

Some Results for General K-table Extraction Proposal Using SPICE

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(From material originally presented January 30, 2015,
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Updated Material

- **More derivation detail: January 30, 2015, “General K-Table Extraction Proposal Using SPICE”**
 - <http://www.ibis.org/summits/jan15/ross2.pdf>
 - Contains Summit references
- **Some results and other observations here**
- **Purpose – Use SPICE for PROTOTYPING IBIS extraction algorithms (with general C_comp, on-die, package structures and fixture loads)**

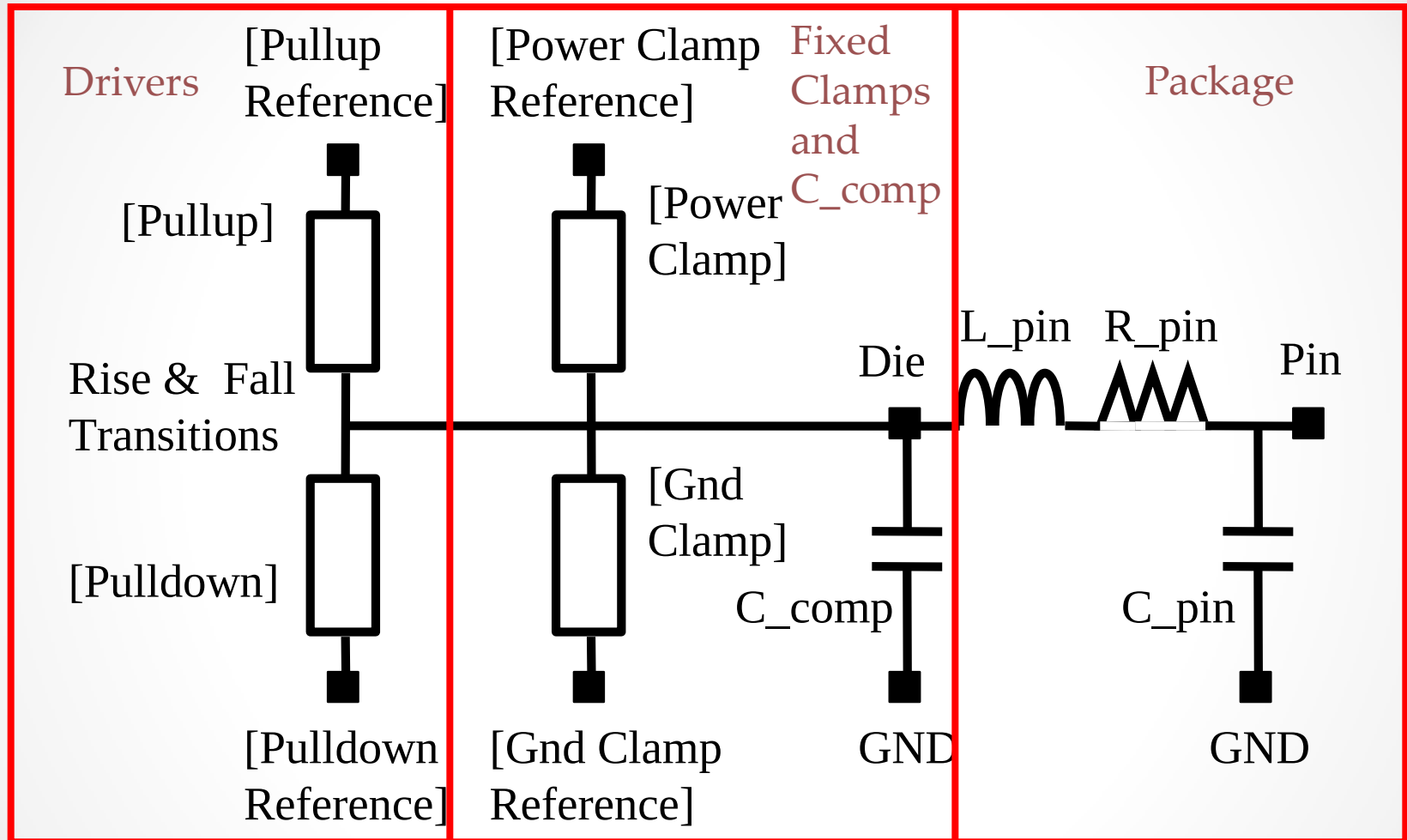


Overview

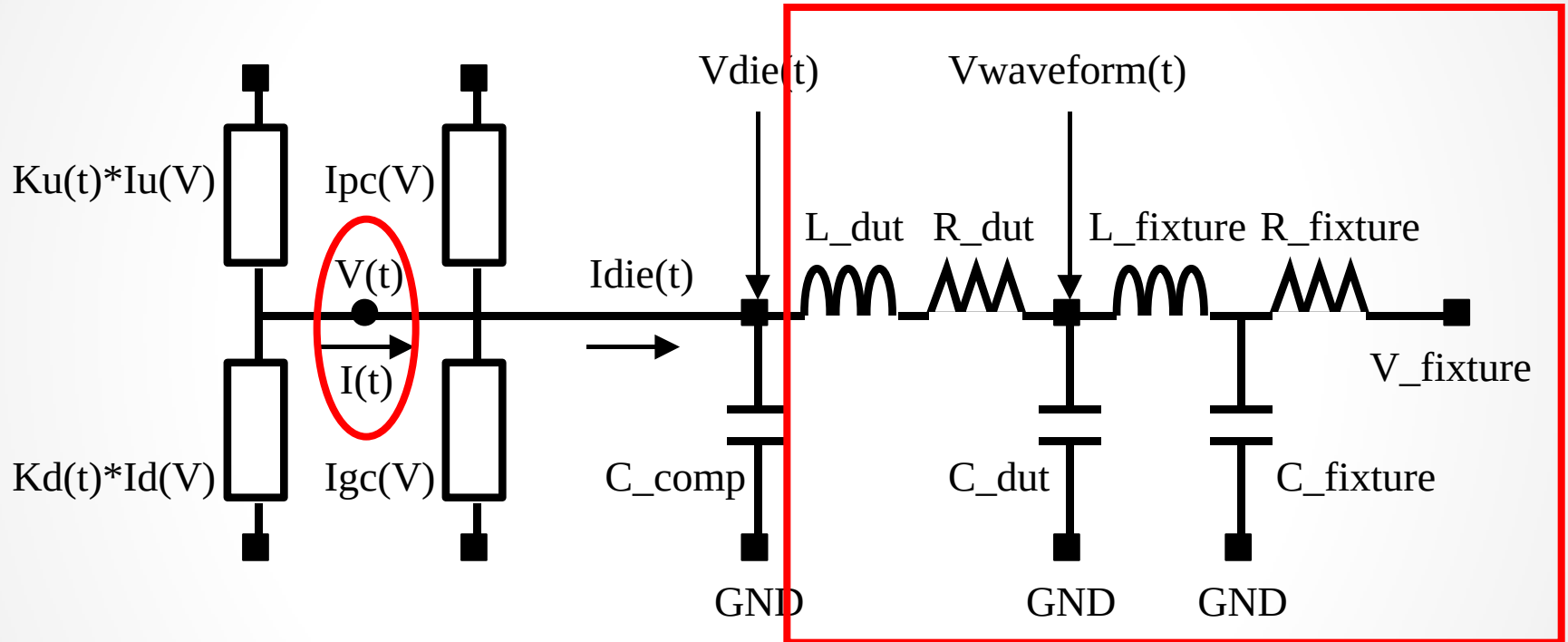
- Fixed C_comp to local GND for extraction
- Detailed C_comp model from S-parameters or IBIS-ISS allowed
- IBIS Interconnect BIRD proposal adds on-die and package models
- SPICE-based extraction proposal supports total path measurement with more detailed C_comp/on-die/package structures
- Limitations exist



