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# IBIS modelling approach for design having high $R_{on}$ variation with process


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# Agenda

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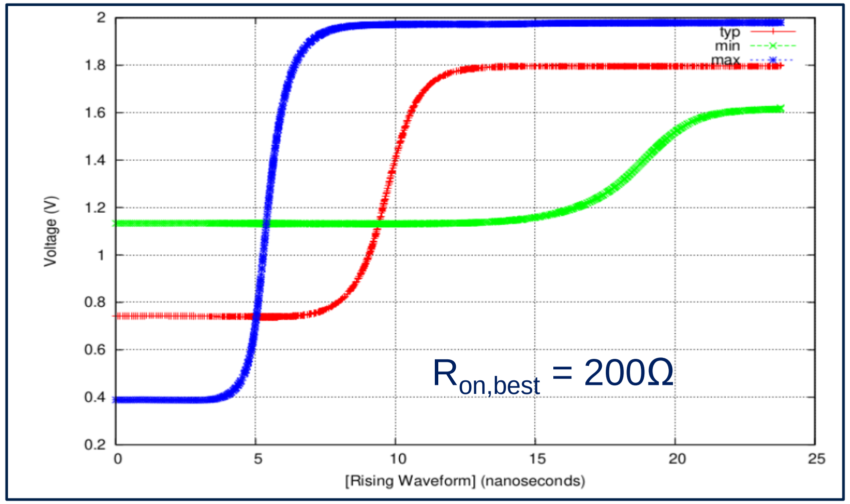
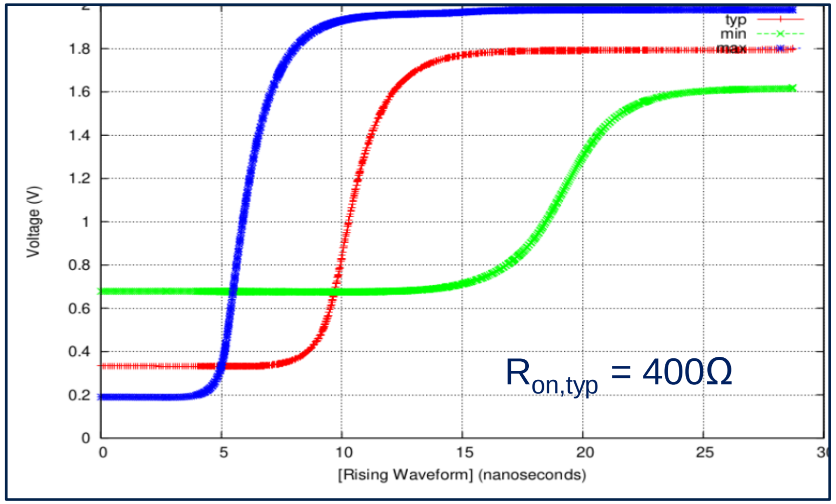
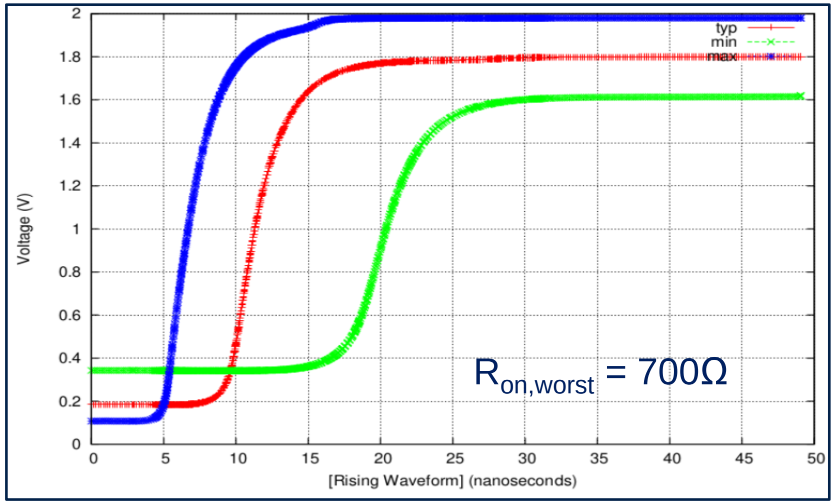
# Challenge

