IC MACROMODELS FROM ON-THE-FLY TRANSIENT RESPONSES

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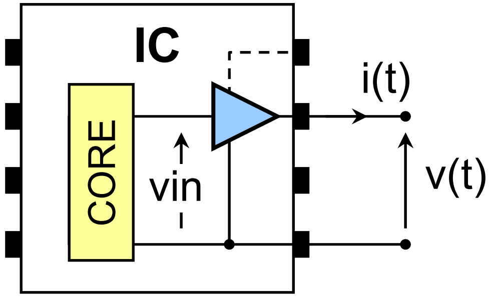
Review of IC model generation (i)

e.g., IC output buffer (single-ended)



In any approach, 2-piece model representation

$$i(t) = w_H(t)\, i_H(v,d/dt) + w_L(t) i_L(v,d/t)$$

$i_{H,L}$: submodels accounting for buffer behavior @ fixed logic H and L state
$w_{H,L}$: weighting signals for state switchings

→ **suitable modifications for handling power/ground pins and different device technologies**

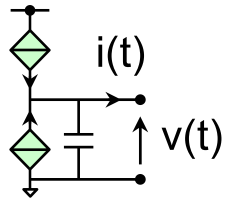
Review of IC model generation (ii)

Classification

$$i(t) = w_H(t)\, i_H(v,d/dt) + w_L(t)\, i_L(v,d/dt)$$

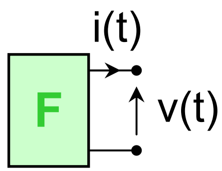
- **Equivalent circuits**

  → Input Output Buffer Information Specification, **IBIS** →



- **Nonlinear parametric relations**

  → Macromodeling via Parametric Identification of Logic Gates, **Mπlog** →



  - parametric relations approximate any nonlinear dynamic system
  - theory/tools from system identification
  - improved accuracy for recent devices
  - IBIS compliant (ver. 4.1)

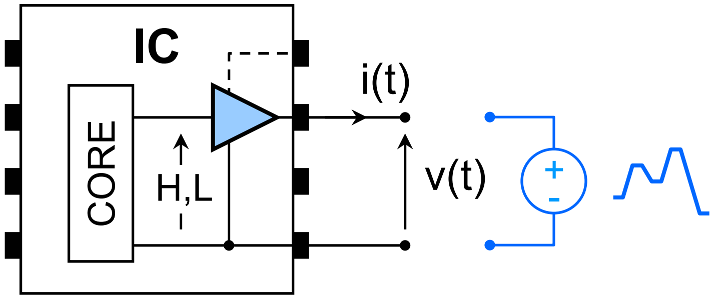
$$i(k) = F(i(k-1),\ldots,v(k), v(k-1),\ldots)$$

Mπlog modeling process (i)

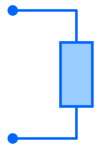
Parameter values obtained from suitable responses recorded @ device ports **by matching reference and model responses**

$$i(t) = w_H(t)\, i_H(v,d/dt) + w_L(t)\, i_L(v,d/dt)$$

- for $i_{H,L}$: transient responses to **suitable voltage stimuli** @ fixed state + standard algorithms



