Some Results for General K-table Extraction Proposal Using SPICE

Bob Ross, Teraspeed Labs
bob@teraspeedlabs.com
Xuefeng Chen, Synopsys
xfchen@synospsys.com

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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)

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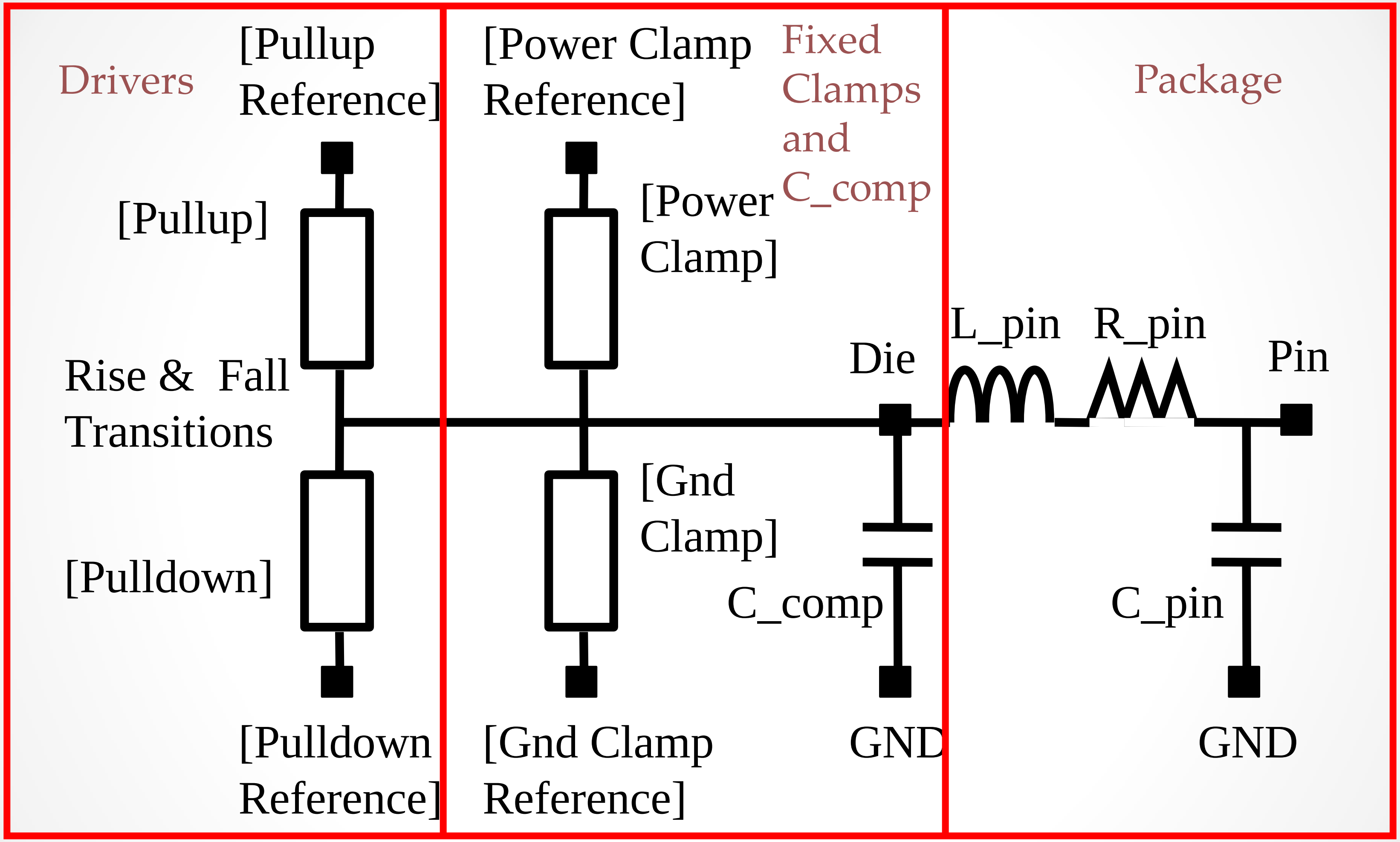