- Non-conventional I/O design using high voltage devices in low voltage applications leads to significant $R_{on}$ variation across PVT
- It affects the accuracy of the IBIS V-T data in capturing the true switching behavior of the design
- Selecting a single $R_{fixture}$ to accurately capture the switching behavior is challenging

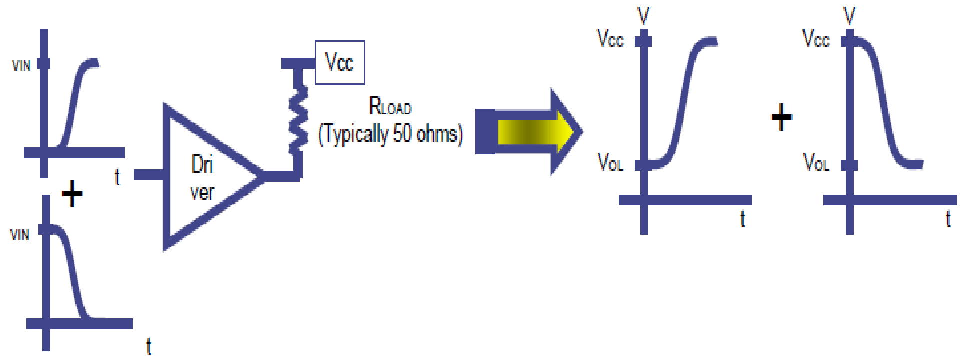


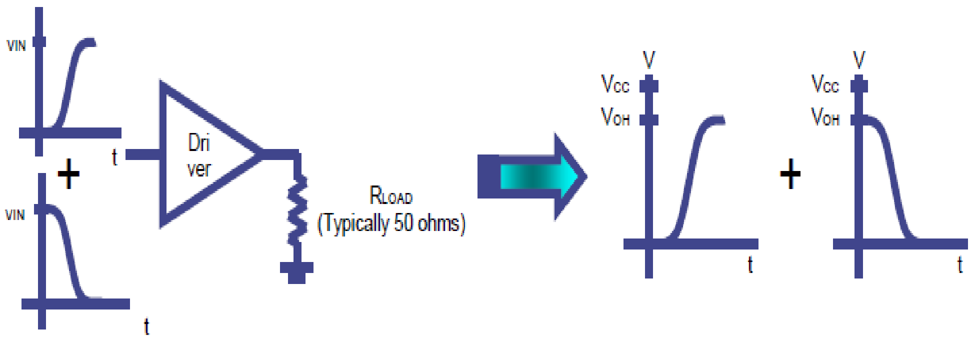



# Conventional buffer V-T data extraction

- V-T data captures the non-linearity of device (based on buffer type 2/4 V-T table is required)
- A typical load condition is applied that the buffer will encounter in actual use
- Transient simulation is performed to capture the complete dynamic behavior of the buffer
- A single model developed using typical $R_{fixture}$ is sufficient for all PVT (typ, min, max)