Standard IBIS Model



Generalized V-T Extraction Load (with L/R/C_dut)



Calculate $V(t)$ and $I(t)$
from load information

Direct $V(t)$, $I(t)$ Solution

- Xuefeng Chen, Asian IBIS Summit (China), September 11, 2007: $V(t)$, $I(t)$ extracted directly for L/R/C/V_fixture by applying $i=C*dv(t)/dt$ and $v=L*di(t)/dt$
- Extension can include L/R/C_dut (where L/R/C_dut replaces the L/R/C_pin values for the measured pin)
- $Ku(t)$ and $Kd(t)$ tables extracted using the 2-equations/2-unknowns (2EQ/2UK) method (later)



Indirect Feedback Solution Next

- Avoids encoding equations for complex structures
- Calculates K-tables with high-gain (e.g., 1E7) feedback loop multiplier
 - $K_{ur}(t)$, $K_{dr}(t)$ from two rising V-T waveforms and fixtures
 - $K_{uf}(t)$, $K_{df}(t)$ from two falling V-T waveforms and fixtures
- Calculated and specified responses converge
- Requires vendor-specific SPICEs (versus IBIS-ISS)
 - Tables
 - Feedback loop issues with tables



Partial SPICE Circuit Showing 2EQ/2UK K-Table Extraction

```

*
* FEEDBACK TABLE ADJUSTMENT ..... VVV
GDET      NDET      GND      CUR=' ( I (VDN2) *I (VUP1) -I (VDN1) *I (VUP2) ) / (1E7) '
VDET      NDET      GND      0
*
GKUR      NKU        GND
+ CUR=' ( (V(IN2) -V(PIN2)) *I (VDN1) - (V(IN1) -V(PIN1)) *I (VDN2) ) / I (VDET) '
VKUR      NKU        GND      0
*
GKDR      NKD        GND
+ CUR=' ( (V(IN1) -V(PIN1)) *I (VUP2) - (V(IN2) -V(PIN2)) *I (VUP1) ) / I (VDET) '
VKDR      NKD        GND      0
*

```

Kur

Kdr

$$I_1(t) = K_u(t) * I_u(V_1(t)) + K_d(t) * I_d(V_1(t))$$

$$I_2(t) = K_u(t) * I_u(V_2(t)) + K_d(t) * I_d(V_2(t))$$



SPICE Encoding

- I-V tables: G elements (VCCS)
- V-T tables: PWL voltage sources
- Voltage rails: Entered
- SPICE interpolation
 - Allows higher resolution time steps in V-T tables
 - Interpolates G table currents
- I-V and V-T tables extended from final values
- Convergence criteria adjustable
- K-tables printed for $K_{ur}(t)$, $K_{dr}(t)$; $K_{uf}(t)$, $K_{df}(t)$
- Simulation done with K-table drivers:
 - G elements for K-tables
 - Scaled controlled ramp (1V/nS)
 - Step stimuli (0 to 1, 1 to 0)



Part of SPICE Encoded IBIS Prototype for Simulation

```

* HIGH SIDE
XUP      OUT1  VCC  NU1          PULLUP
VUP      NU1   VCC  0
GUP      OUT1  VCC  CUR=' -I (VUP) * ( I (VKUR) * I (VON) + I (VKUF) * (1-I (VON) ) ) '
XPC      OUT1  VCC
*
* LOW SIDE
XDN      OUT1  GRD  ND1          PULLDOWN
VDN      ND1   GRD  0
GDN      OUT1  GRD  CUR=' -I (VDN) * ( I (VKDR) * I (VON) + I (VKDF) * (1-I (VON) ) ) '
XGC      OUT1  GNDC
*