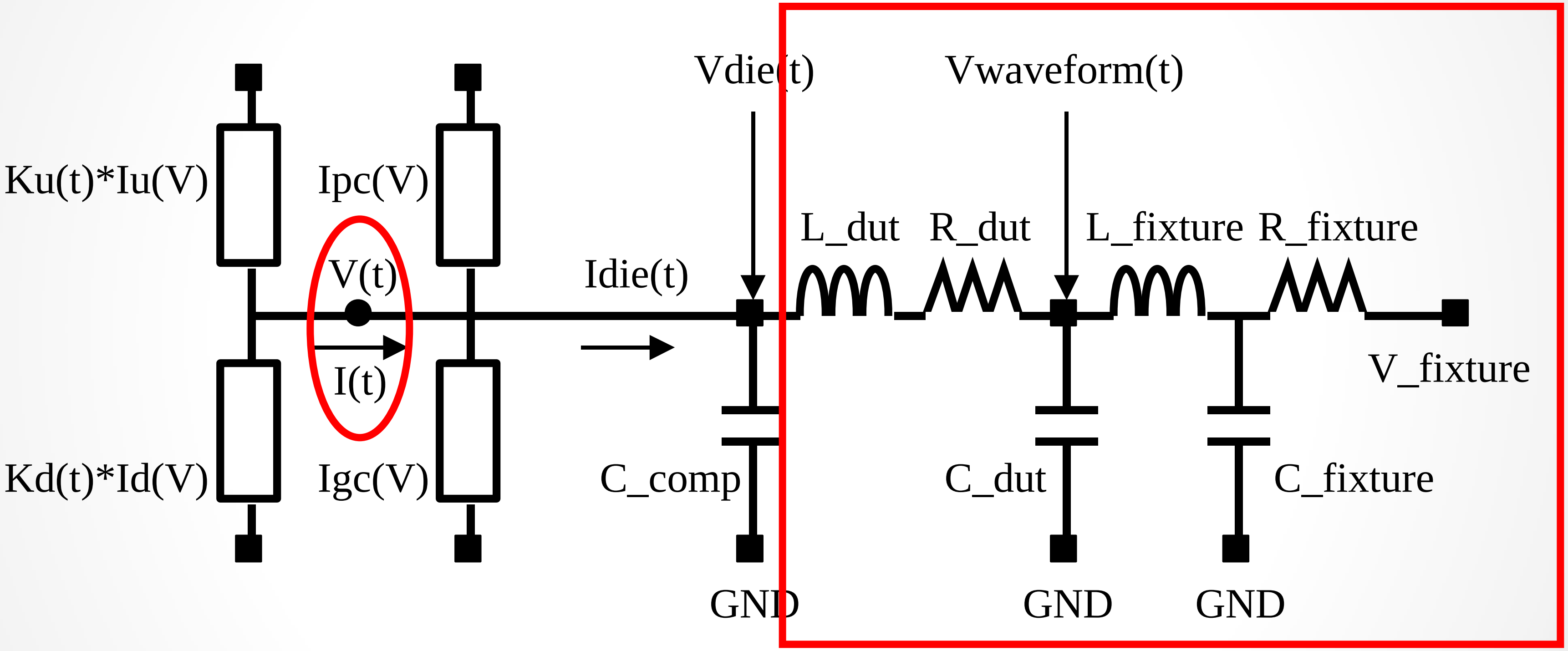
Overview

- 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**
  - **Kur(t), Kdr(t) from two rising V-T waveforms and fixtures**
  - **Kuf(t), Kdf(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

$$I_1(t) = Ku(t)*Iu(V_1(t)) + Kd(t)*Id(V_1(t))$$

$$I_2(t) = Ku(t)*Iu(V_2(t)) + Kd(t)*Id(V_2(t))$$