Pull-up reference V/T measurement setup



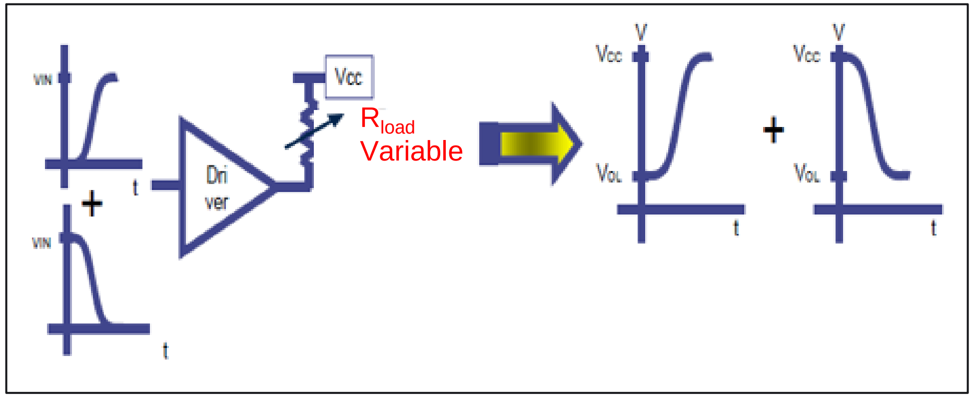

Pull-down reference V/T measurement setup

# Implemented V-T extraction approach

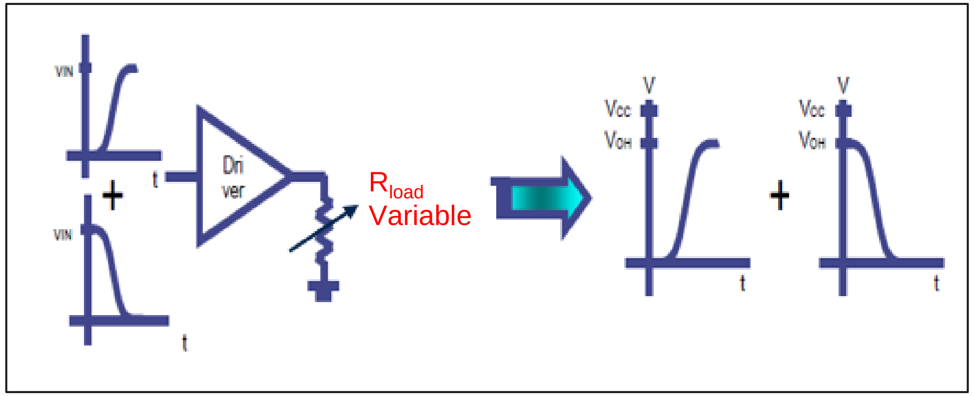
- Non-conventional I/O designs exhibit significant $R_{on}$ variation with process (best, worst, typ)

- Capturing accurate transient characteristics using typical $R_{fixture}$ is not feasible

- Three separate models are required, each based on different $R_{on}$
  - It enhances the captured swing
  - Captures accurately the non-linear waveform shapes with Ron variation




Implemented Pull-up reference V/T measurement setup




Implemented Pull-down reference V/T measurement setup

# Modification in IBIS table

All max data

```
[Rising Waveform]
R_fixture     = 200.0
V_fixture     = 1.98V
V_fixture_min = 1.98V
V_fixture_max = 1.98V
  0s       389.15818mV  389.15818mV  389.15818mV
  48.0ps   389.15820mV  389.15820mV  389.15820mV
  100.0ps  389.15819mV  389.15819mV  389.15819mV
  148.0ps  389.15819mV  389.15819mV  389.15819mV
  196.0ps  389.15818mV  389.15818mV  389.15818mV
  248.0ps  389.15820mV  389.15820mV  389.15820mV
  296.0ps  389.15824mV  389.15824mV  389.15824mV
  348.0ps  389.16291mV  389.16291mV  389.16291mV
  396.0ps  389.16303mV  389.16303mV  389.16303mV
  444.0ps  389.14998mV  389.14998mV  389.14998mV
  496.0ps  389.11195mV  389.11195mV  389.11195mV
  544.0ps  389.08820mV  389.08820mV  389.08820mV
  592.0ps  389.10966mV  389.10966mV  389.10966mV
  644.0ps  389.13647mV  389.13647mV  389.13647mV
```

Best process V-T table

($R_{fixture}$=200Ω)

All typ data

```
[Rising Waveform]
R_fixture     = 400.0
V_fixture     = 1.8V
V_fixture_min = 1.8V
V_fixture_max = 1.8V
  0s       332.75576mV  332.75576mV  332.75576mV
  92.0ps   332.75577mV  332.75577mV  332.75577mV
  184.0ps  332.75577mV  332.75577mV  332.75577mV
  280.0ps  332.75573mV  332.75573mV  332.75573mV
  372.0ps  332.75579mV  332.75579mV  332.75579mV
  464.0ps  332.76044mV  332.76044mV  332.76044mV
  556.0ps  332.76071mV  332.76071mV  332.76071mV
  648.0ps  332.74332mV  332.74332mV  332.74332mV
  744.0ps  332.70460mV  332.70460mV  332.70460mV
  836.0ps  332.70018mV  332.70018mV  332.70018mV
  928.0ps  332.71706mV  332.71706mV  332.71706mV
  1.02ns   332.77458mV  332.77458mV  332.77458mV
  1.116ns  332.87317mV  332.87317mV  332.87317mV
  1.208ns  332.94713mV  332.94713mV  332.94713mV
  1.3ns    333.01333mV  333.01333mV  333.01333mV
```

Typ process V-T table

($R_{fixture}$ =400Ω)