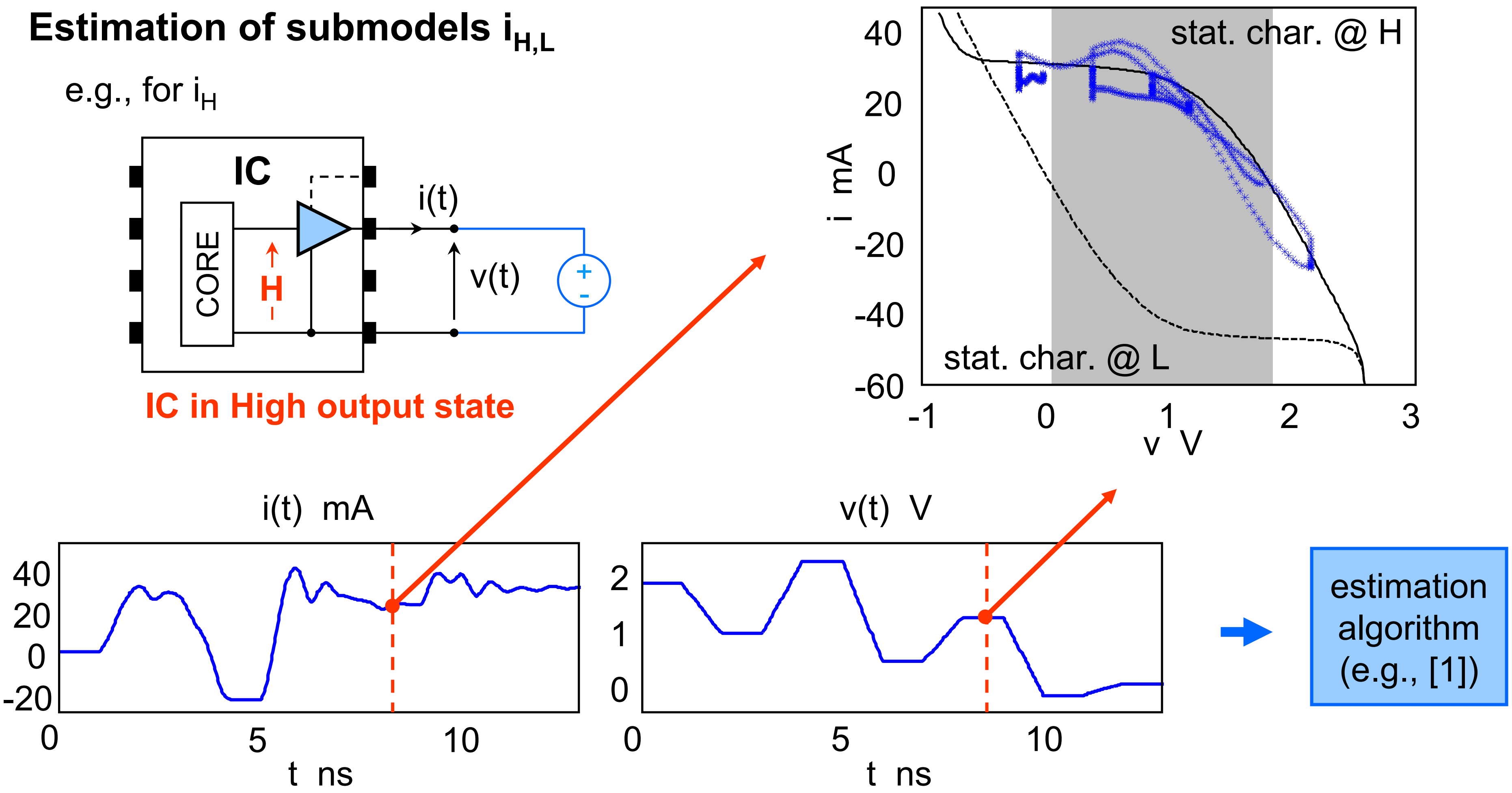
- for $w_{H,L}$: transient responses while the port is connected to reference loads and performs state transitions (e.g, 50 Ω resistor) + linear inversion of model equation



Mπlog modeling process (ii)

Estimation of submodels $i_{H,L}$

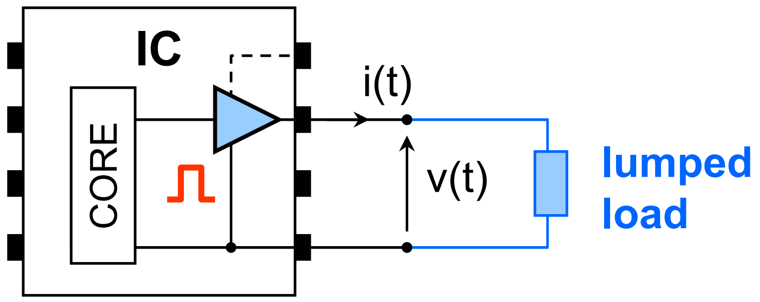
e.g., for i_H



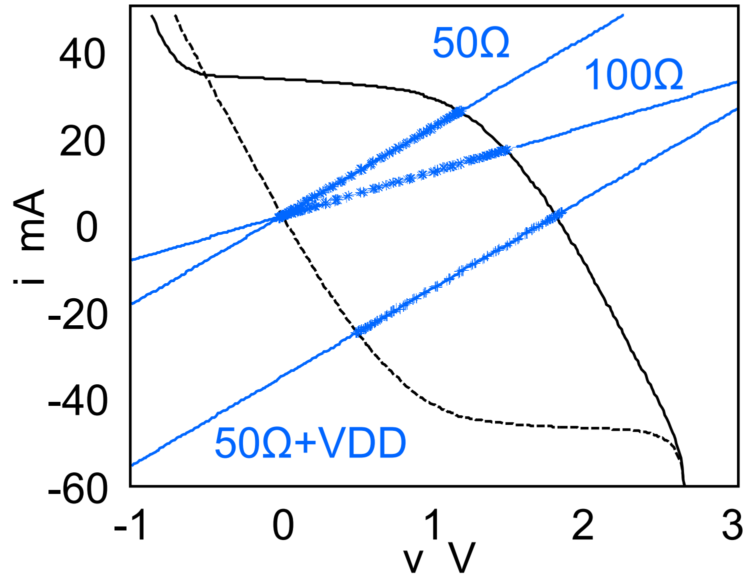
[1] M.T.Hagan et Al. “Training feedforward networks with the marquardt algorithm”, IEEE Trans. on NNs, Nov. 1994.