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 Kur(t), Kdr(t); Kuf(t), Kdf(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                  POWER_CLAMP
*
* 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                 GND_CLAMP
*
* C_COMP AND DUT PACKAGE
XCAP    OUT1   GRD                  C_COMP
XPKG    OUT1   GRD   PIN1           PACKAGE
*
* 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)
```

Kur, Kdr

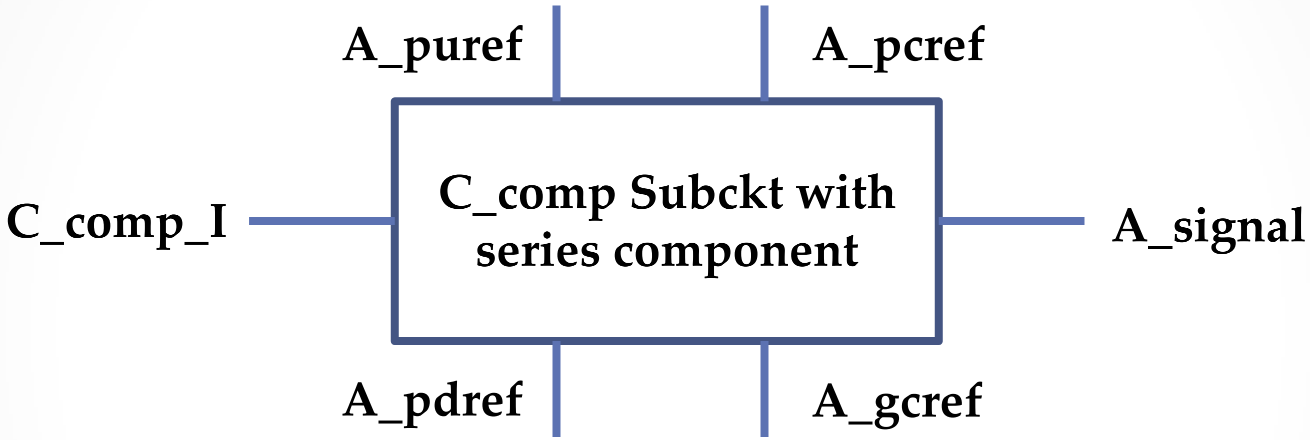
Kuf, Kdf

Table switching control

Enter simulation load

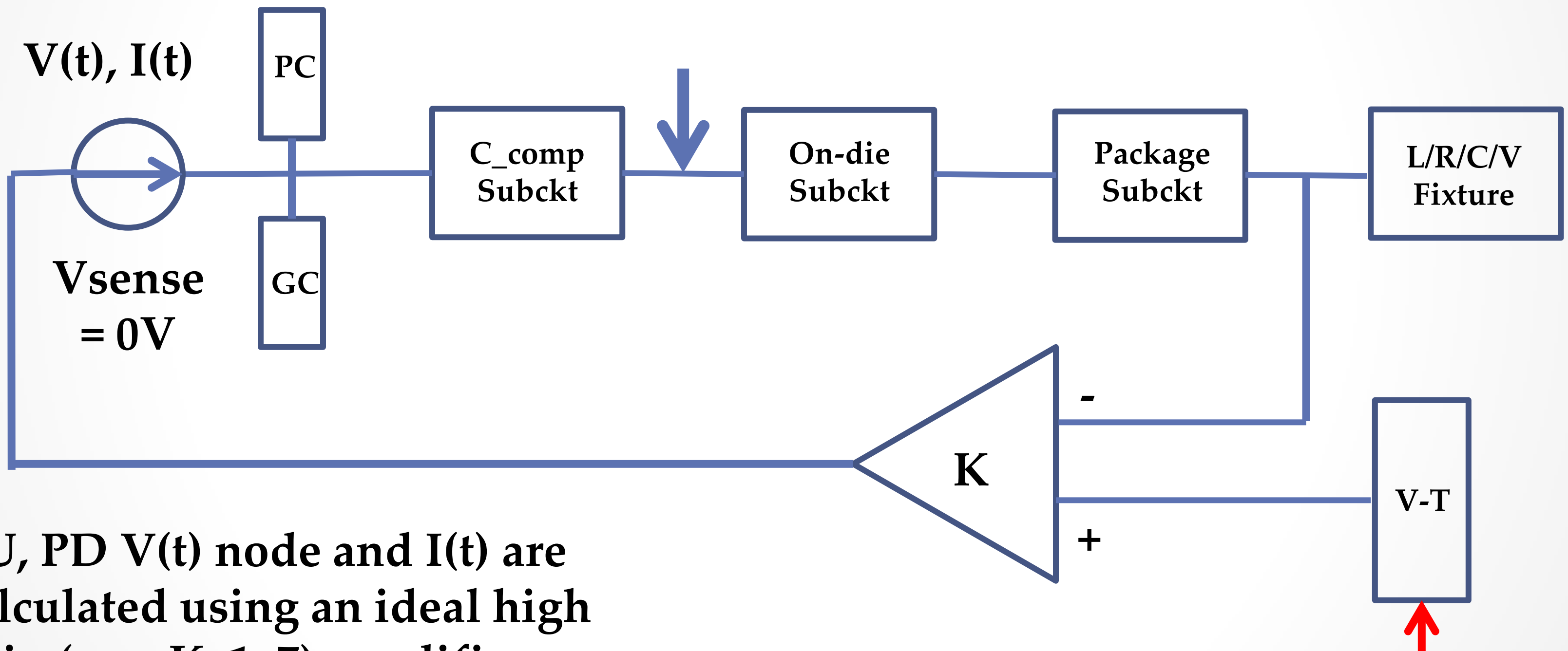
Ideal Step Stimulus

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