All min data

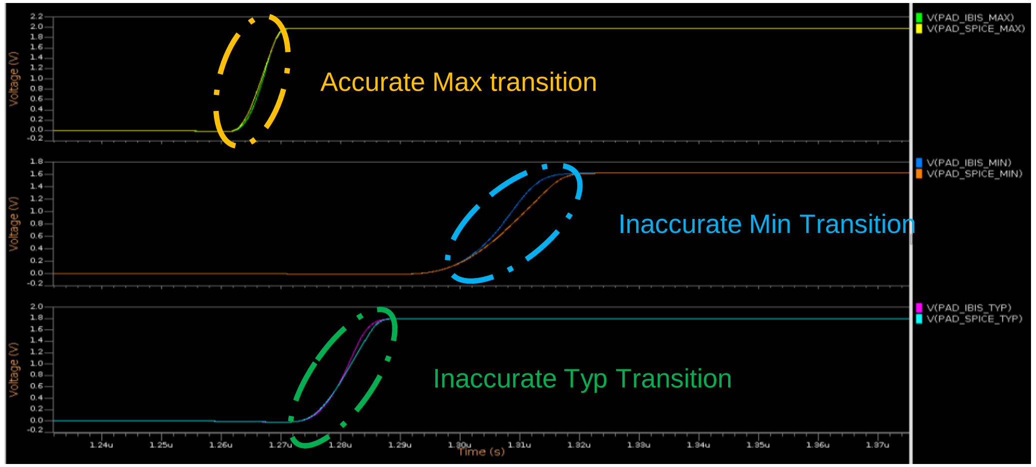
```
[Rising Waveform]
R_fixture     = 700.0
V_fixture     = 1.62V
V_fixture_min = 1.62V
V_fixture_max = 1.62V
  0s       342.83640mV  342.83640mV  342.83640mV
  164.0ps  342.83643mV  342.83643mV  342.83643mV
  328.0ps  342.83639mV  342.83639mV  342.83639mV
  492.0ps  342.83649mV  342.83649mV  342.83649mV
  656.0ps  342.83885mV  342.83885mV  342.83885mV
  820.0ps  342.84069mV  342.84069mV  342.84069mV
  984.0ps  342.84002mV  342.84002mV  342.84002mV
  1.148ns  342.83134mV  342.83134mV  342.83134mV
  1.312ns  342.81394mV  342.81394mV  342.81394mV
  1.476ns  342.79253mV  342.79253mV  342.79253mV
  1.64ns   342.80076mV  342.80076mV  342.80076mV
  1.804ns  342.81565mV  342.81565mV  342.81565mV
  1.968ns  342.85708mV  342.85708mV  342.85708mV
```

Worst process V-T table

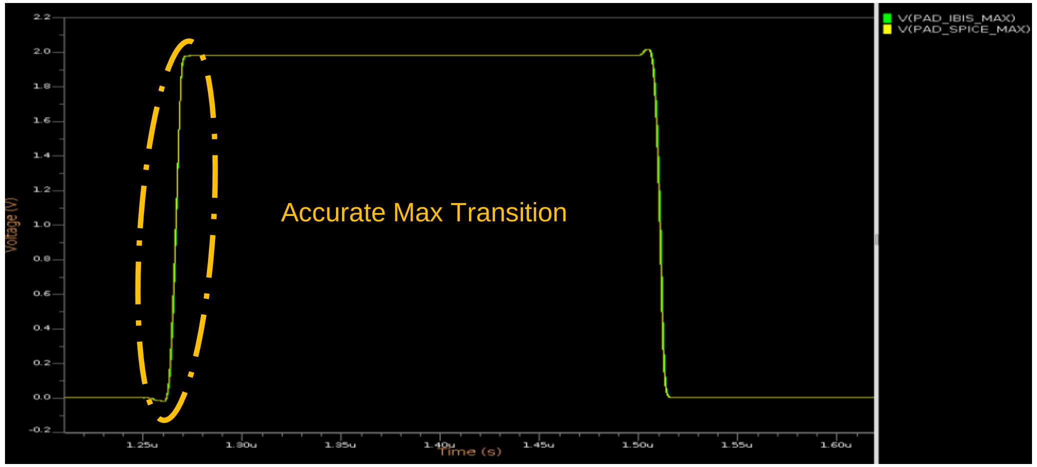
($R_{fixture}$ =700Ω)