```

Kur, Kdr

Kuf, Kdf

Table switching control

```

* C_COMP AND DUT PACKAGE

```

```

XCAP     OUT1  GRD
XPKG     OUT1  GRD  PIN1
*

```

```

* LOAD

```

```

TLOAD    PIN1  GRD  PIN9  GRD  Z0=50 TD=1N
RLOAD    PIN9  GND  50G
*

```

```

* VOLTAGE CONTROL (AMPLITUDE (0 TO 1), PULSE WIDTH & PERIOD)
VPULSE STEP  GRD  0  PULSE (1 0 0P 1P 1P 5N 10N)

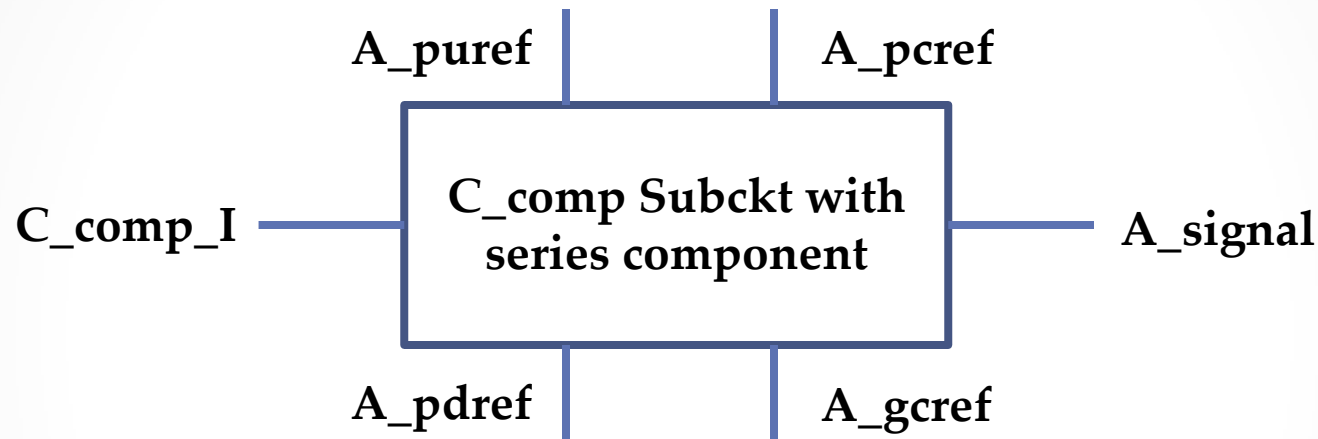
```

Enter simulation load

Ideal Step Stimulus



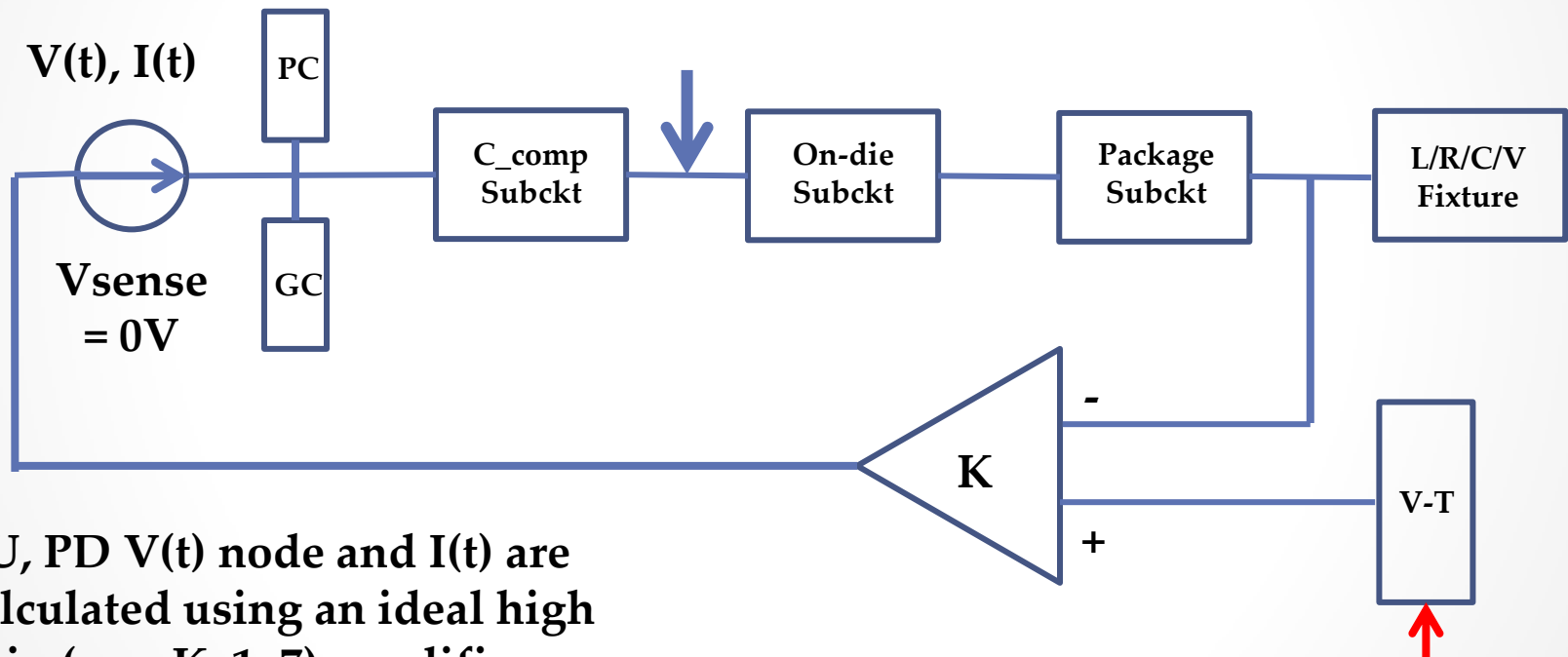
General Proposed Single-ended C_comp Subckt Model



- (Notation and details under development)
- C_comp_I: If needed for series path
 - Resistance needs to be de-embedded from I-V tables
- A_signal: Output
- Extend model for differential connections