Mπlog modeling process (iii)

Computation of weighting signals $w_{H,L}$



IC driven to perform complete state transitions

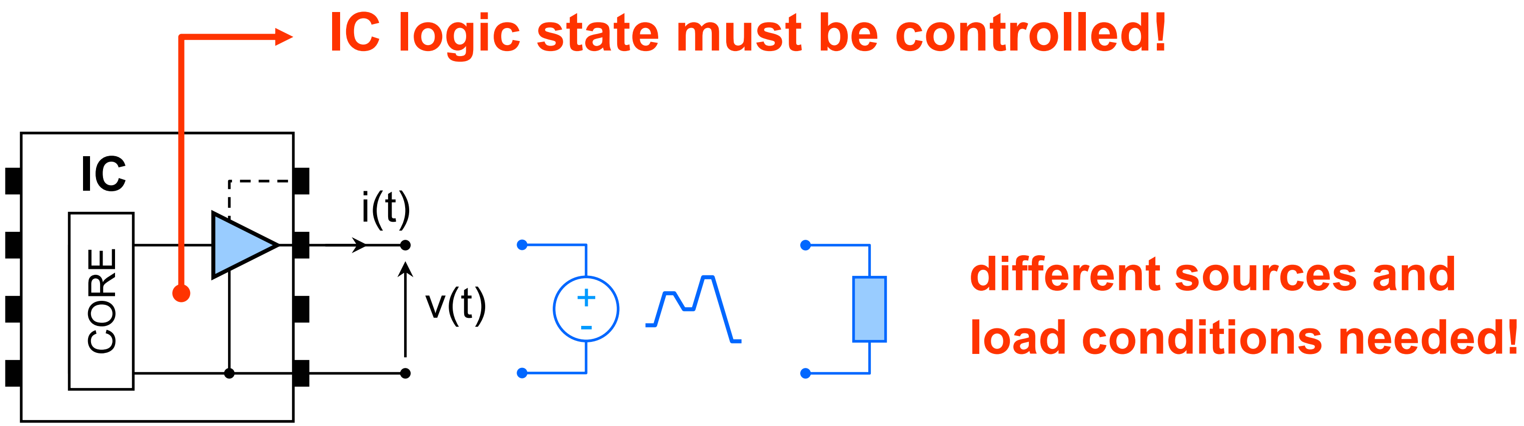


$w_{H,L}$ obtained by linear inversion of model equation

$$i(t) = w_H(t)\, i_H(v,d/dt) + w_L(t)\, i_L(v,d/dt)$$

by using 1,2,… set of responses **(solution of a standard LS problem)**

Mπlog modeling process (iv)

