# Modeling of Generic Transfer Functions in SystemVerilog

Elvis Shera, Dialog Semiconductor

dialog SEMICONDUCTOR

accellera SYSTEMS INITIATIVE

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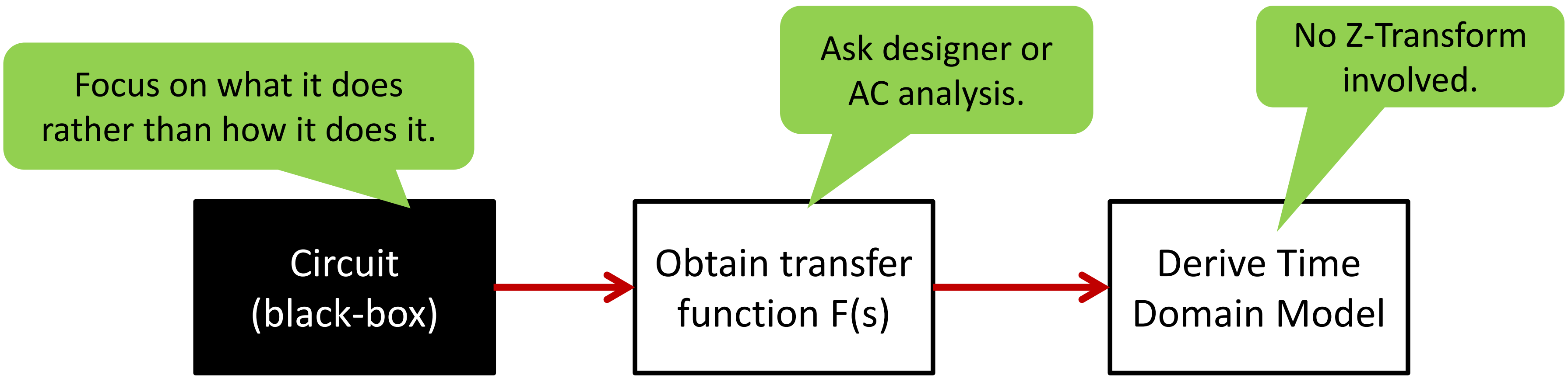
# Transfer Function Based Models in an Event-driven Simulator




- No assumption on small/large signal model. The time domain model is ok assuming that the F(s) is valid.
- Unlike a typical Z-Transform, we do not want to do sampling.

# Background & Issues

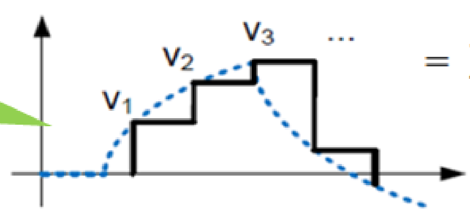
$$H(s) = \frac{Y(s)}{X(s)} = \frac{b0+b_1 s^1+....+b_m s^m}{a0+a_1 s^1+\cdots+a_n s^n}$$

$$y(t) = L^{-1}\{Y(s)\} = L^{-1}\{H(s)X(s)\} = h(t) * x(t) = \int_{-\infty}^{+\infty} h(t)x(t-\tau)d\tau$$

The tasks required can then be summarized into three main steps:

1. Inversion of H(s). — No Problem
2. Inversion of X(s). — Issue
3. Perform in the time domain, the convolution integral. — Some challenge

Digital representation of an analog signal. Discrete in time and continuous in amplitude.