SPICE Extraction of $V(t)$, $I(t)$ Setup and C_comp A_signal Node

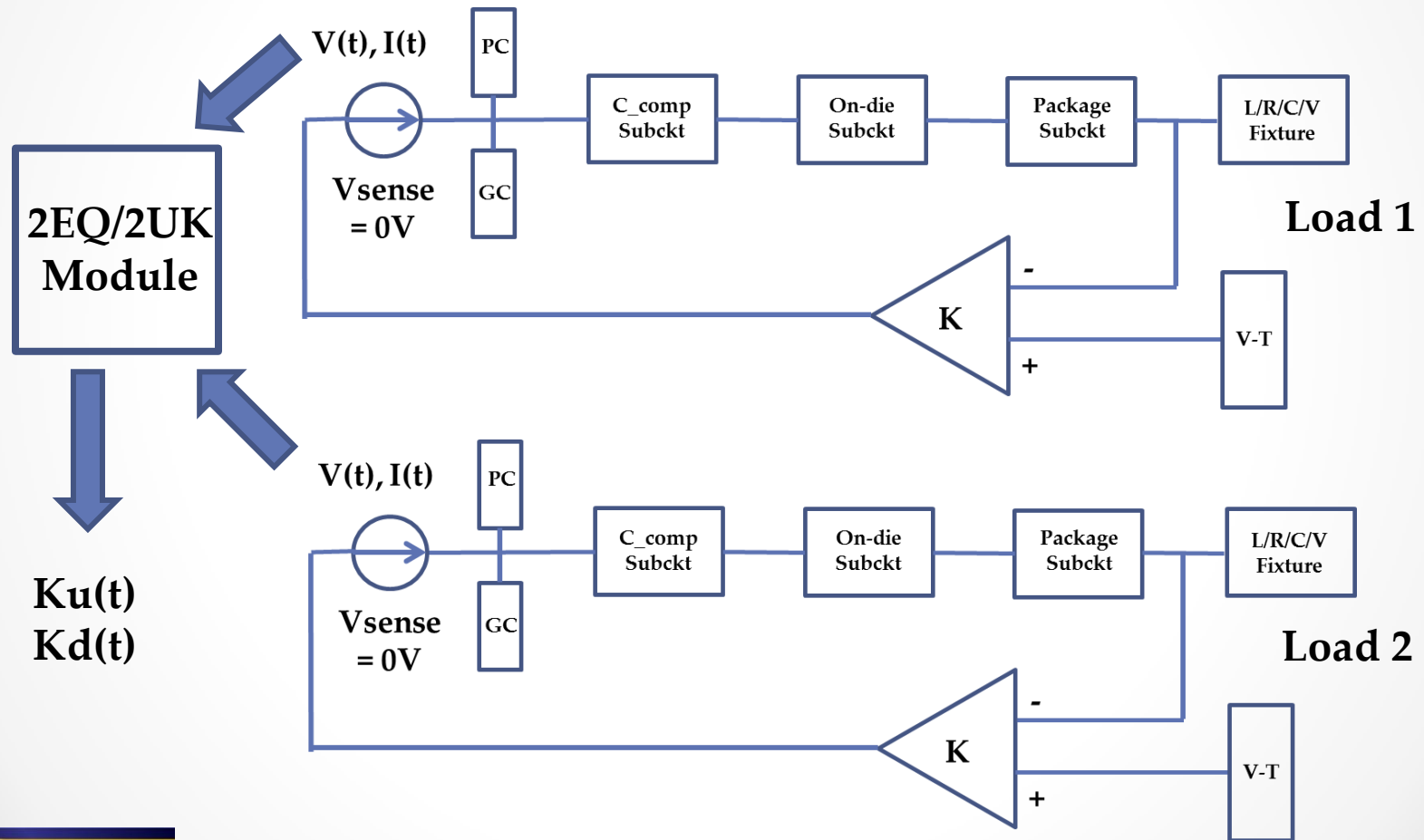


PU, PD $V(t)$ node and $I(t)$ are calculated using an ideal high gain (e.g., $K=1e7$) amplifier

V-T table (originally extracted at the Fixture) is now a PWL driver



2EQ/2UK SPICE Setup to Generate $K_u(t)$, $K_d(t)$ Tables



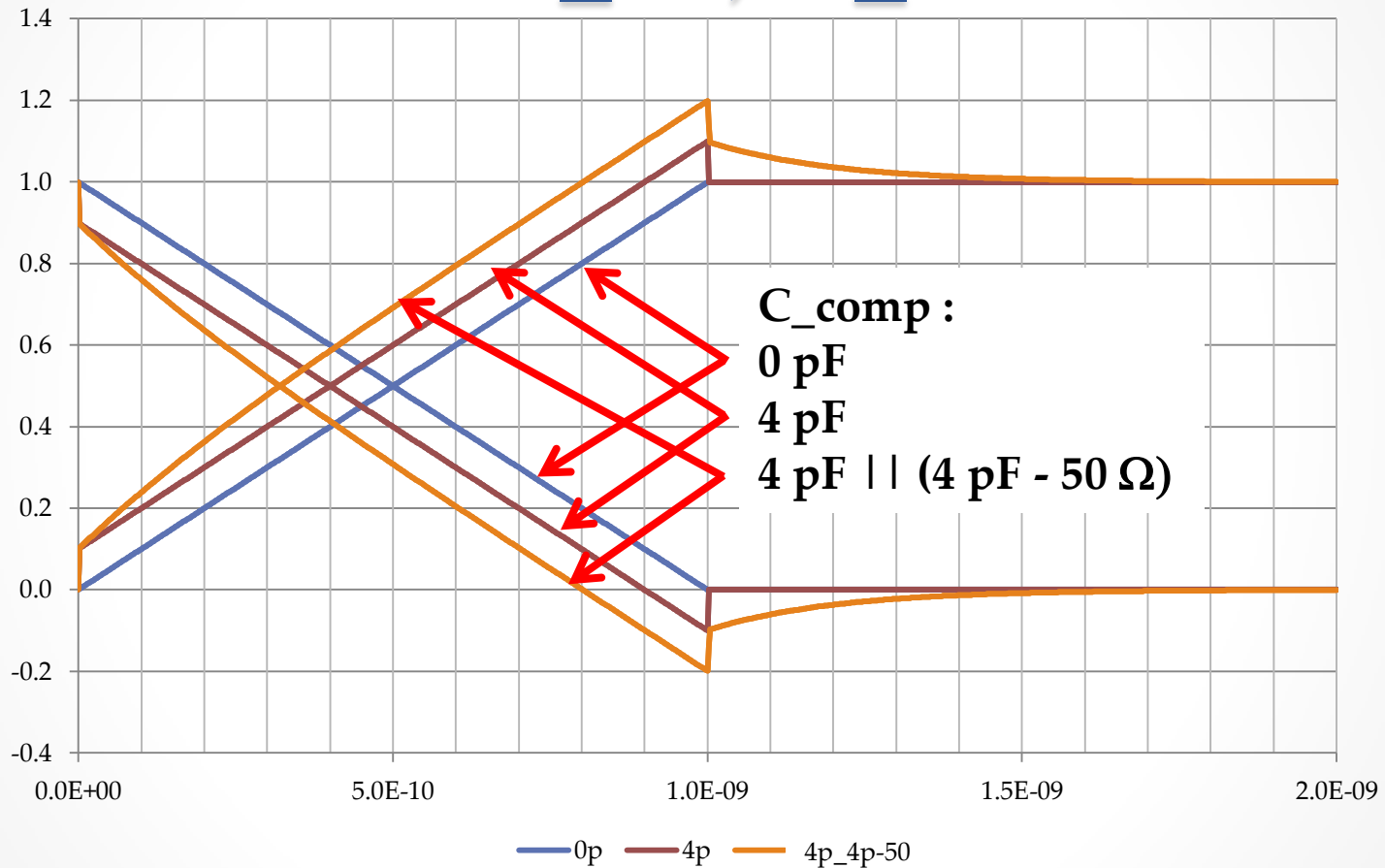
Ideal Ramp Test Cases

- **Reference Waveforms**
 - 1 ns ramp (0% to 100%) into 50 Ω -to-gnd and 50 Ω -to-vcc loads
 - 5 V supply
 - 2 ns duration
- **C_comp cases**
 - 0 pF (0p)
 - 4 pF (4p)
 - 4 pF || (4 pF – 50 Ω) (4p_4p-50)
- **Pullup/Pulldown I-V tables**
 - 50 Ω straight lines
- 1001 point extractions (not critical)