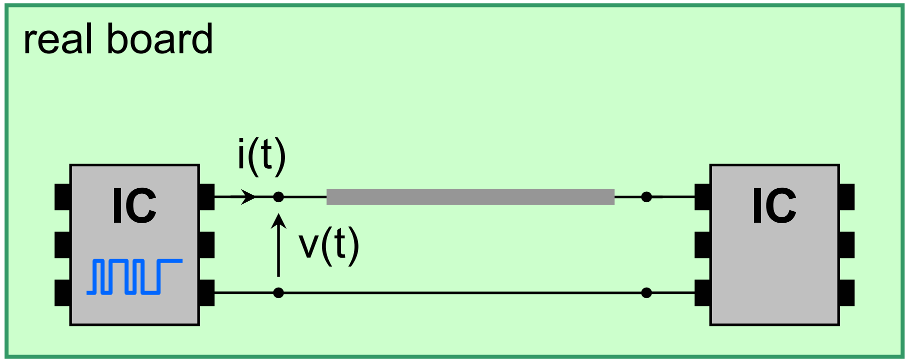


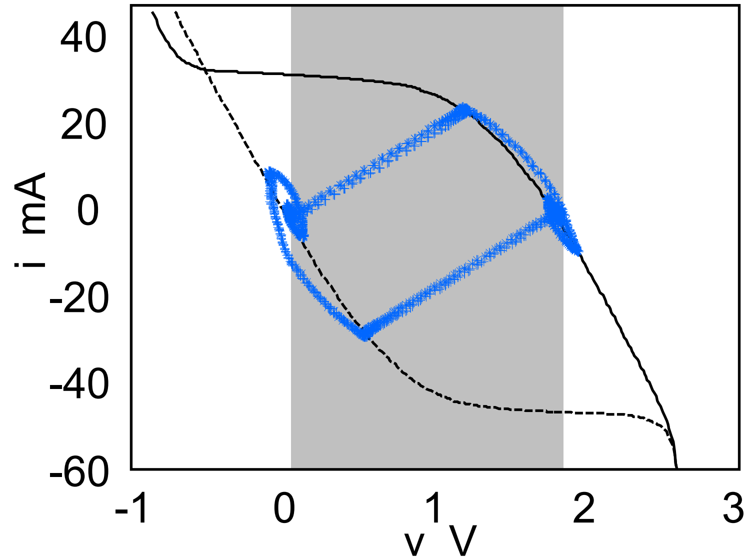
→ **CRITICAL** for model generation of complex ICs

How to obtain waveforms useful for model estimation from device **operating in normal condition**?

Mπlog models from measurements "on-the-fly" (i)

❖ **Typical structure**

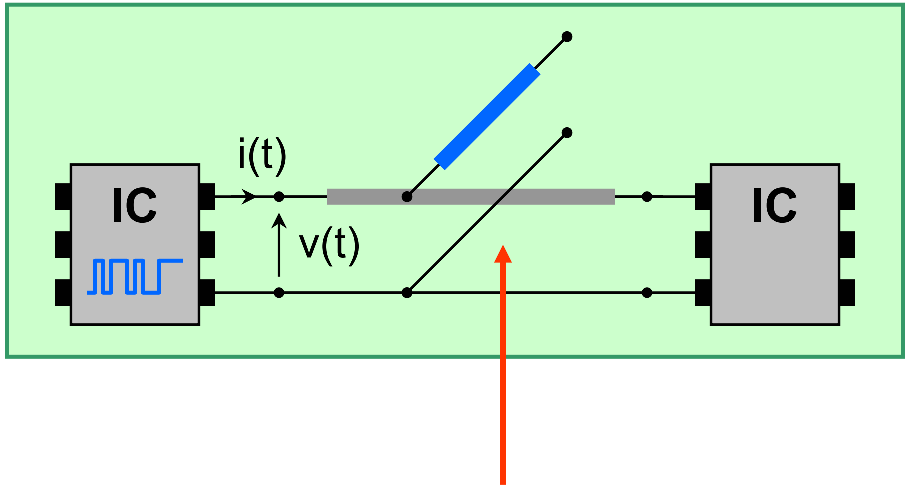


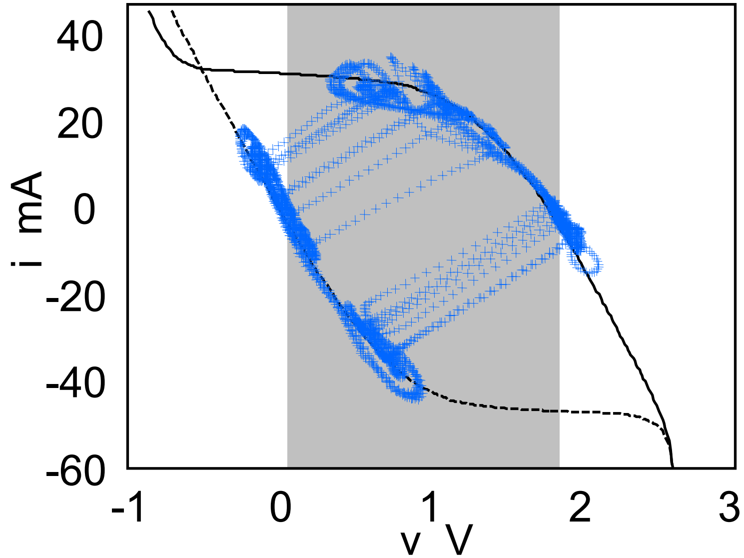


→ v(t) and i(t) have pieces of information on both state transitions and device behavior @ fixed state **(limited region explored)**

Mπlog models from measurements "on-the-fly" (ii)