- To prevent confusion during model usage, the V-I, V-T table are modified in accordance with the process
- Column containing typ, min, max data is adjusted based on the process for which the model is developed
- Each column contains data extracted for Ron specific to a particular process

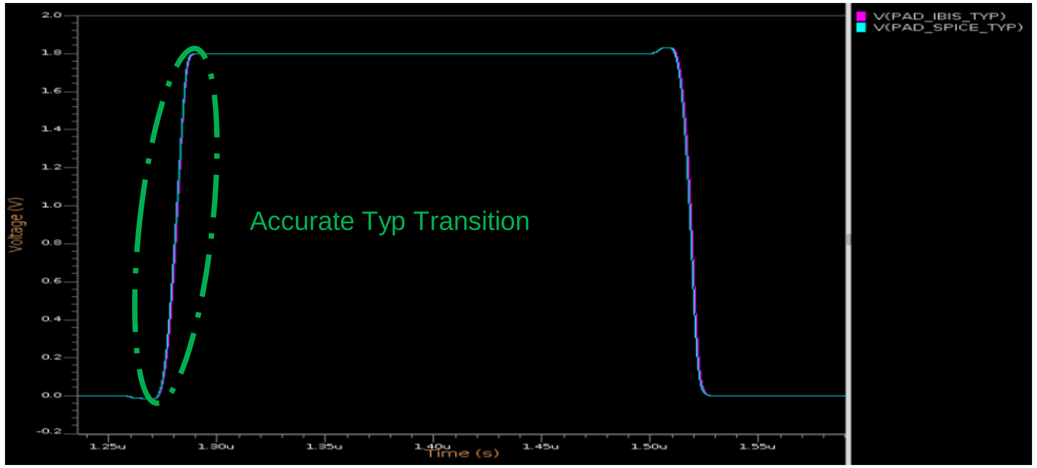
# IBIS vs SPICE matching results



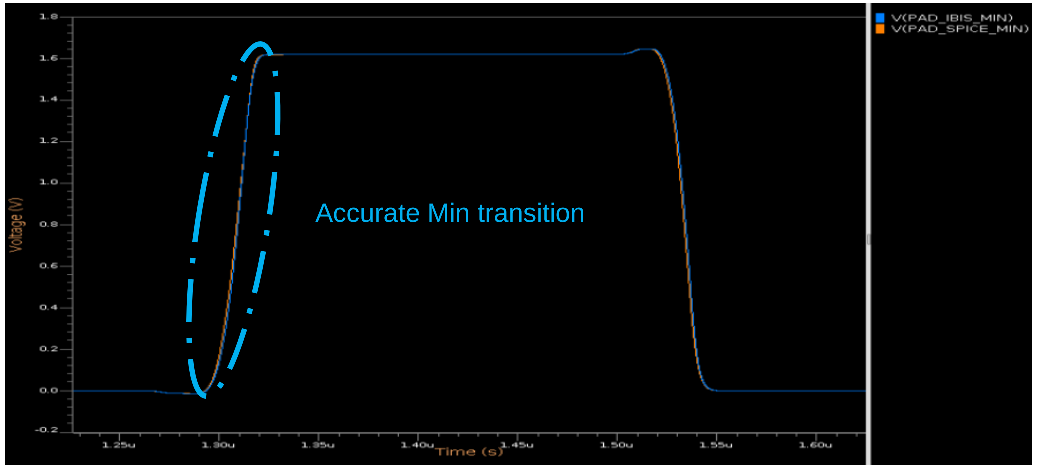

Conventional approach model matching
($R_{fixture}$ = 200Ω)




Implemented approach best process model matching
($R_{fixture}$ = 200Ω)




Implemented approach typ process model matching
($R_{fixture}$ = 400Ω)




Implemented approach worst process model matching
($R_{fixture}$ = 700Ω)

# Three takeaways

## 1

Non-conventional IO design is becoming the new normal.

- HV devices in LV application

## 2

IBIS modeling of such non-conventional designs requires a non-standard approach

Ron dependent V-T data extraction to capture accurate non-linearity of design across PVT

## 3

Implemented approach improves IBIS vs SPICE correlation but increases modeling time

- Verify Ron variation before V-T data extraction
- Manual modification of IBIS V-I, V-T table

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