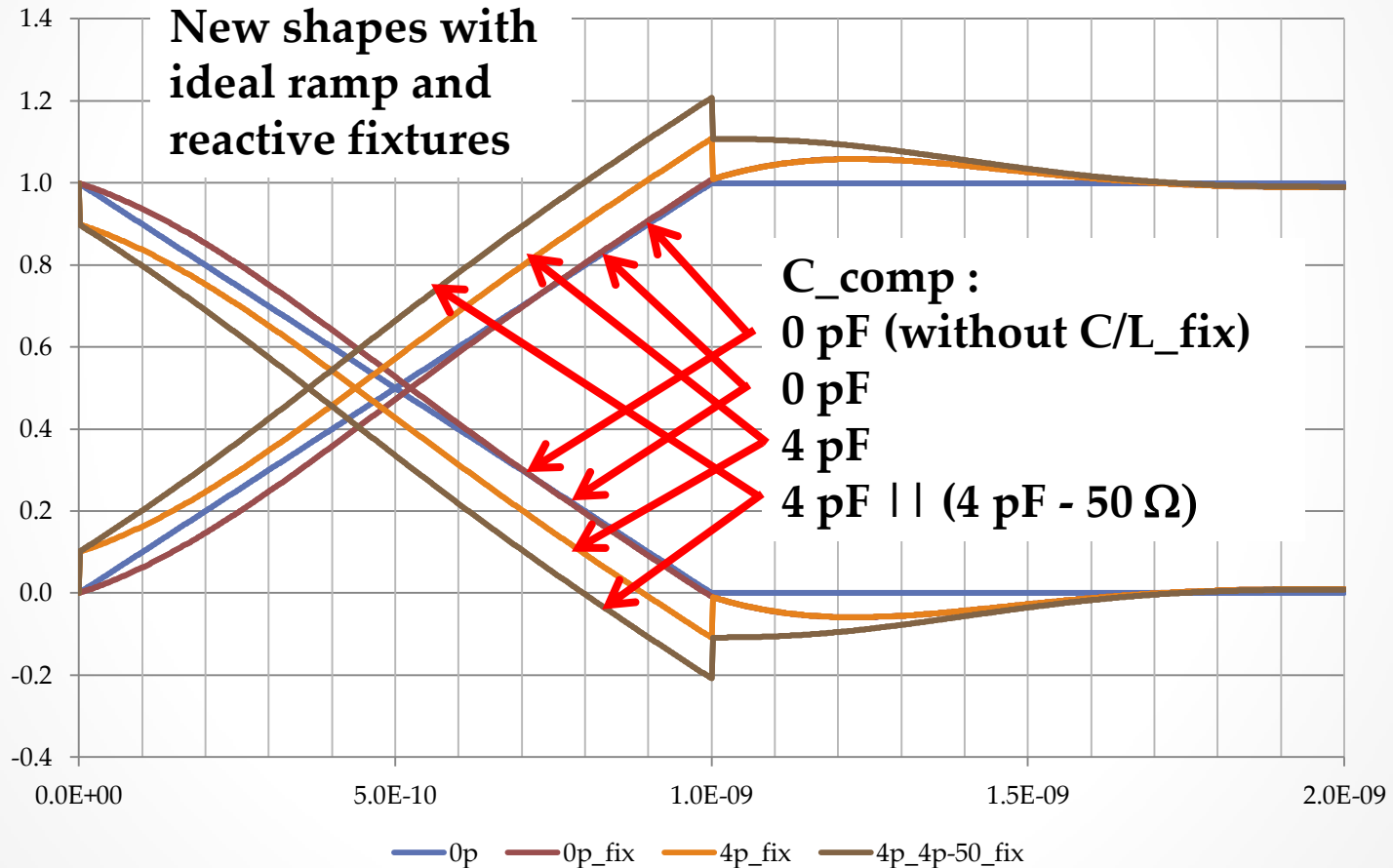


K-tables Shapes Versus Time (s)