❖ **Typical structure + perturbing element**





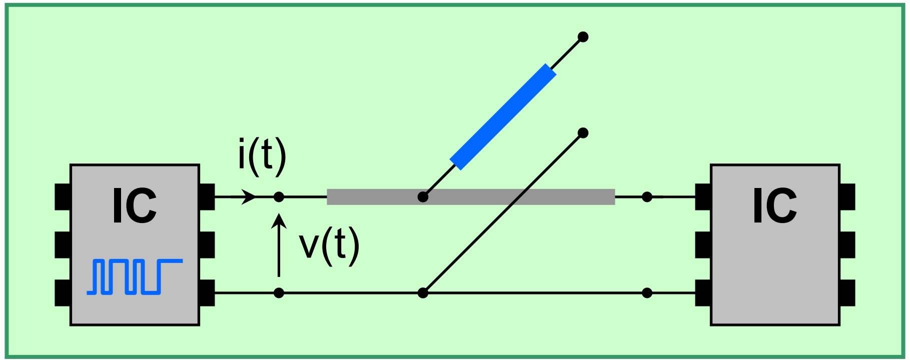
Simplest (passive) **perturbing element**: stub (time delay > 1/3÷1 bit time)

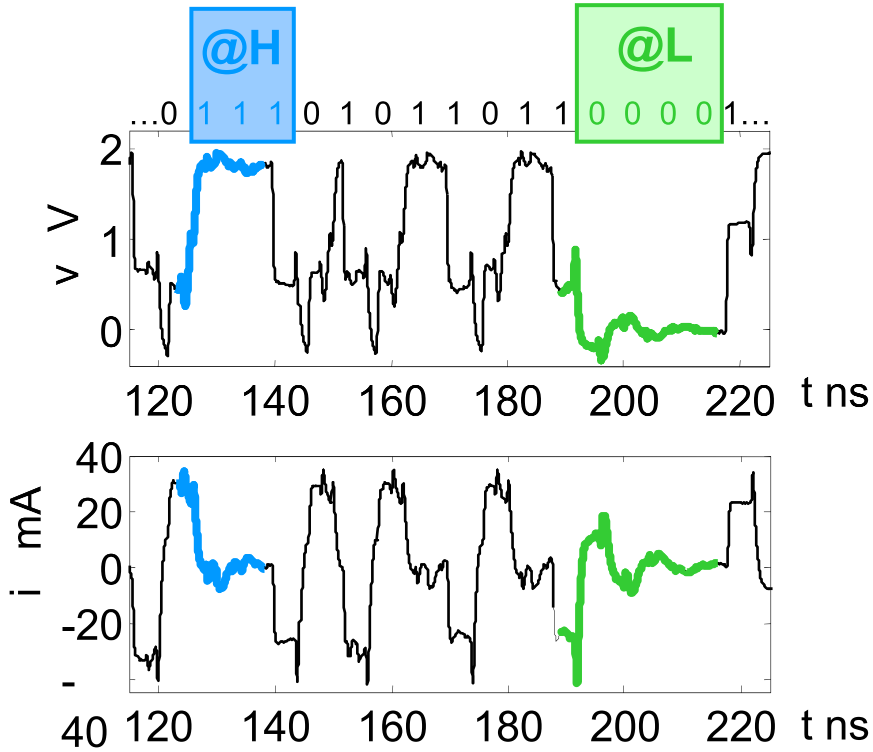
→ v(t) and i(t) explore a **more wide region** of the solution space
→ waveforms for **both estimation of submodels and of weighting signals**

Mπlog modeling process "on-the-fly" (i)