Time-value pairs

$$x(t) = V_1 u(t-t_1) + (V_2 - V_1)u(t-t_2) + (V_3 - V_2)u(t-t_3) + ......$$

$$= \sum_{i=t_0}^{T} (V_{t_i} - V_{t_{i-1}})u(t-t_i) = \sum_{i=t_0}^{T} A_{t_i} u(t-t_i)$$

The unknowns are:

1. $V_i$
2. $t_i$

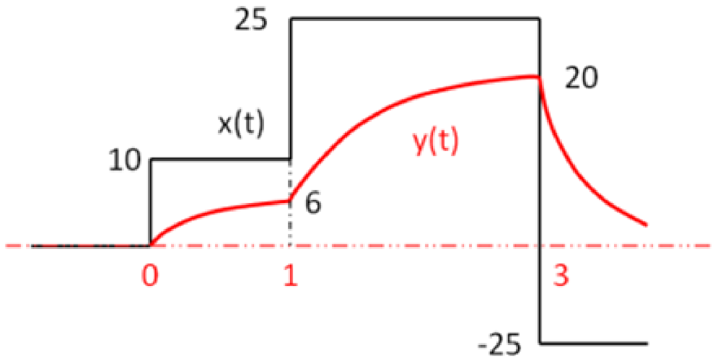
# From the Mathematics to the Simulation

$$H(s) = \frac{Y(s)}{L\{\sum_{i=t_0}^{T} A_{t_i} u(t-t_i)\}} = \frac{Y(s)}{\sum_{i=t_0}^{T} \frac{A_{t_i} e^{-st_i}}{S}}$$

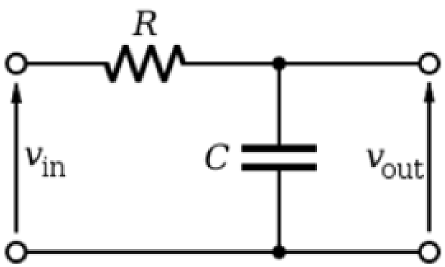
$$Y(s) = \sum_{i=t_0}^{T} \frac{A_{t_i} e^{-st_i}}{S} H(s) = \sum_{i=t_0}^{T} A_{t_i} e^{-st_i} \frac{H(s)}{s} = G(s) \sum_{i=t_0}^{T} A_{t_i} e^{-st_i} \quad \Longrightarrow \quad y(t) = L^{-1}\left\{ G(s) \sum_{i=t_0}^{T} A_{t_i} e^{-st_i} \right\}$$

During simulation time is relative. If the input changes (a new step at time $t_i$) is like starting simulation from the beginning. This time with new initial condition. This allows us to remove from consideration the factor $e^{-st_i}$ which is due to the time shift and consider only G(s) which needs to be inverted just one time.

@ interval [0-1] -> 10*g(t)*
@ interval [1-3] -> 6 + 16*g(t)*.
@ interval [3- [ -> 20 – 45*g(t)*.



