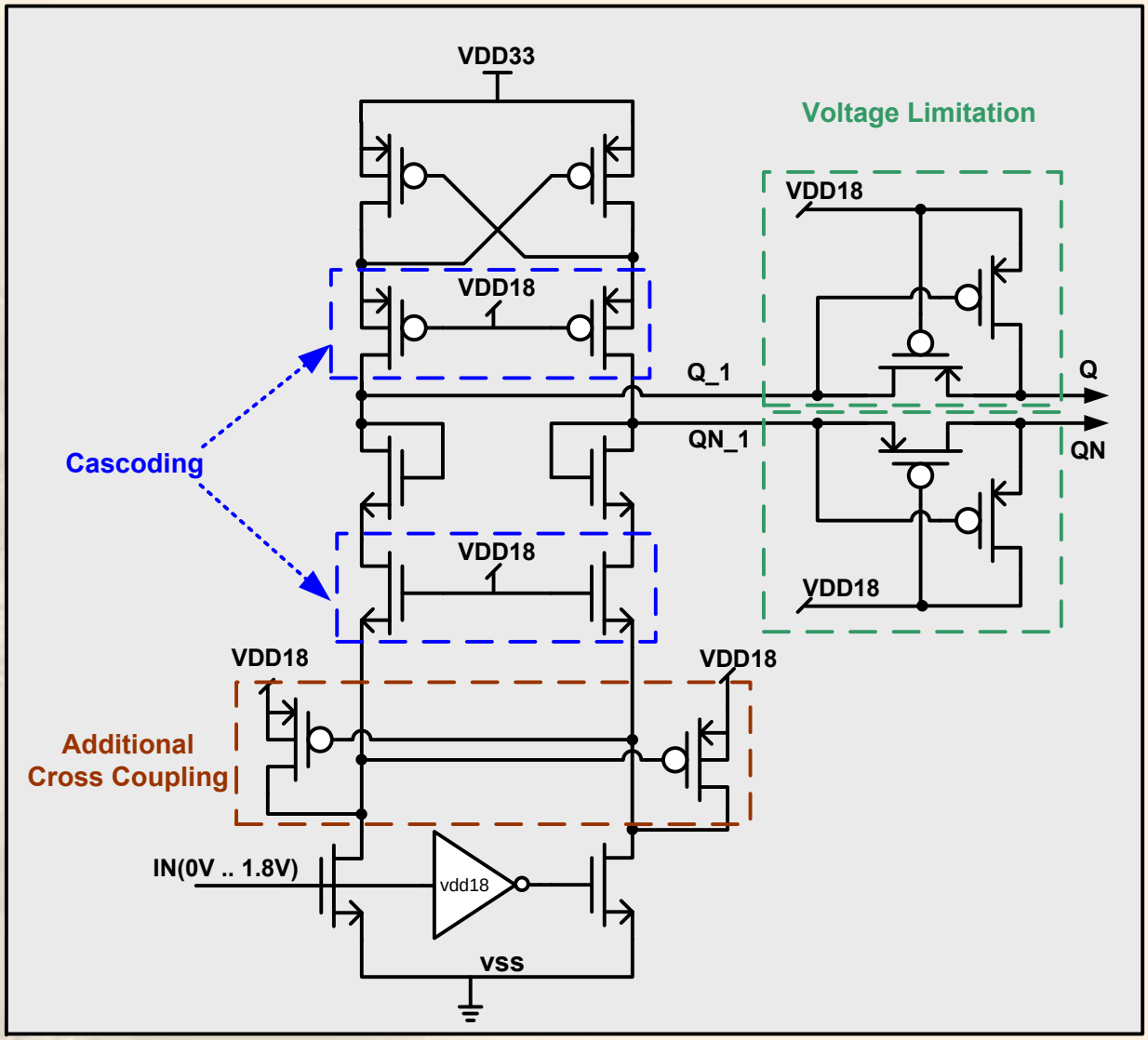


- Cascoding techniques employed for devices' overstress protection as well as positive feedback
- Circuit provides two invert outputs Q and QN with:

  V_{LO}=VDD18

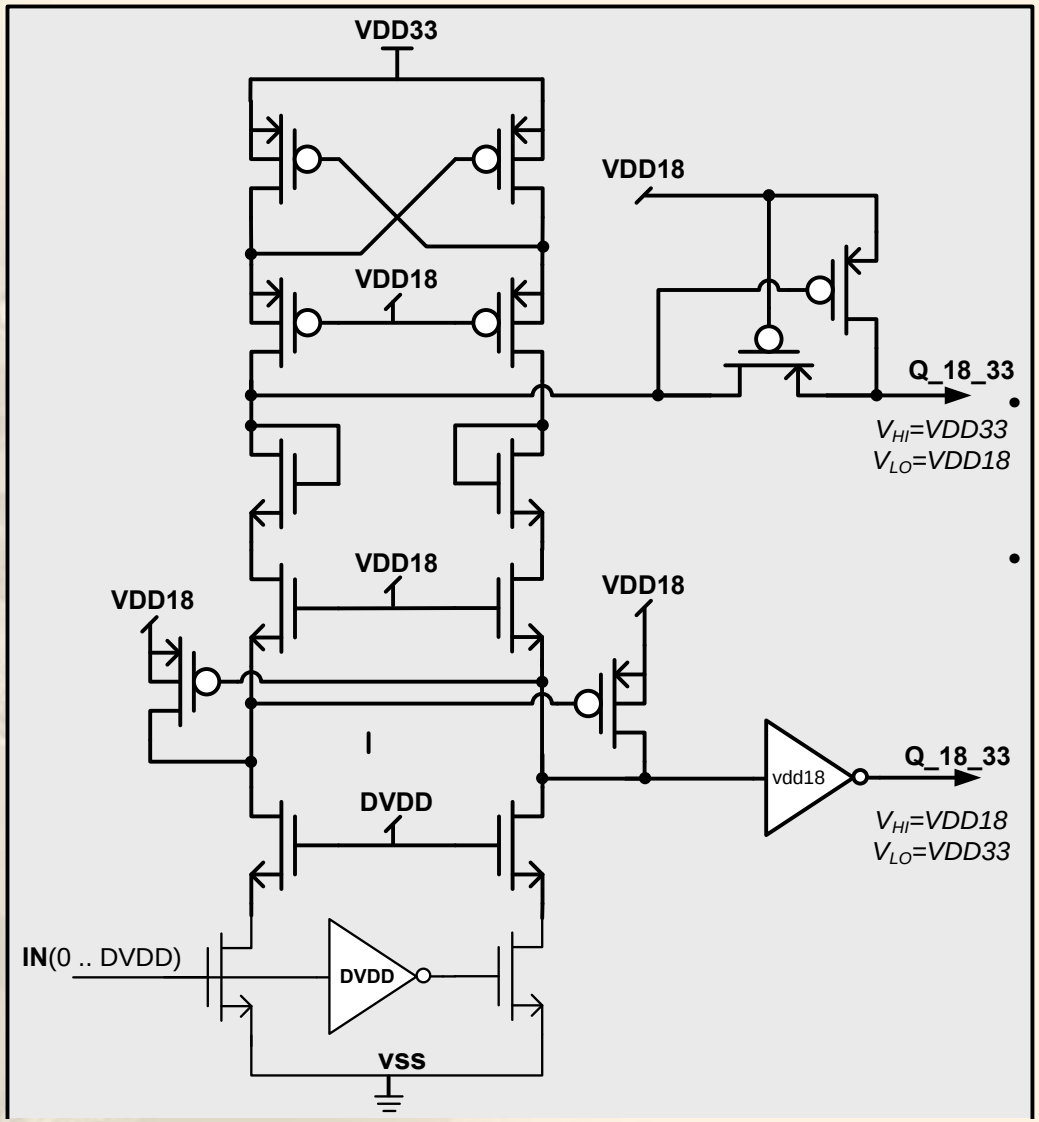
  V_{HI}=VDD33

Proposed Solution
Level Shifter Based on 1.8V Devices



- Large swing on Q_1 and QN_1
  V_{LO}=VDD18
  V_{HI}=VDD33
- Additional cross coupling improves performance and relieves overstress