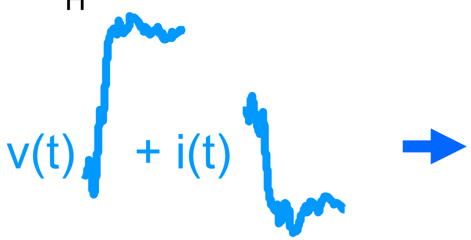
Estimation of submodels $i_{H,L}$

$$i(t) = w_H(t)\, i_H(v,d/dt) + w_L(t)\, i_L(v,d/dt)$$





e.g, for i_H

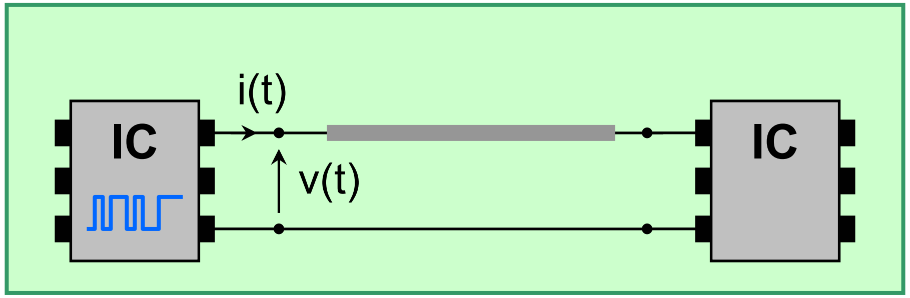


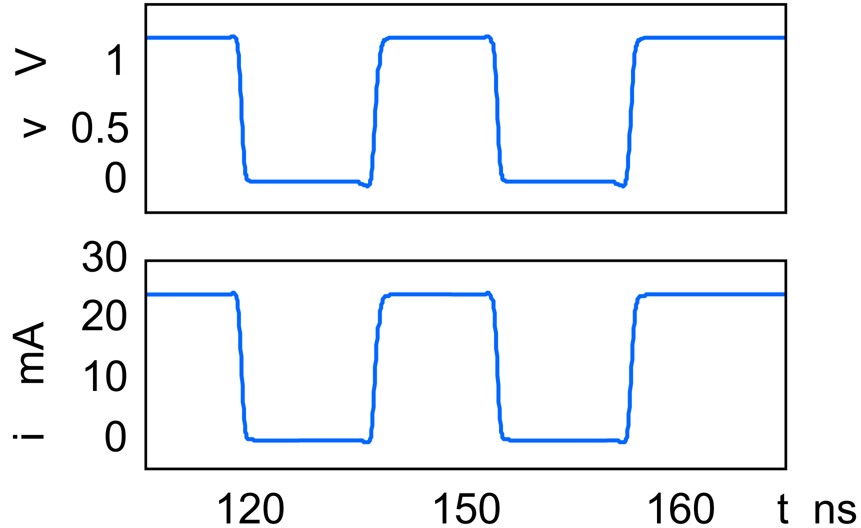
estimation algorithm (e.g., [1])

Mπlog modeling process "on-the-fly" (ii)

Computation of weighting signals $w_{H,L}$

$$i(t) = w_H(t)\, i_H(v,d/dt) + w_L(t)\, i_L(v,d/dt)$$



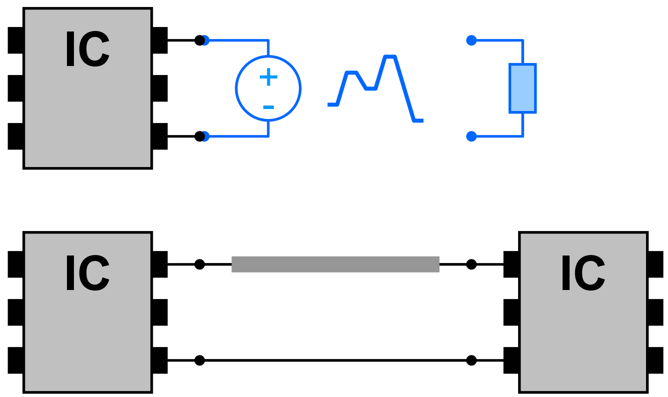


e.g, for $w_L(t) = (1-w_H(t))$

$$w_H(t) = (i(t)-i_L(v,d/dt)) / (i_H(v,d/dt)-i_L(v,d/dt))$$

Summary of Mπlog model generation

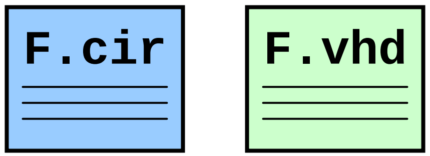
(1)
- Device is conveniently stimulated and reaction is recorded
- Device mounted directly on the board and responses are recorded



(2) Port responses feed an algorithm for the computation of model parameters

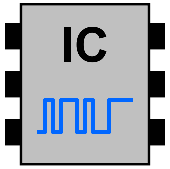
$$i(k) = F(i(k-1),\dots,v(k),v(k-1),\dots)$$

(3) Model equation F is implemented in SPICE or in metalanguages like VHDL-AMS



Modeling example

Modeled device



8-bit bus transceiver, SN74ALVCH16973,
VDD=1.8V, bit time: 6ns

Model 1: estimation using **noiseless signals**

→ responses from SPICE simulation

Model 2: estimation in a **noisy environment**

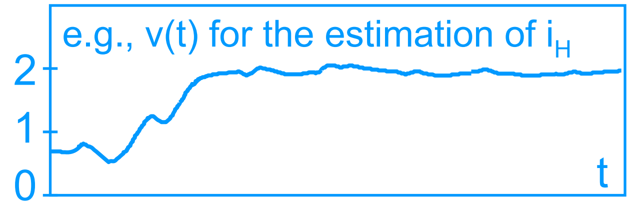
→ responses from SPICE simulation
+ superimposed noise