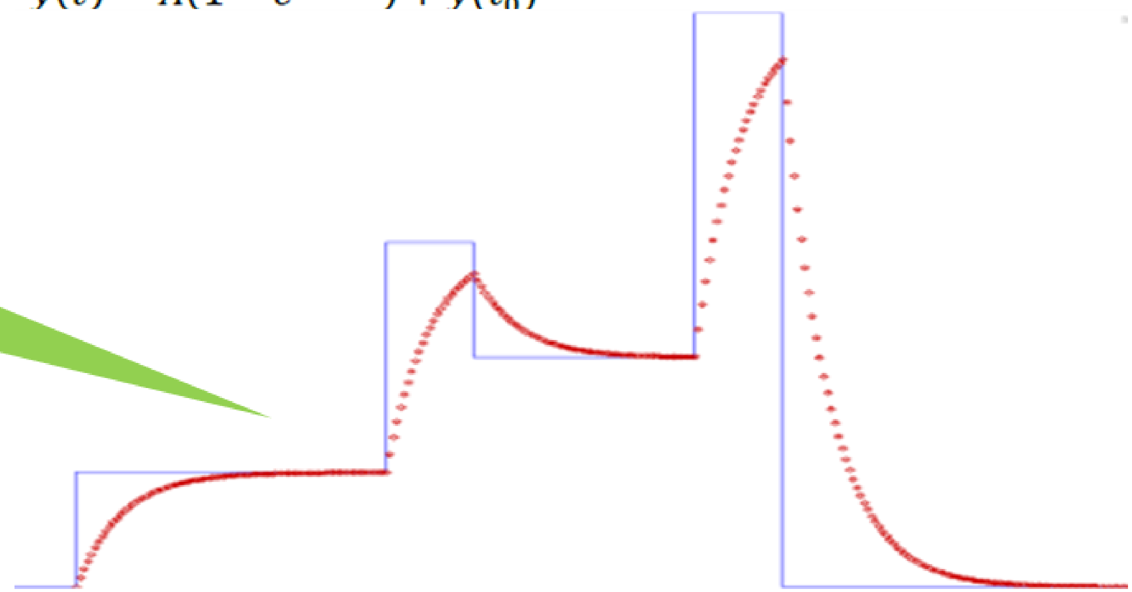
# Low Pass Filter Example




$$H(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{1}{s + 1/RC} \rightarrow Y(s) = \frac{1}{s + 1/RC} \frac{A}{s}$$

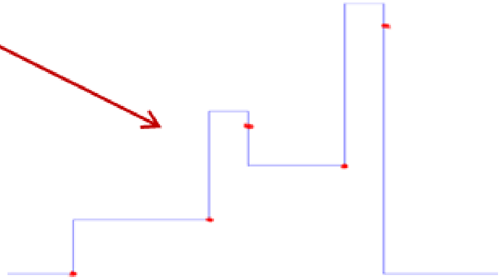
$$y(t) = A(1 - e^{-t/RC}) + y(t_0)$$

On a second input change, the model recalculates the new initial conditions and new input variation.



# Caveats

Model recalculates the output **only** when there is a change in the input and this might not be acceptable for the downstream blocks.



A timer is required to insert additional calculation points to more accurately generate the output when the input does not change, so that downstream blocks 'see' a more representative signal.

To keep the simulaion performance, a limitation on the number of additional points has been implemented.

Points per time constant.

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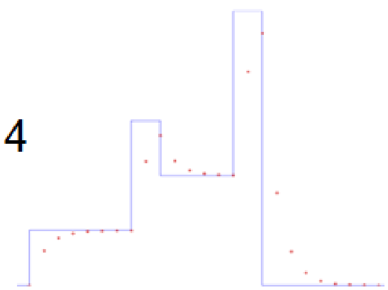

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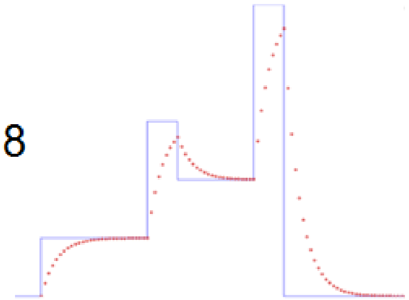