Proposed Solution
Dual output Level Shifter



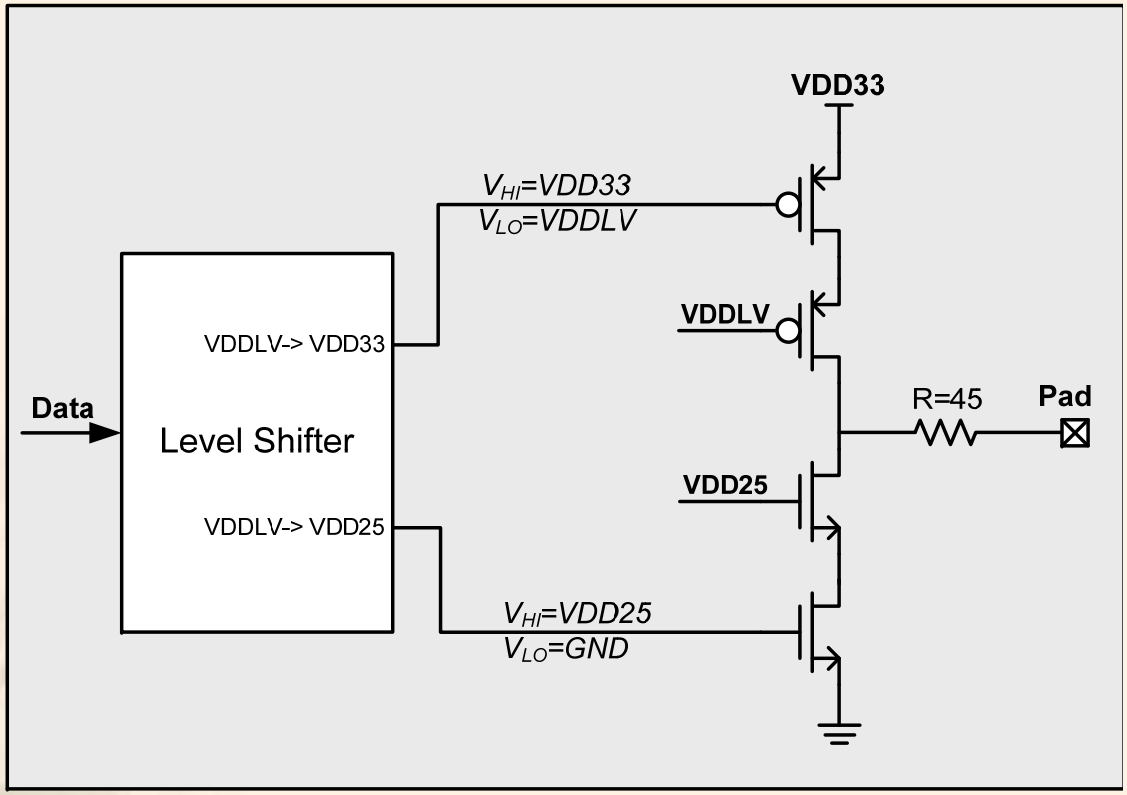
Cascoding techniques employed for devices' overstress protection as well as positive feedback

Circuit provides two invert outputs Q and QN with:

V_{LO}=VDD18

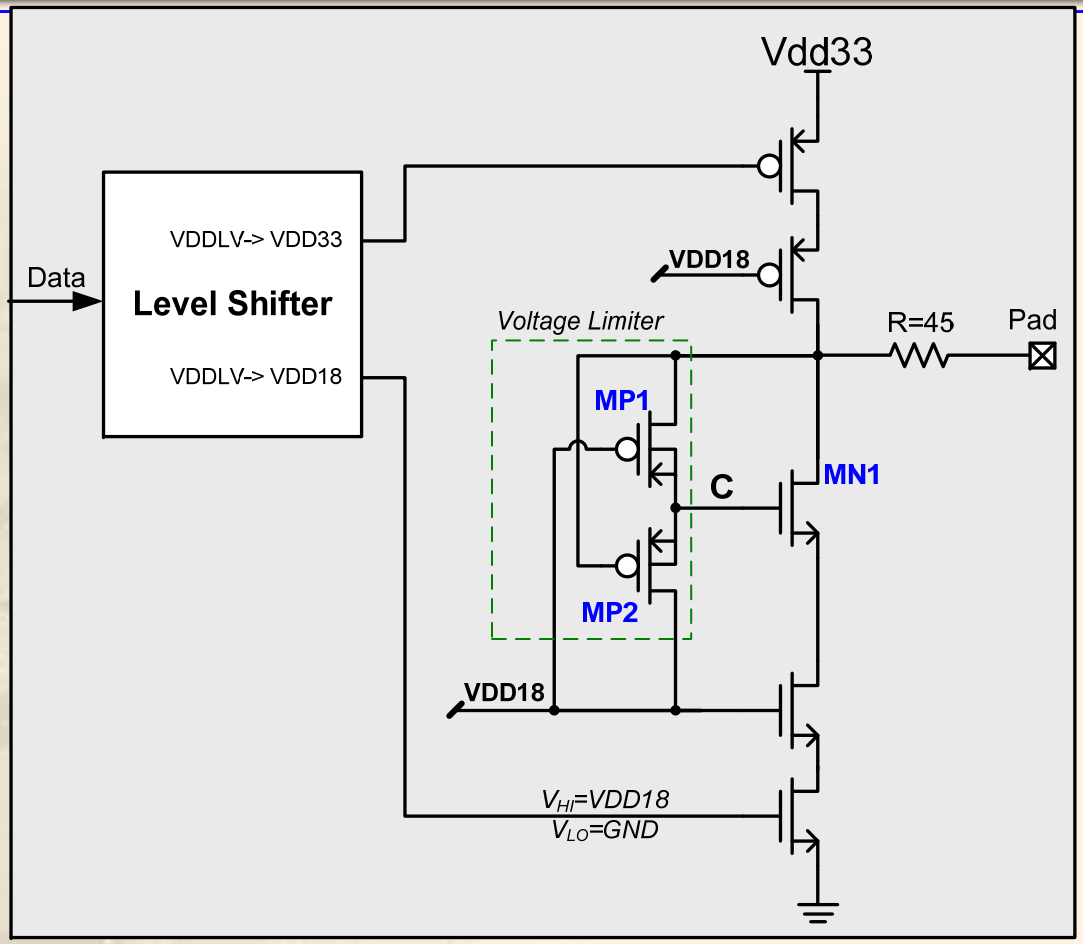
V_{HI}=VDD33

USB FS Driver
Proposed Solution on 2.5V Devices



- Cascoding techniques used for redistributing large voltage over two devices.

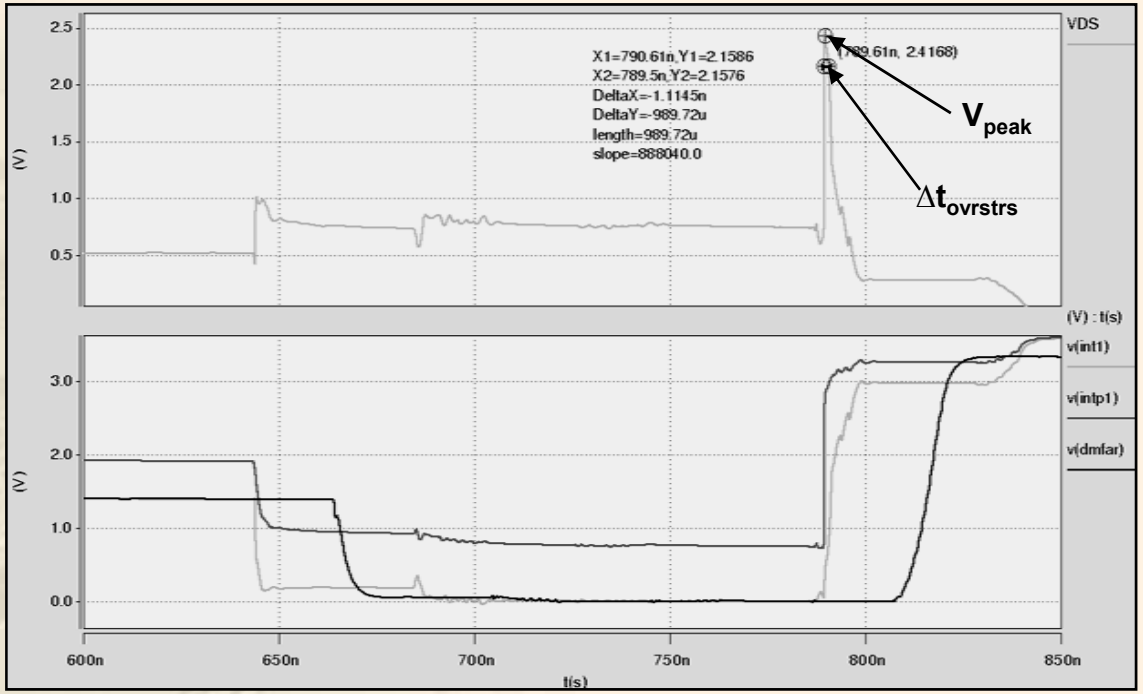
USB FS Driver
Proposed Solution on 1.8V Devices



- **Additional cascoding with MN1 provides overstress protection when V(pad)=3.3V**
- **MP1 and MP2 provide following function:**

$$V(C) = \begin{cases} V(pad), V(pad) > VDD18 \\ VDD18, V(pad) < VDD18 \end{cases}$$

Overstressed Device's Lifetime Calculation



$$T_{life} = T_{life\_DC} / (\Delta t_{ovrstrs} * F)$$

T_{life} - overstressed device lifetime

$T_{life\_DC} = f(V_{peak})$ – device lifetime under DC overstress

$\Delta t_{ovrstrs}$ – overstress duration

F – frequency of repetition

- Simple in calculation
  - No need to taking into account overstress voltage variation during the time
- Pessimistic
  - Takes into account the maximal overstress voltage V_{peak}

Conclusion

- Cascoding as a method of voltage distribution over several devices
- Voltage limitation circuit for preventing from wide voltage swing and controlling gates of additional cascodes
- Proposed USB FS driver configuration and Level-Shifter design based on 2.5V and 1.8V devices with lifetime >10yrs.
- Level-shifter and USB FS driver designs are silicon proven

Thank you