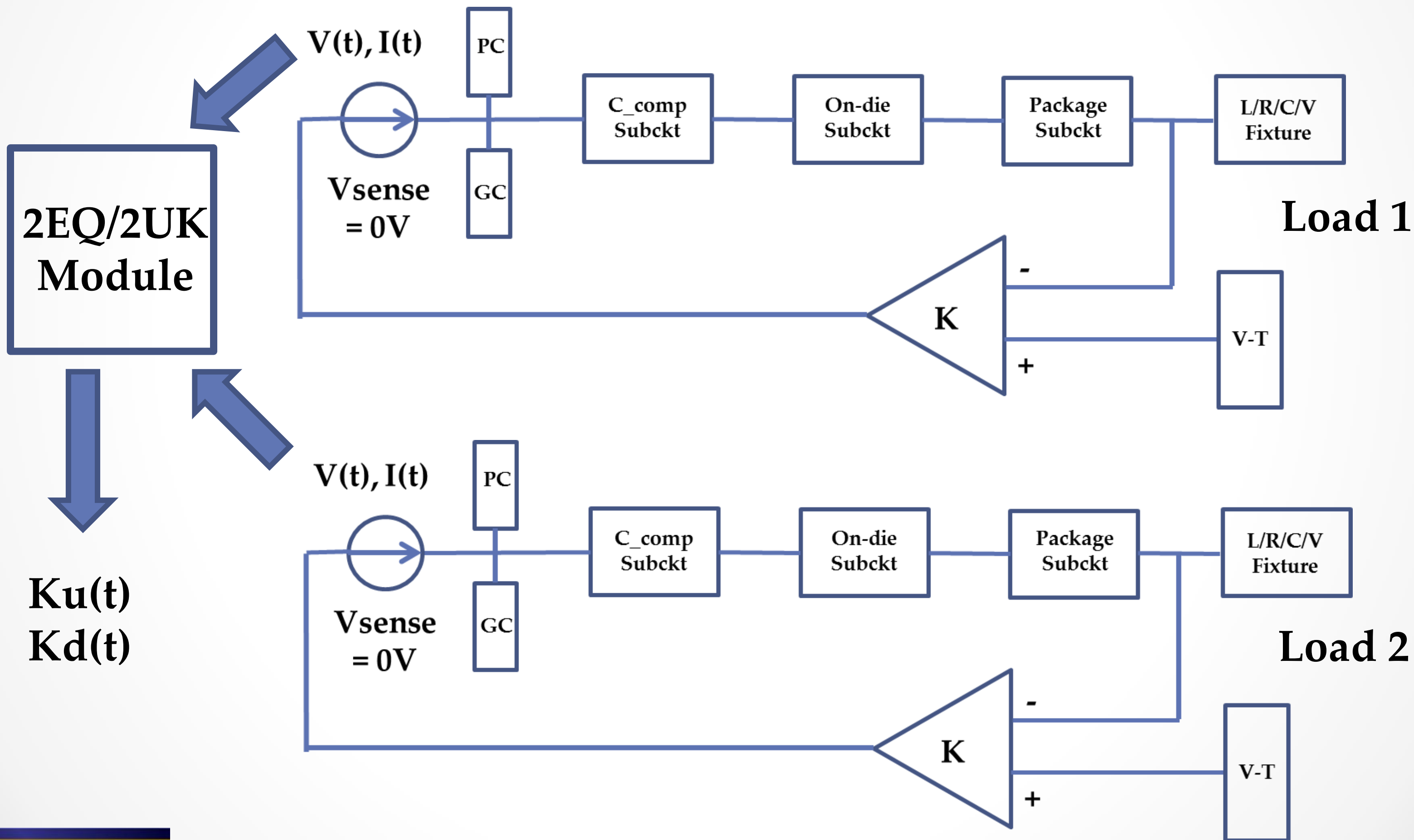
SPICE Extraction of V(t), I(t) Setup and C_comp A_signal Node



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

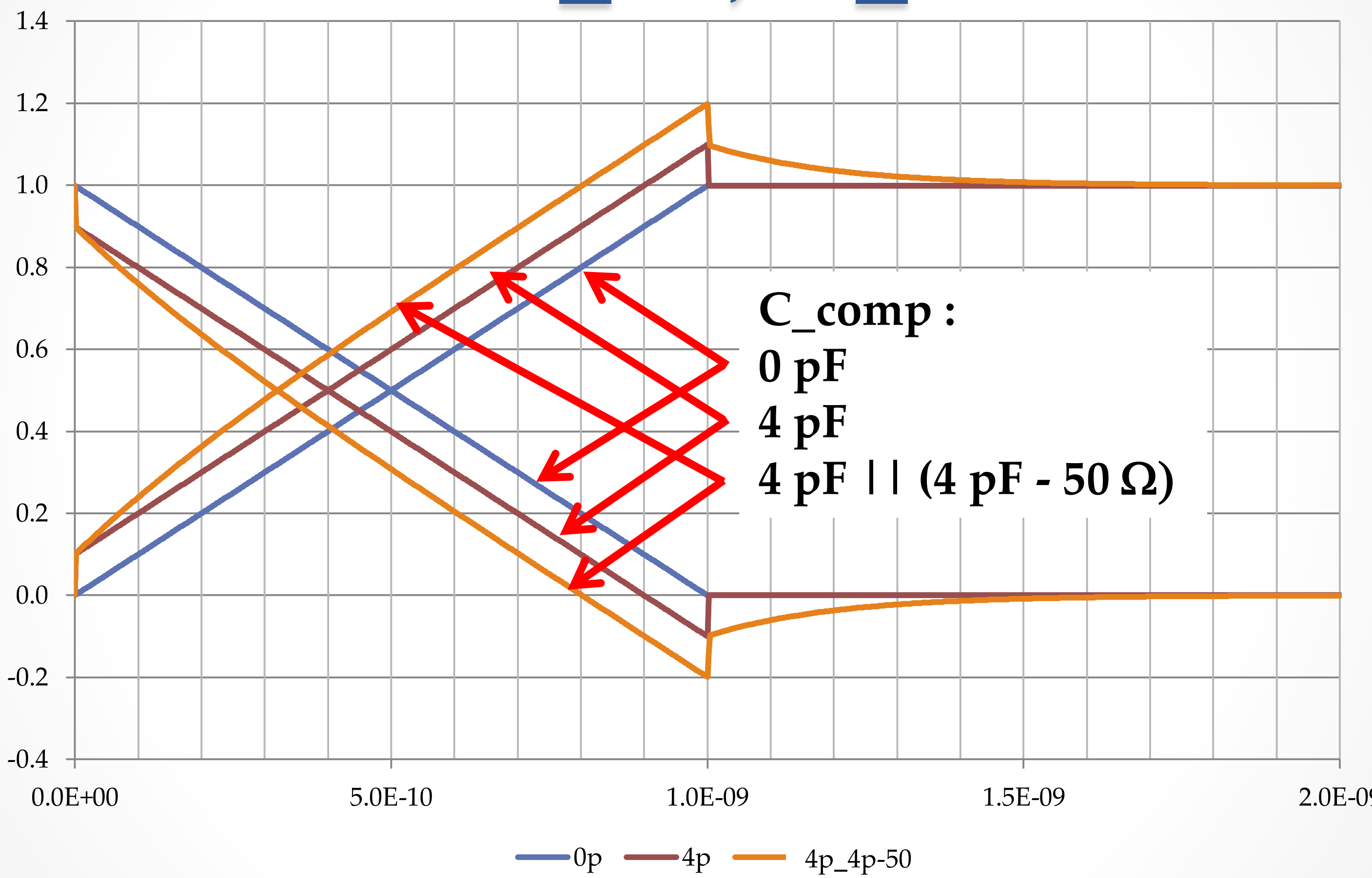
2EQ/2UK SPICE Setup to Generate Ku(t), Kd(t) Tables



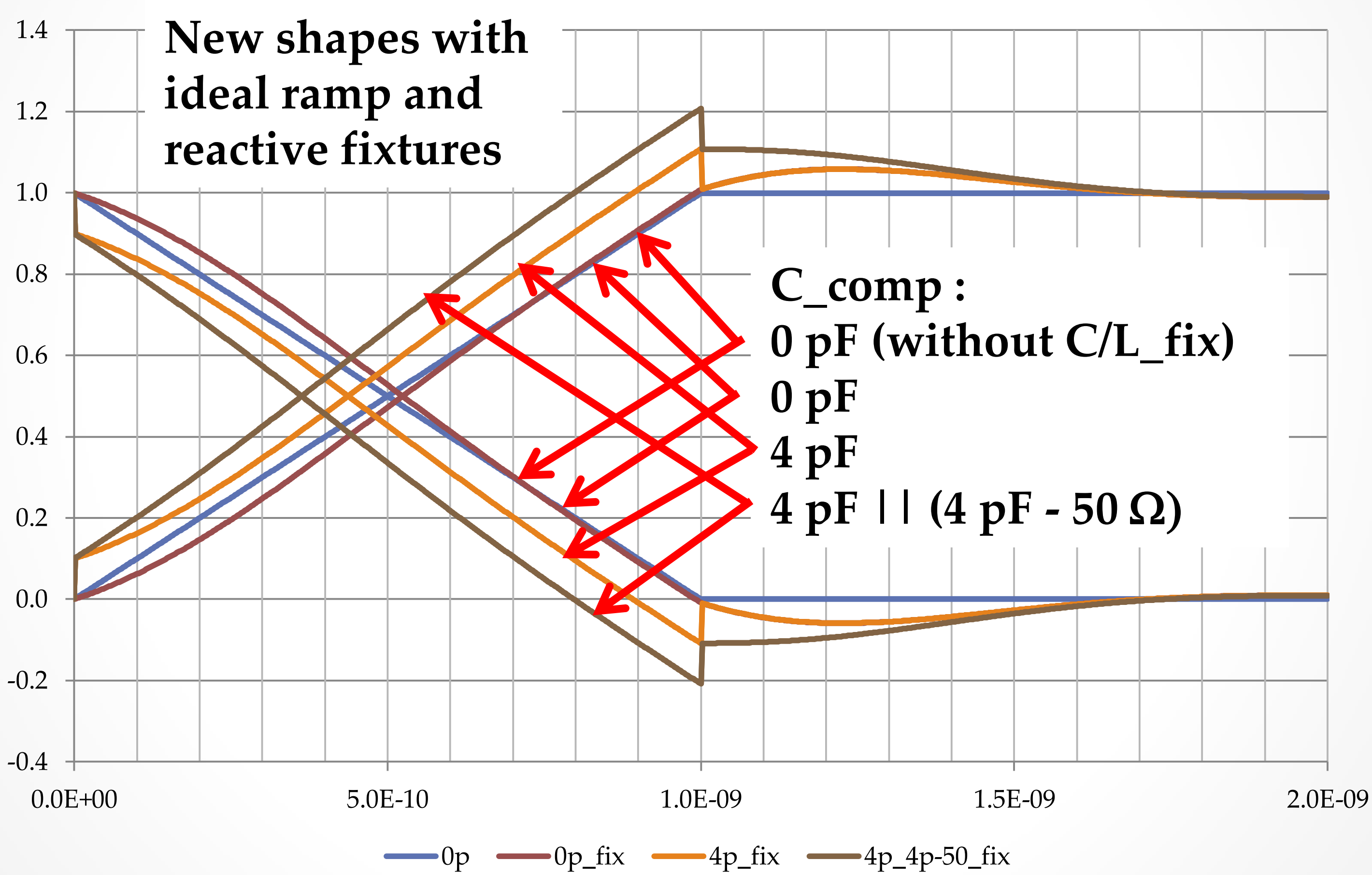
Ideal Ramp Test Cases

- **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)**