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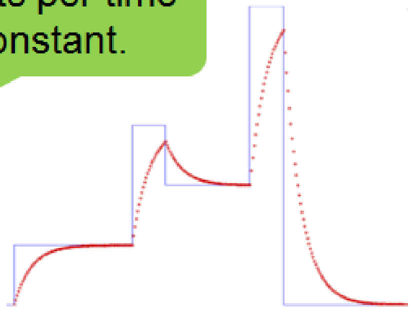
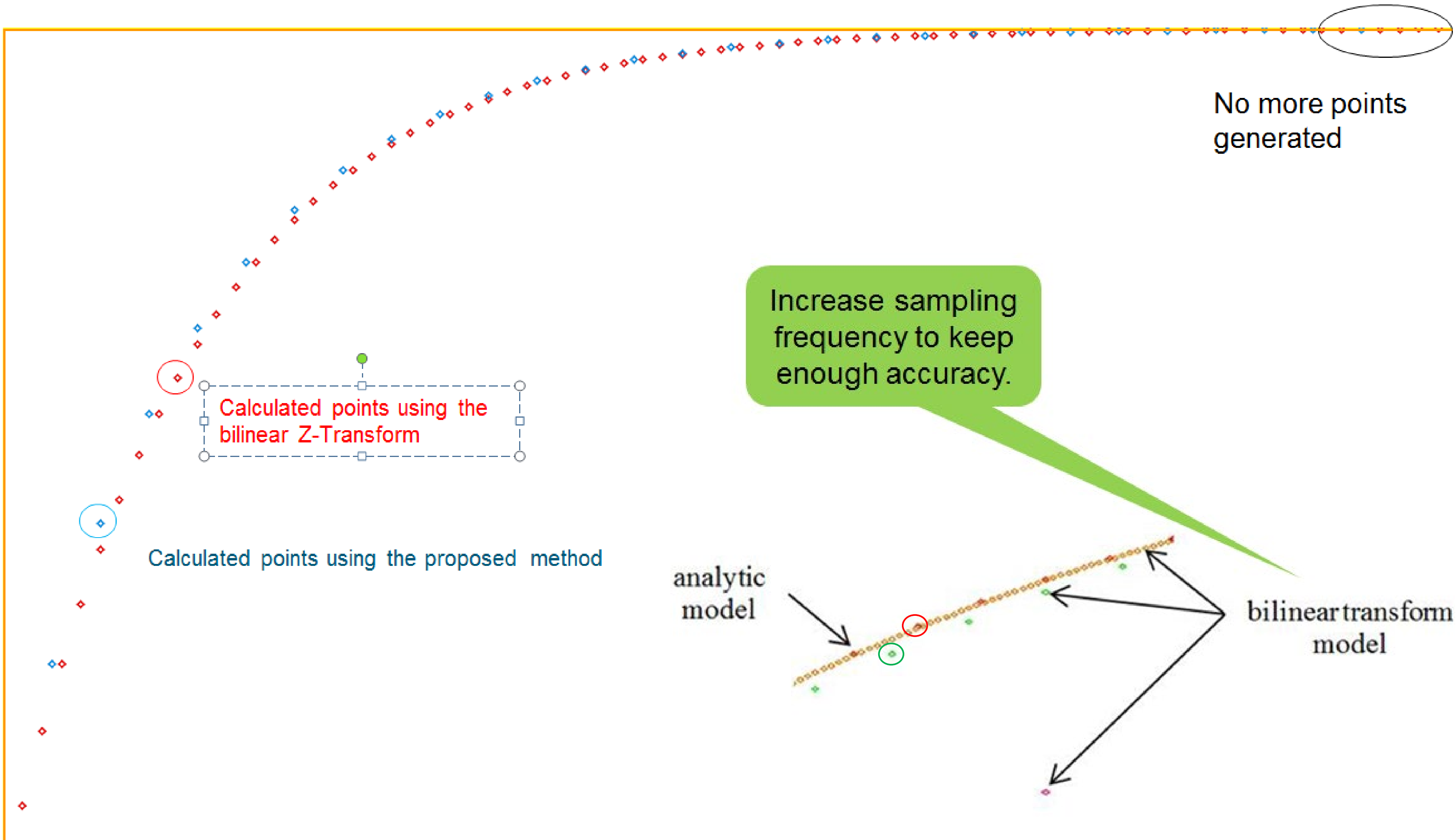