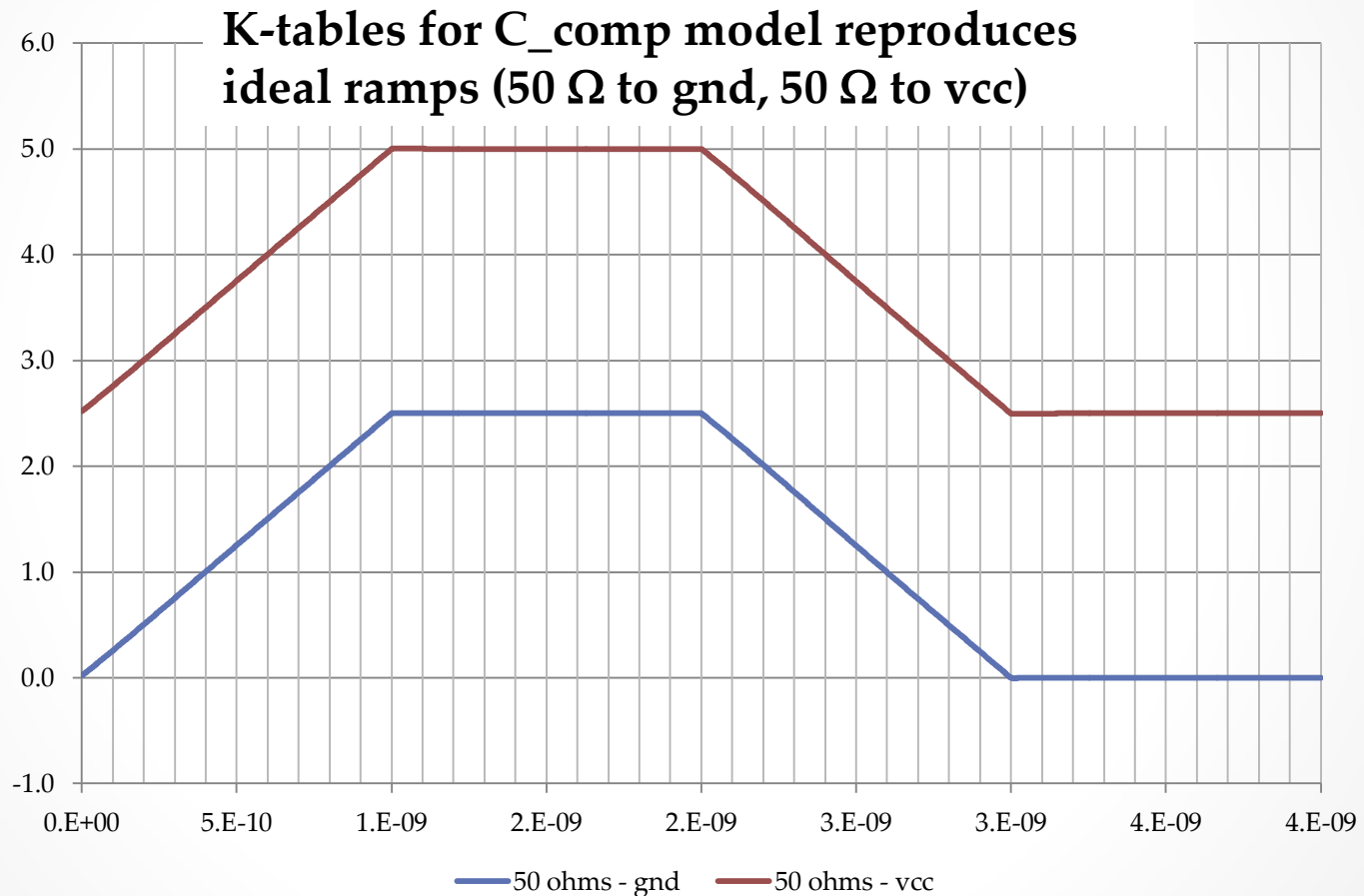
No L_fix, C_fix



K-tables Versus Time (s) – With $L_{fix}=10$ nH, $C_{fix}=4$ pF Fixtures

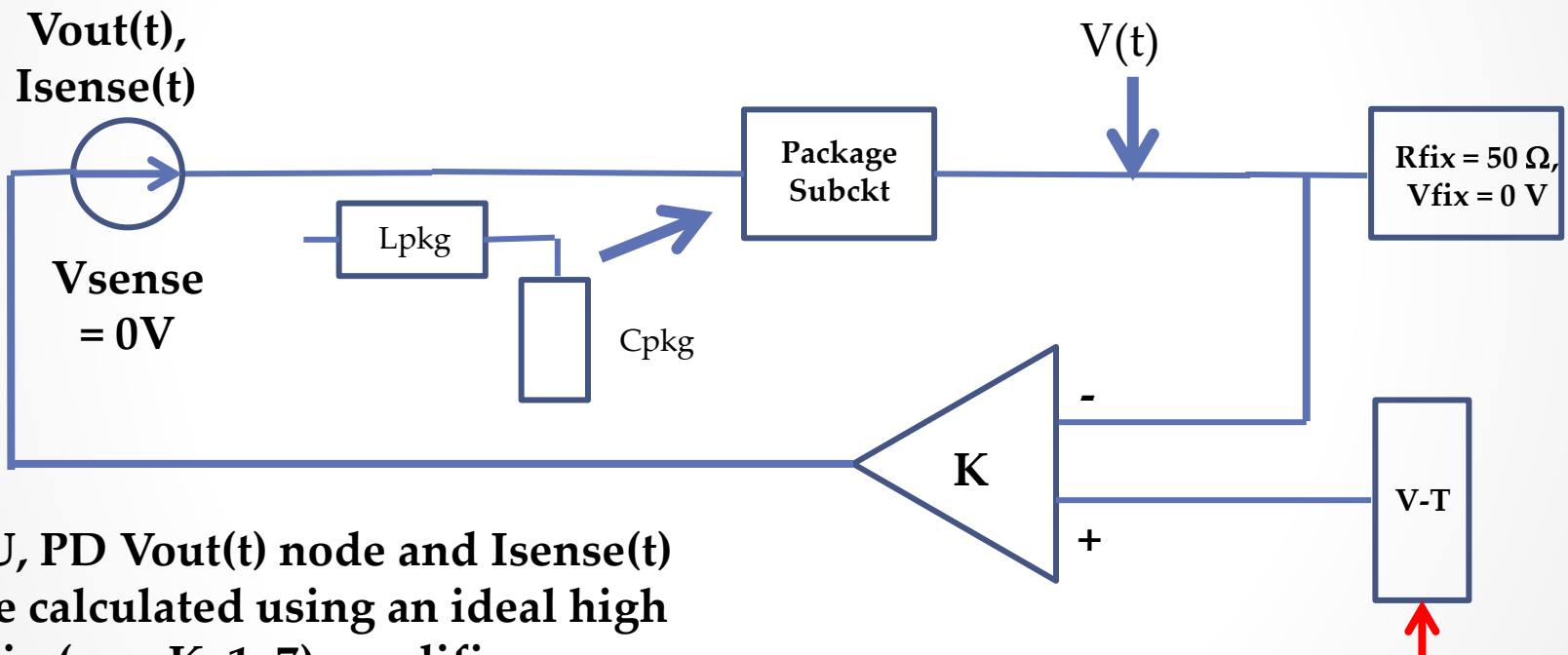


4 ns Cycle Simulations for 4p_4p-50 C_comp Model



Test Case Notation Change for $V_{out}(t)$ & $I_{sense}(t)$; Given $V(t)$

No C_{comp} , no clamps, just a Package model which could be a C_{comp} model or an on-die model