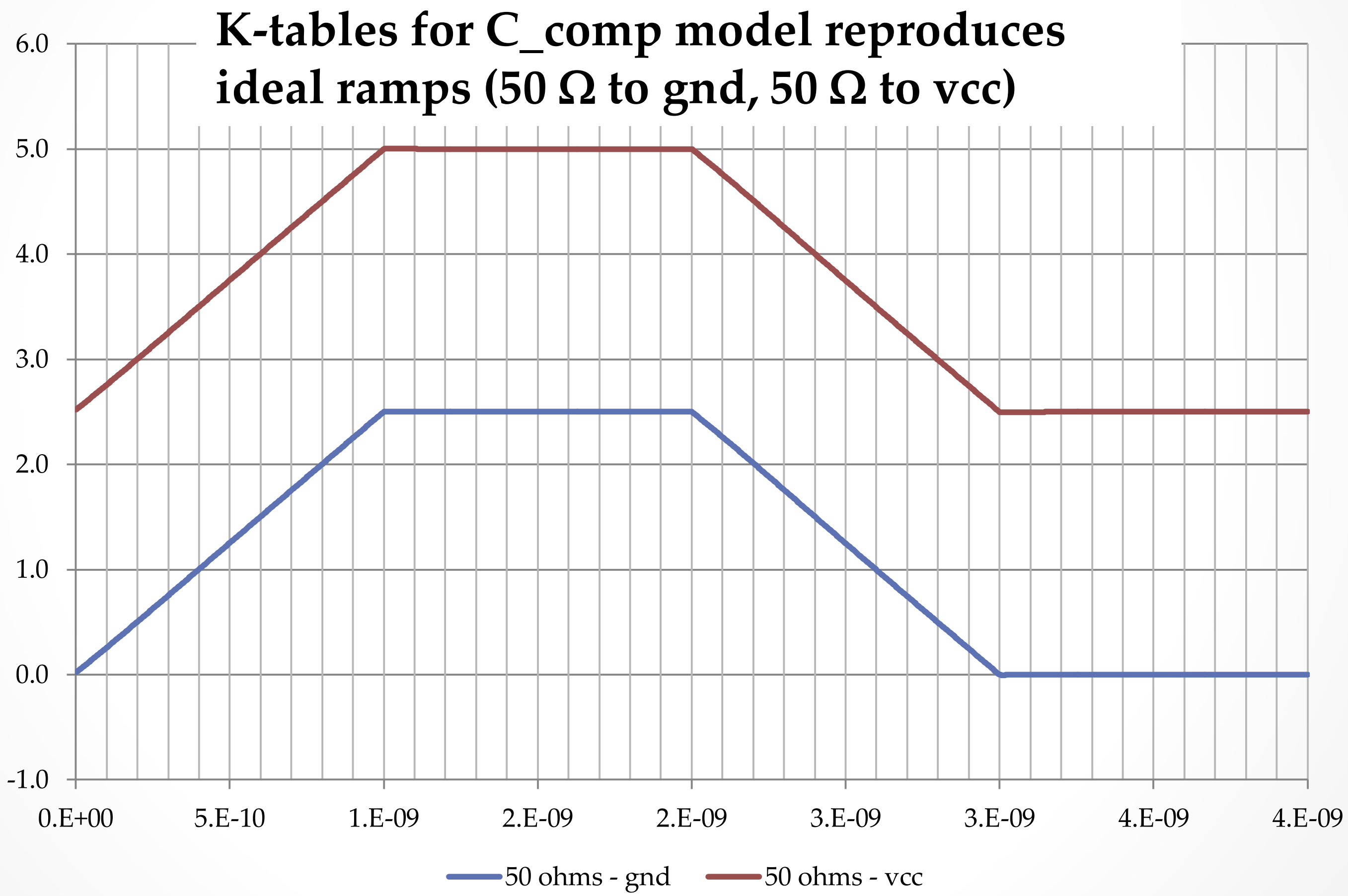
K-tables Shapes Versus Time (s)
No L_fix, C_fix



K-tables Versus Time (s) – With L_fix=10 nH, C_fix=4 pF Fixtures

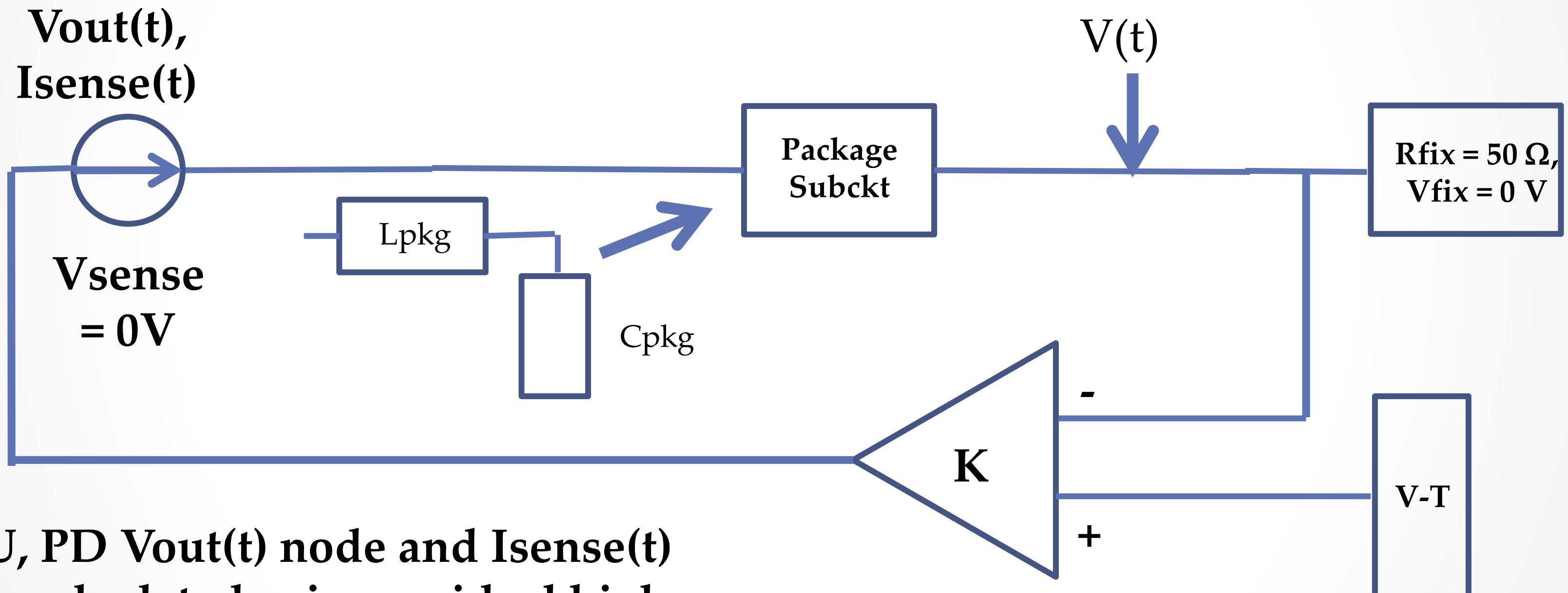


4 ns Cycle Simulations for 4p_4p-50 C_comp Model



Test Case Notation Change for Vout(t) & Isense(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 