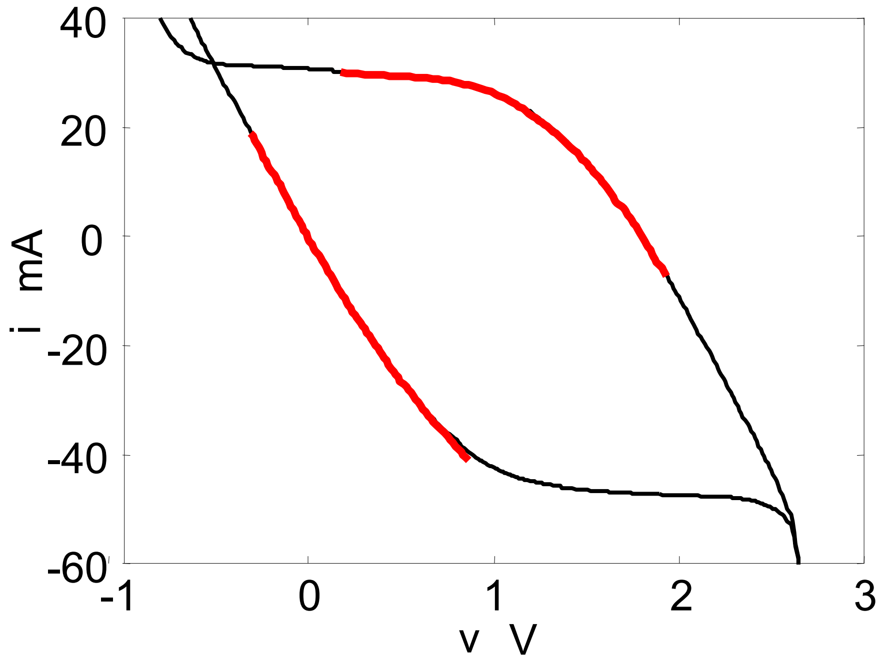
feasibility for estimation from measured data

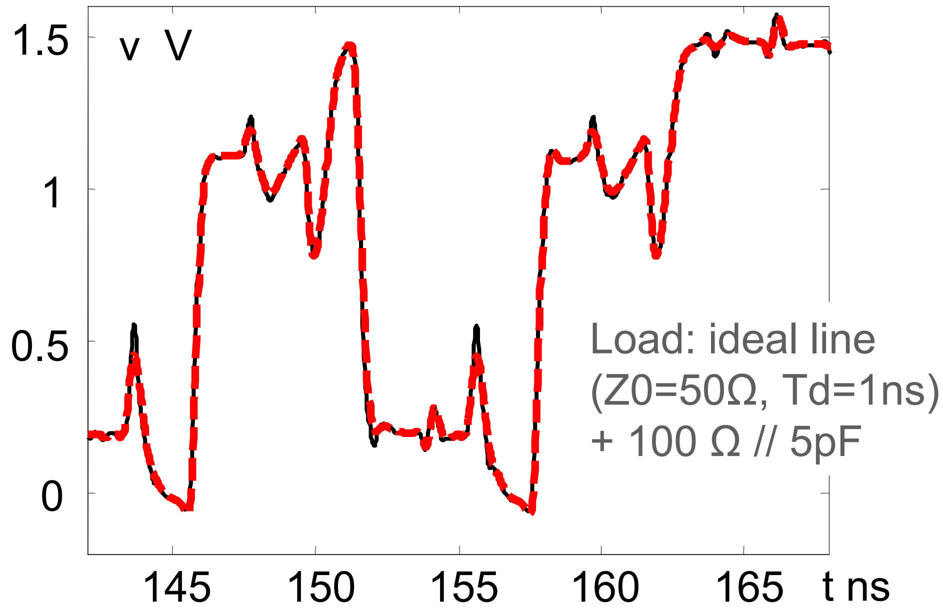
($i_{H,L}$ are sums of 2÷5 sigmoidal functions, dynamic order 2)