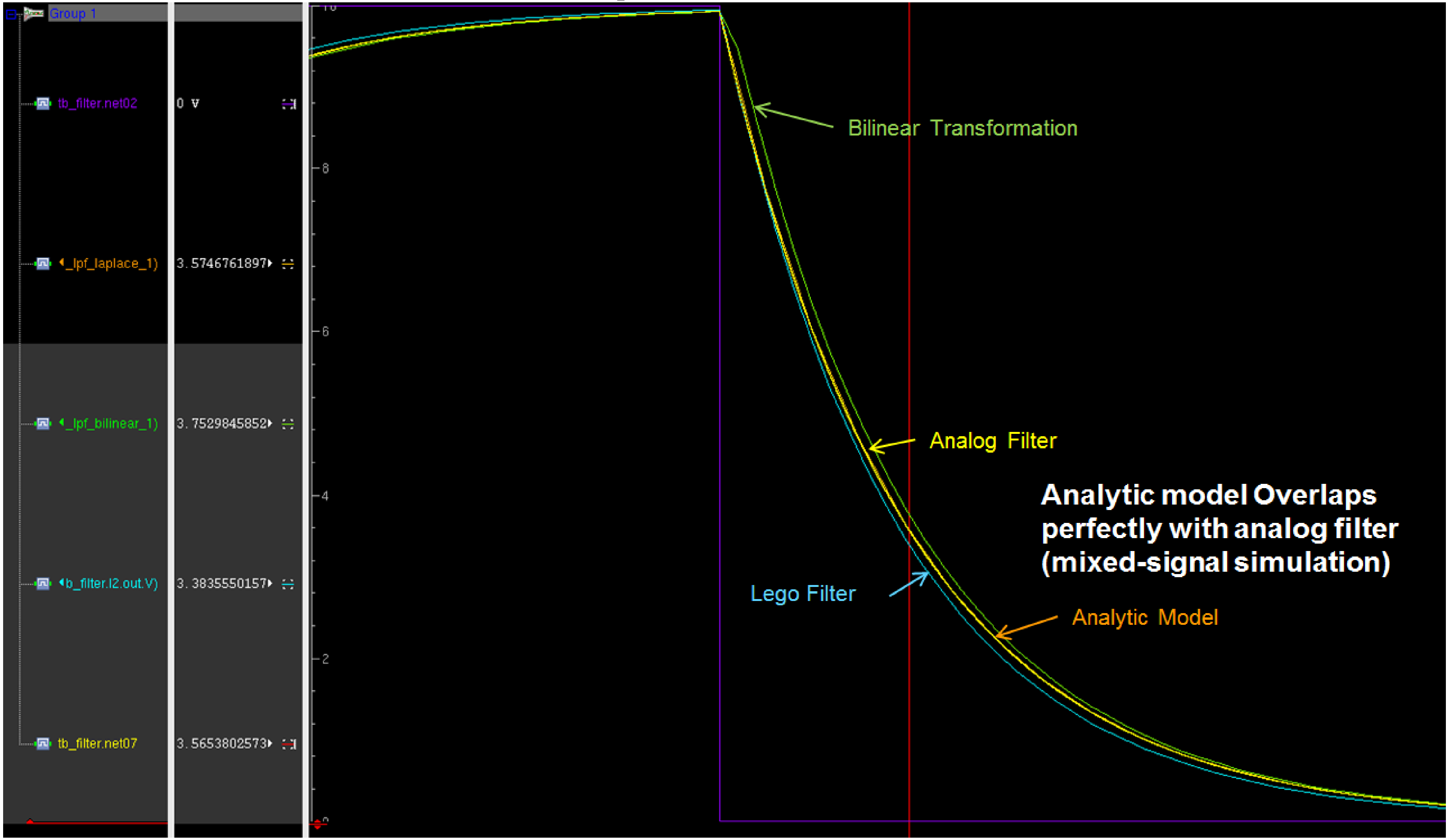
Advantages over fixed sampling techniques are:

- it generates just enough points for the output, without compromising model accuracy.
- It stops the timer if abs(output – $output_{infinte}$) < Error. Error can be a model parameter.