Vout(t) node and Isense(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

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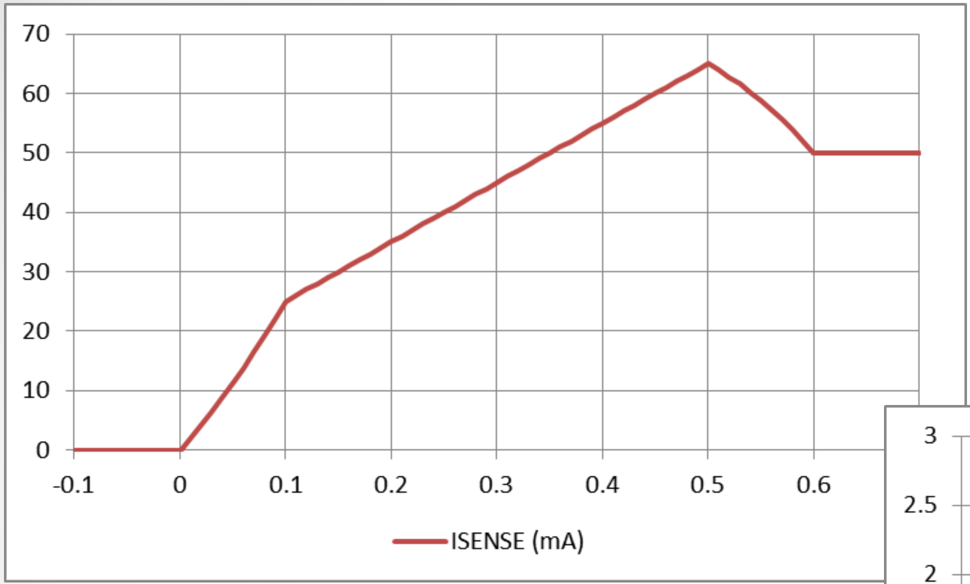
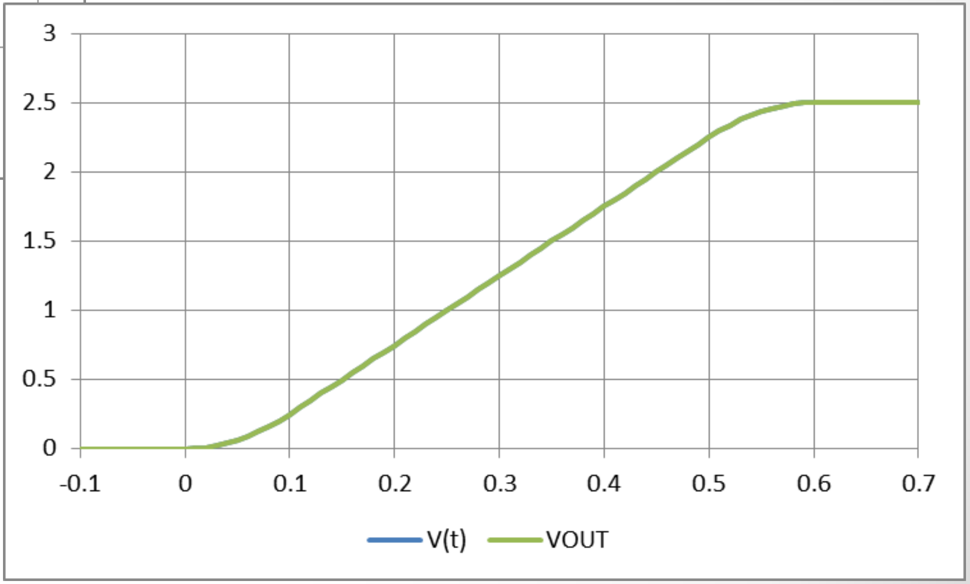
Lpkg = 0 nH, Cpkg = 0.004 nF

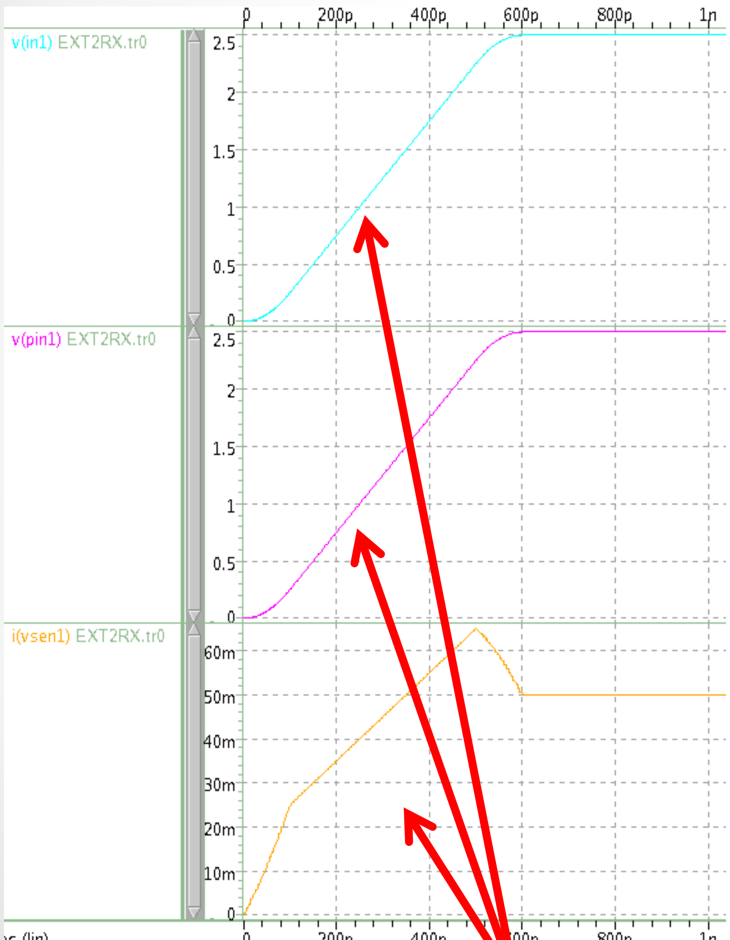


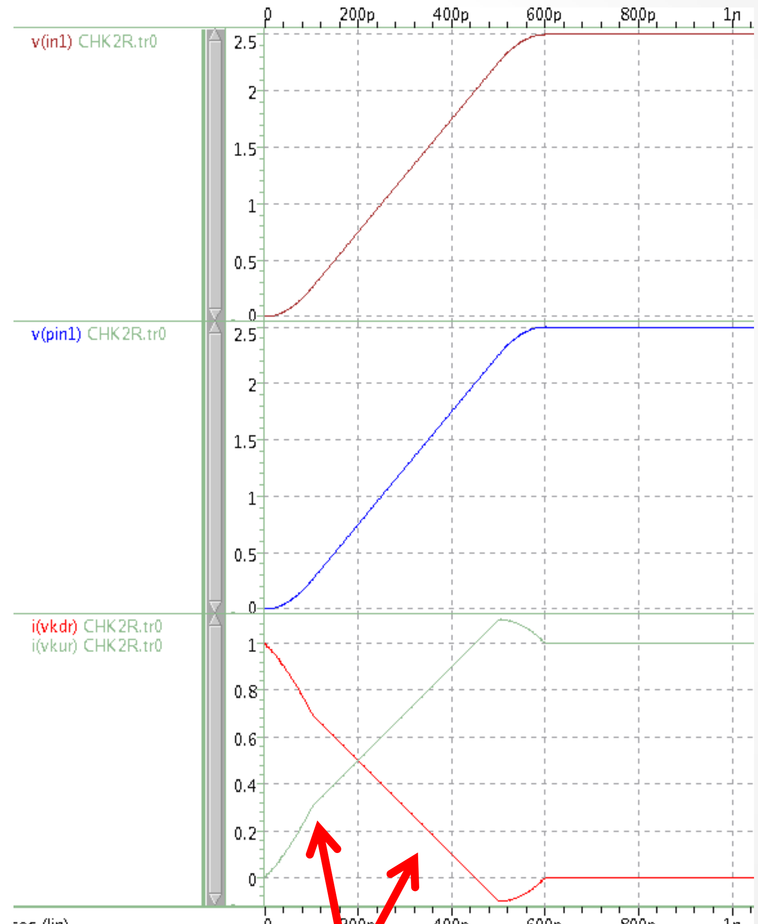