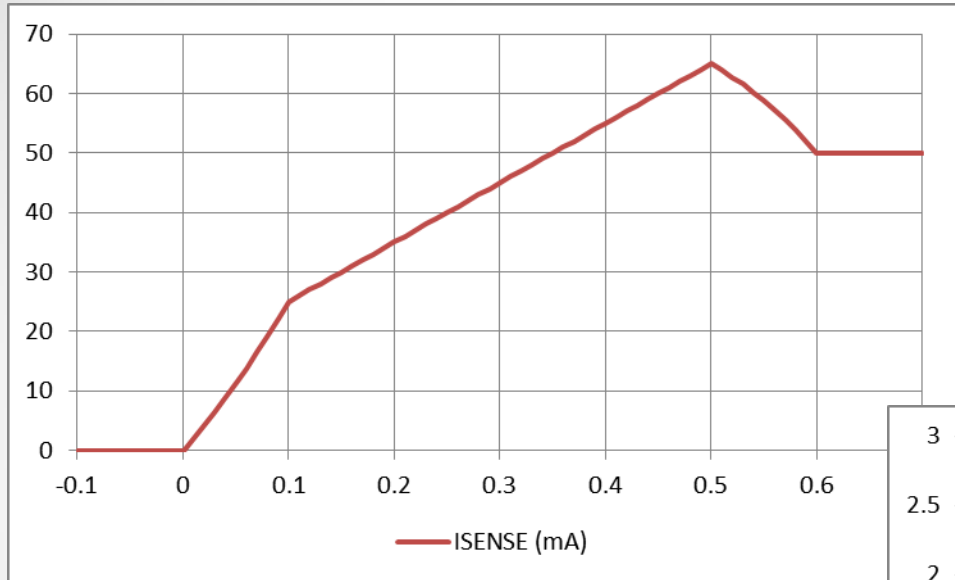


PU, PD $V_{out}(t)$ node and $I_{sense}(t)$ are calculated using an ideal high gain (e.g., $K=1e7$) amplifier

$V-T$ table (originally extracted at the Fixture) is now a PWL driver

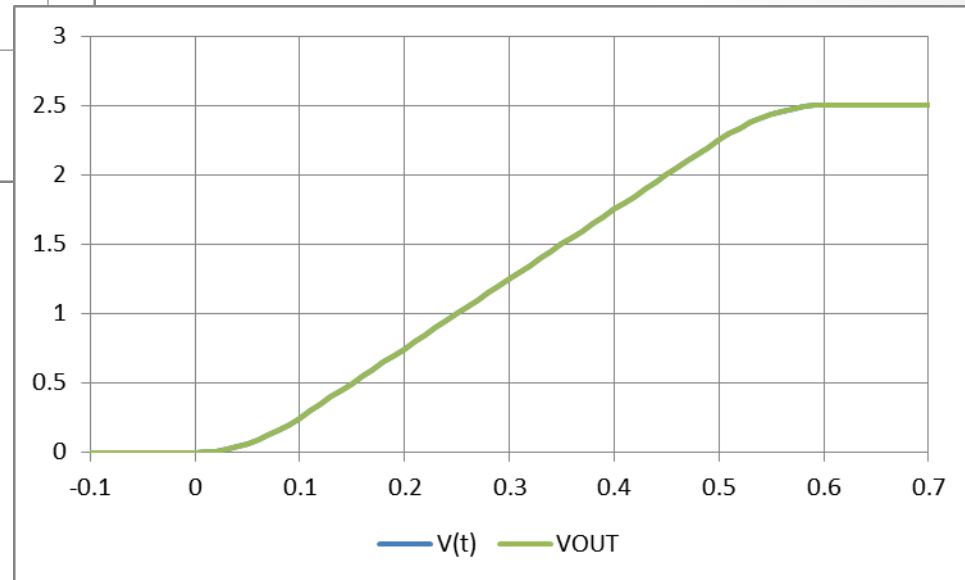


$L_{pkg} = 0 \text{ nH}, C_{pkg} = 0.004 \text{ nF}$

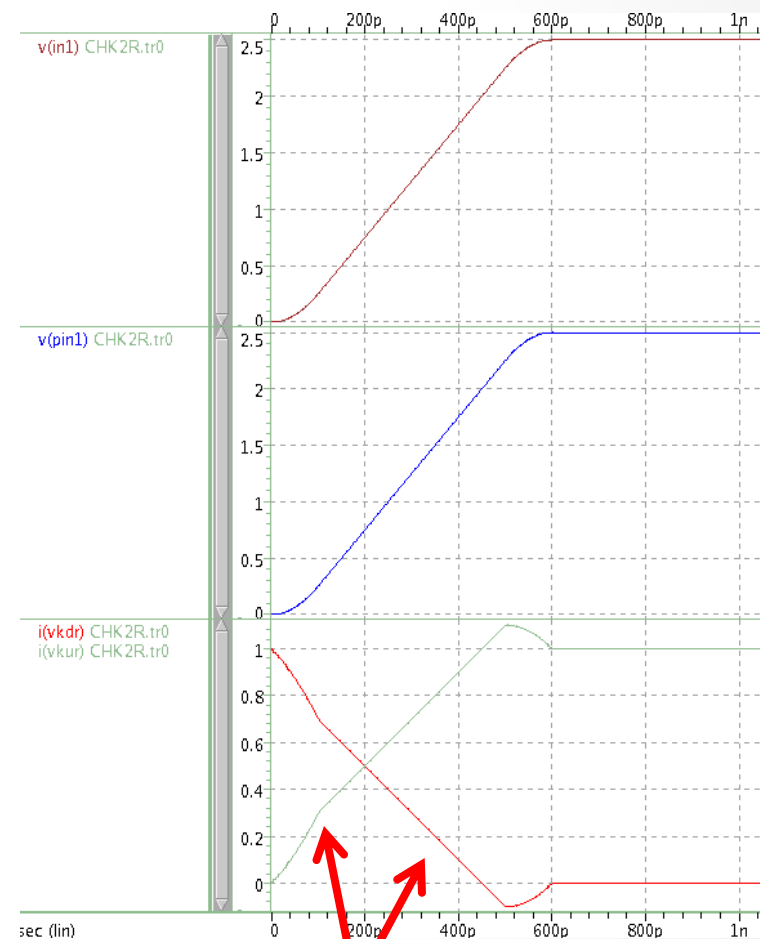
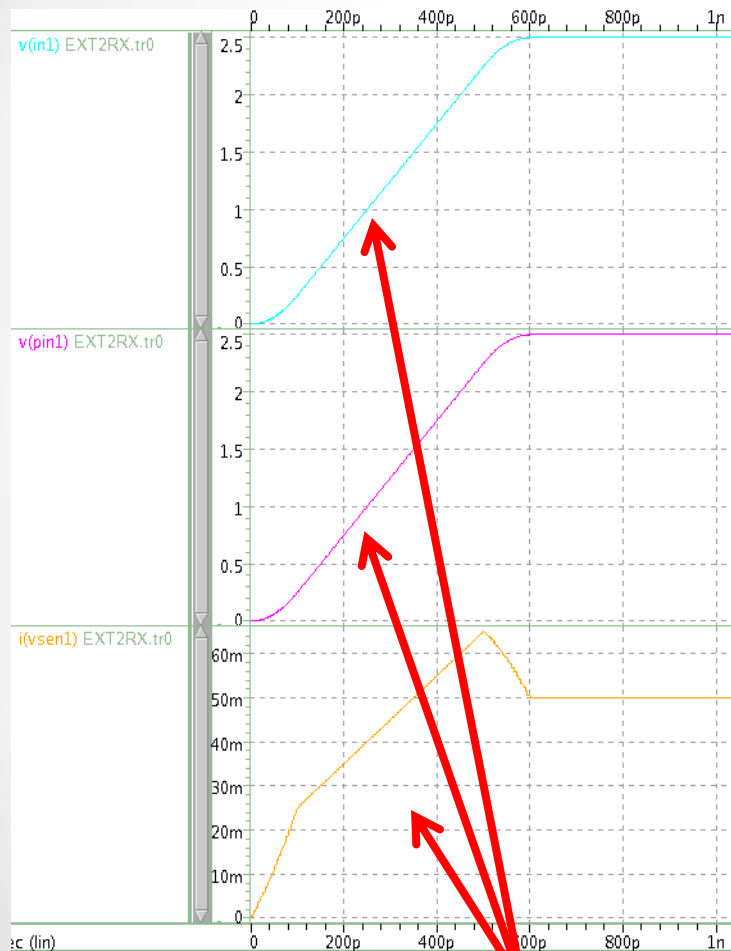