Model 1 validation

Model built from noiseless signals



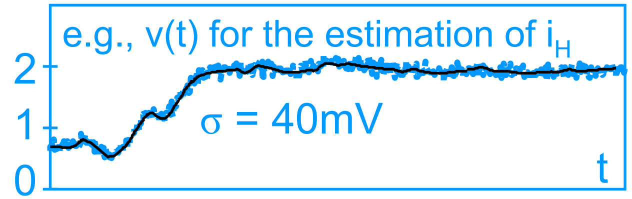


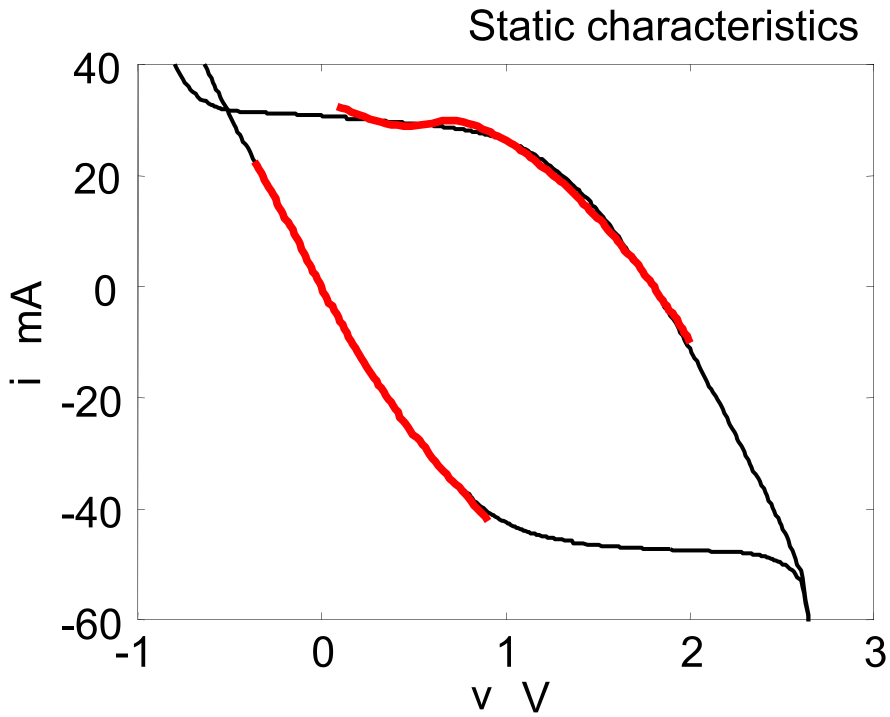


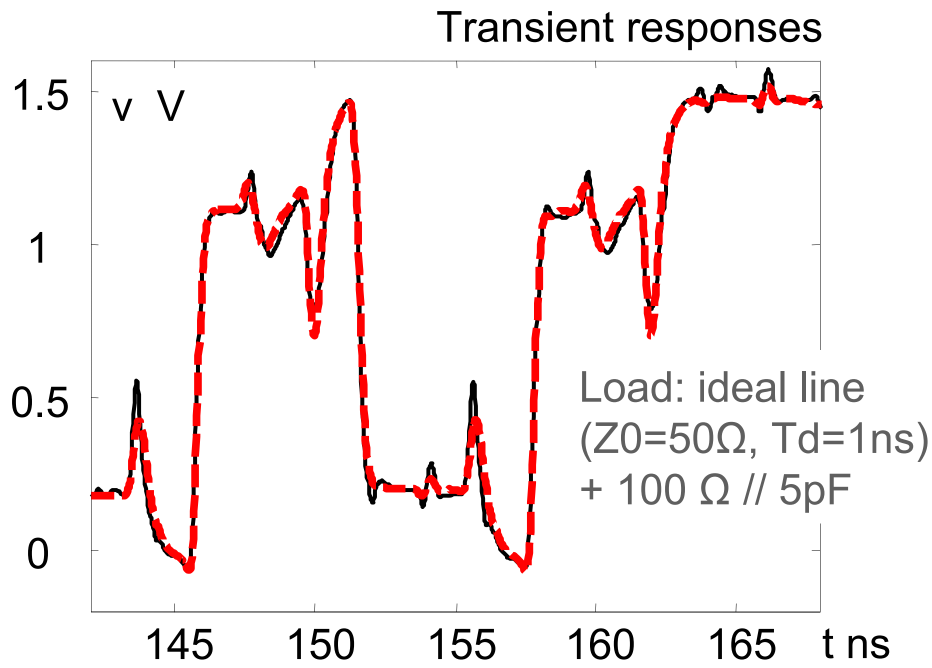
– **reference** (Hspice), – **macromodel** (Spice implementation)

Model 2 validation

Model built from noisy signals







– reference (Hspice), **– macromodel** (Spice implementation)

Conclusions

Mπlog model generation from measurements carried out "on-the-fly"

- **allows the modeling of complex ICs** from transient responses recorded during **normal IC activity**
- **does not need any control of IC logic state**
- **minimizes experimental cost** (no dedicated test fixtures)
- enables accurate estimation of device **static characteristics from transient measurements**