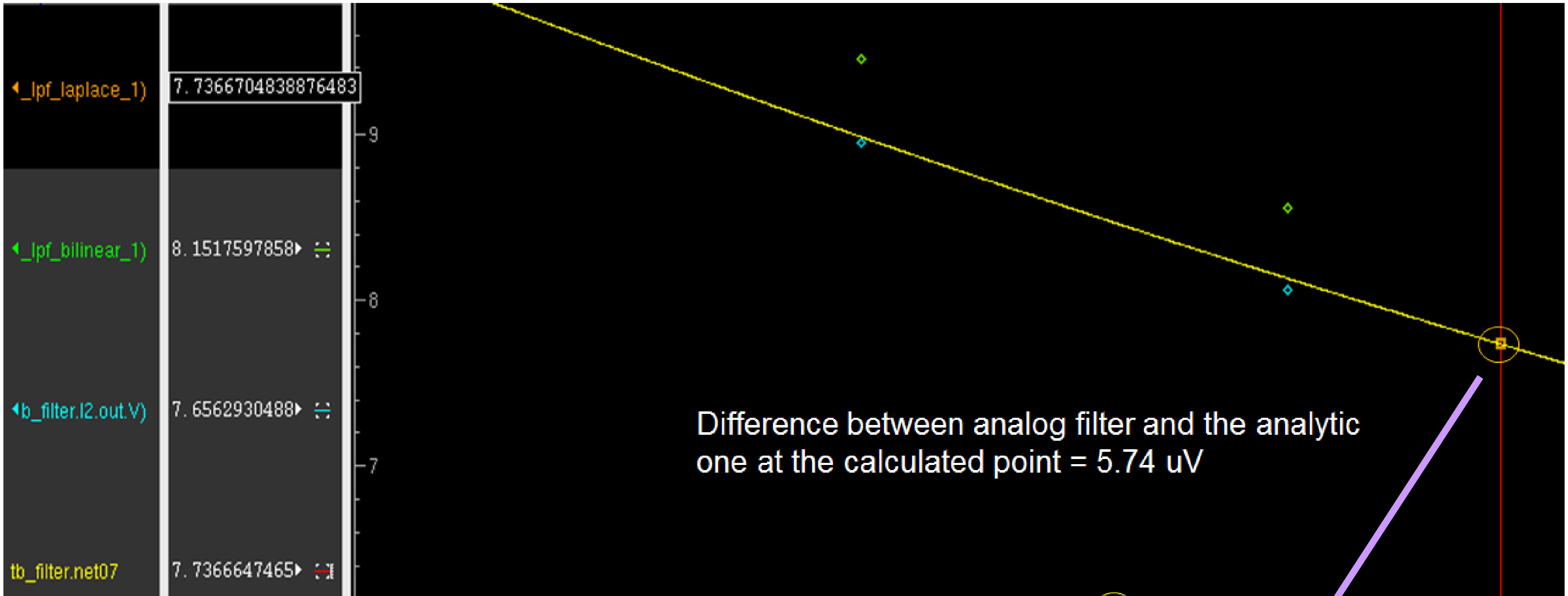
# Comparison - I



# Comparison - II

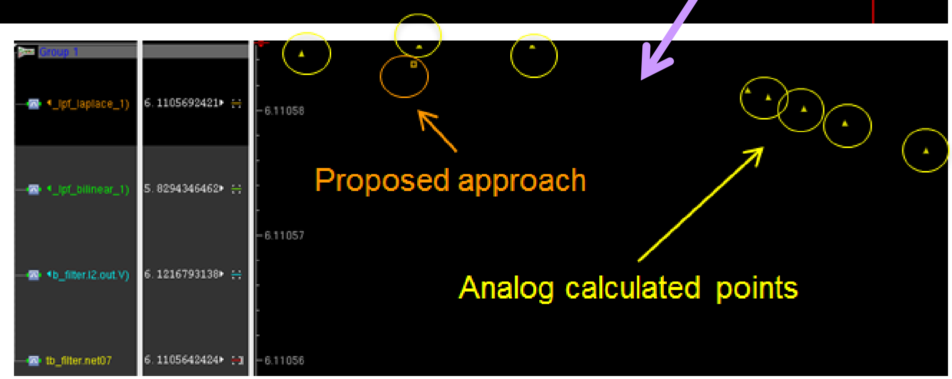


# Comparison - III




Fewer points calculated with the proposed approach.

Analog solver would still calculate points at an average of 100ps which is still high in terms of number of events.



# Conclusions

- We can model a generic transfer function with high accuracy in the event-driven simulator.

- To optimize model performances in simulation, just enough points are generated for the output in relation to the time constant of the circuit.

- In line with the modeling paradigm: Consider what it does and not how it does it.

# Questions ?