**Closed-form references
(50 Ω to GND)**

Continuous V(t) and dV(t)/dt



Extractions using Laplace Element



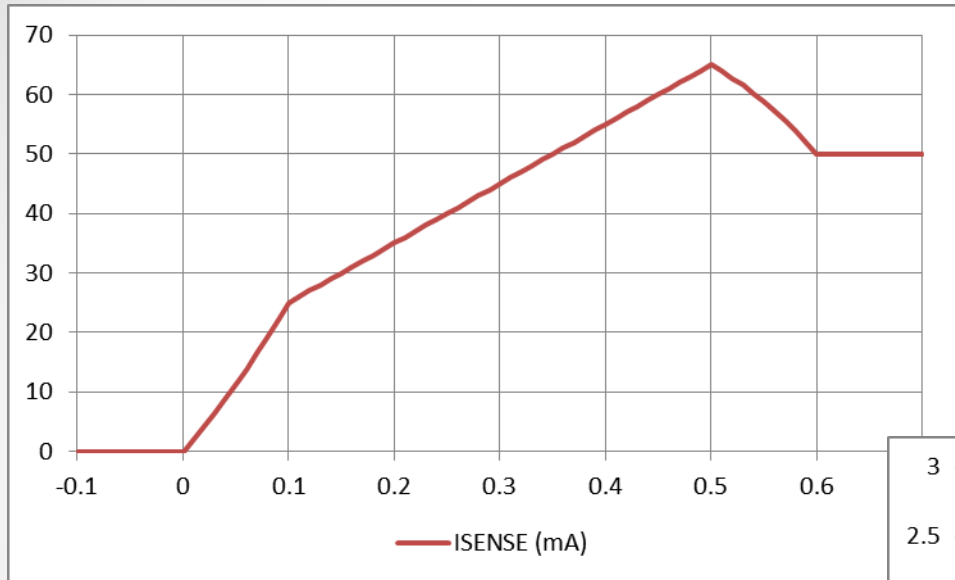
Same as closed-form references

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K-tables

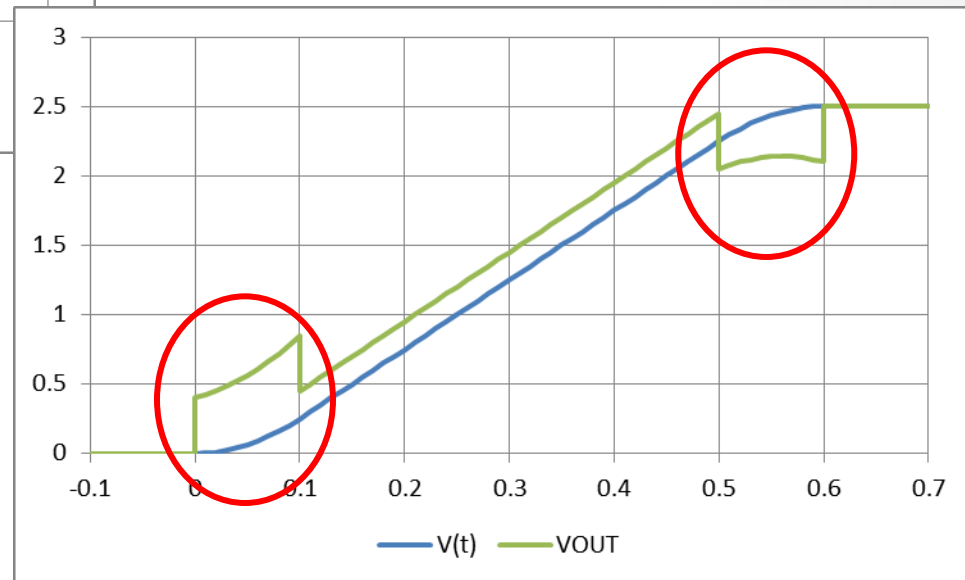
SYNOPSYS
Silicon to Software™

$$L_{pkg} = 2 \text{ nH}, C_{pkg} = 0.004 \text{ nF}$$



**VOUT discontinuities:
Feedback loop fails**

**Closed-form references
(50 Ω to GND)**



Observations and Conclusions

- **Result accuracy**
 - K-table extraction insensitive to $K=1e5$ to $K=1e9$ feedback multipliers
 - Requires SPICE maximum accuracy settings
 - Not sensitive to number of extraction points
- **Severe test cases**
 - Sharp waveform derivative discontinuity in ideal ramp
 - Large C_comp model load can be used
 - Large L_fixture, C_fixture reactive loads are ok
 - BOTH L_pkg, and C_pkg do not converge (even with smooth waveforms) – therefore topology limited and must use tool-dependent methods
 - Fails for T-line models (delay in feedback loop)
 - Works for S-parameter, Laplace transform, lumped models