Closed-form references (50 Ω to GND)

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



Extractions using Laplace Element

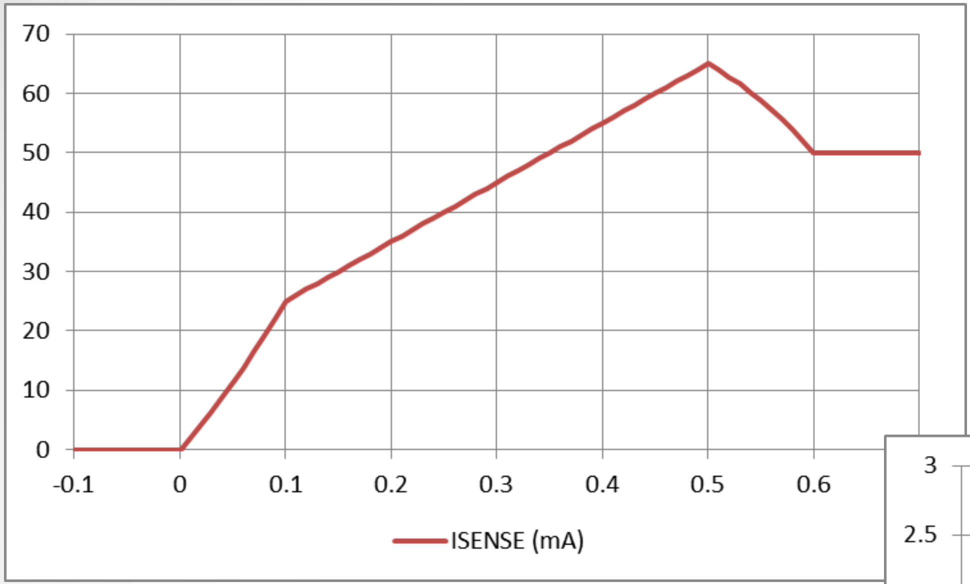




Same as closed-form references

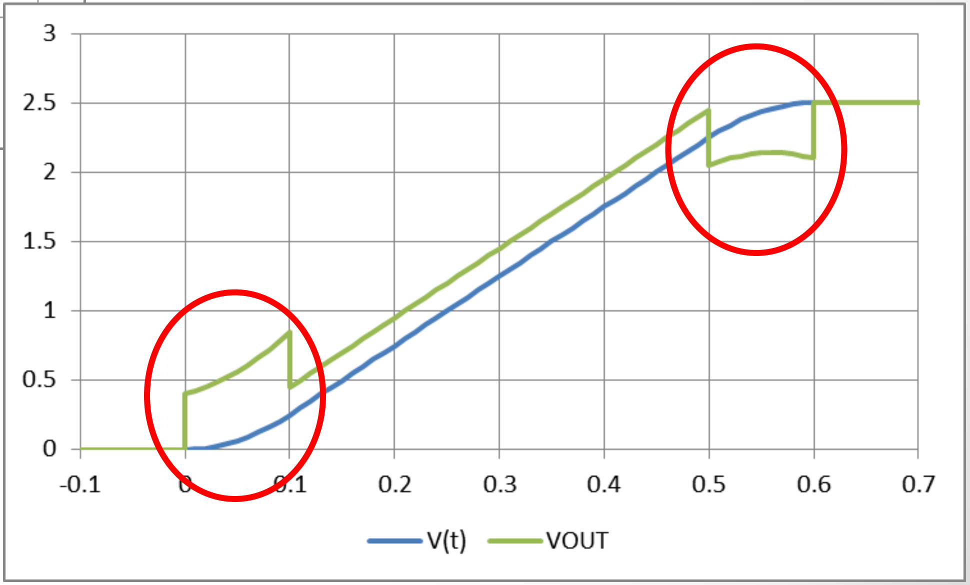
K-tables

Lpkg = 2 nH, Cpkg = 0.004 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