Implementation of receiver macromodel with supply port: third tests

In the following we present the last hypothesis about the implementation of a receiver macromodel with supply port.

I. Test configuration

Fig. 1 shows the test structure modeled in the TLM code. The dimensions are specified with the discretisation step *dl* = 1mm. The strip is zero-thickness and perfectly conducting, the substrate is assumed lossless. The configuration is surrounded by absorbing boundary conditions in the lateral and top directions, and a perfect electric conductor one at the substrate back.

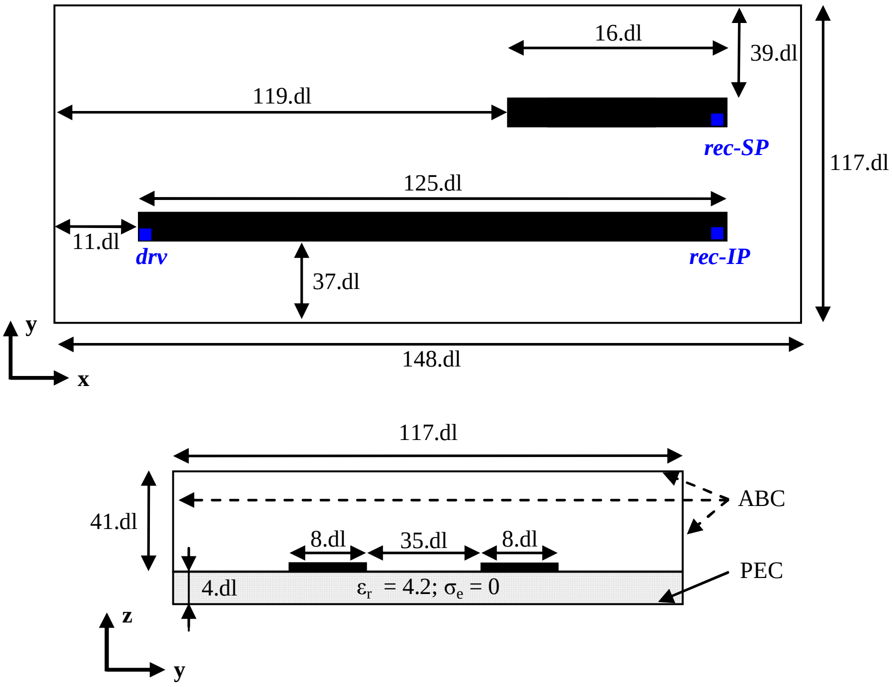

Figure 1: First test microstrip structure

The main strip is fed by the driver of a DDR (left side) distributed as specified in Fig. 2a). The load consists of the receiver input port of the same DDR (Fig. 2 b)).

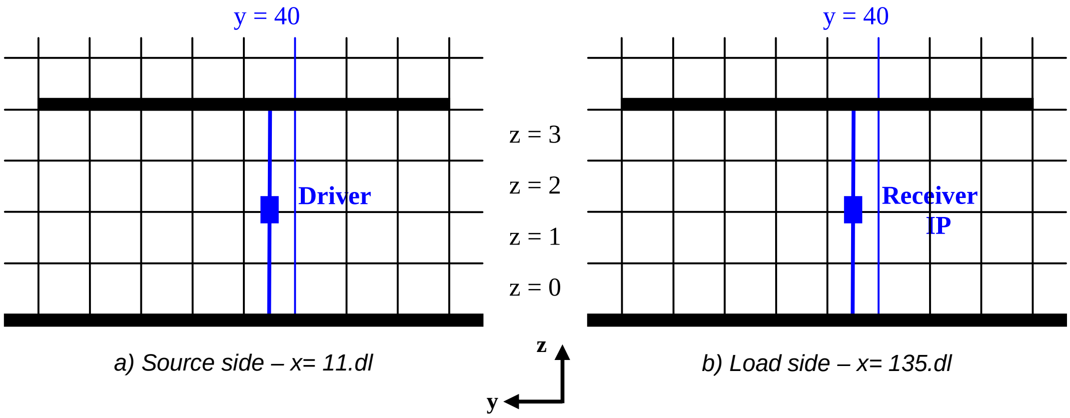

Figure 2: Distribution of the feed and load on the main strip

The supply strip is short-circuited at the place of the 1.8V constant supply (Fig. 3a)), that is directly applied under the solution search function. The track is loaded with the supply port macromodel (Fig. 3d)). All the macromodels are spread over several cells.

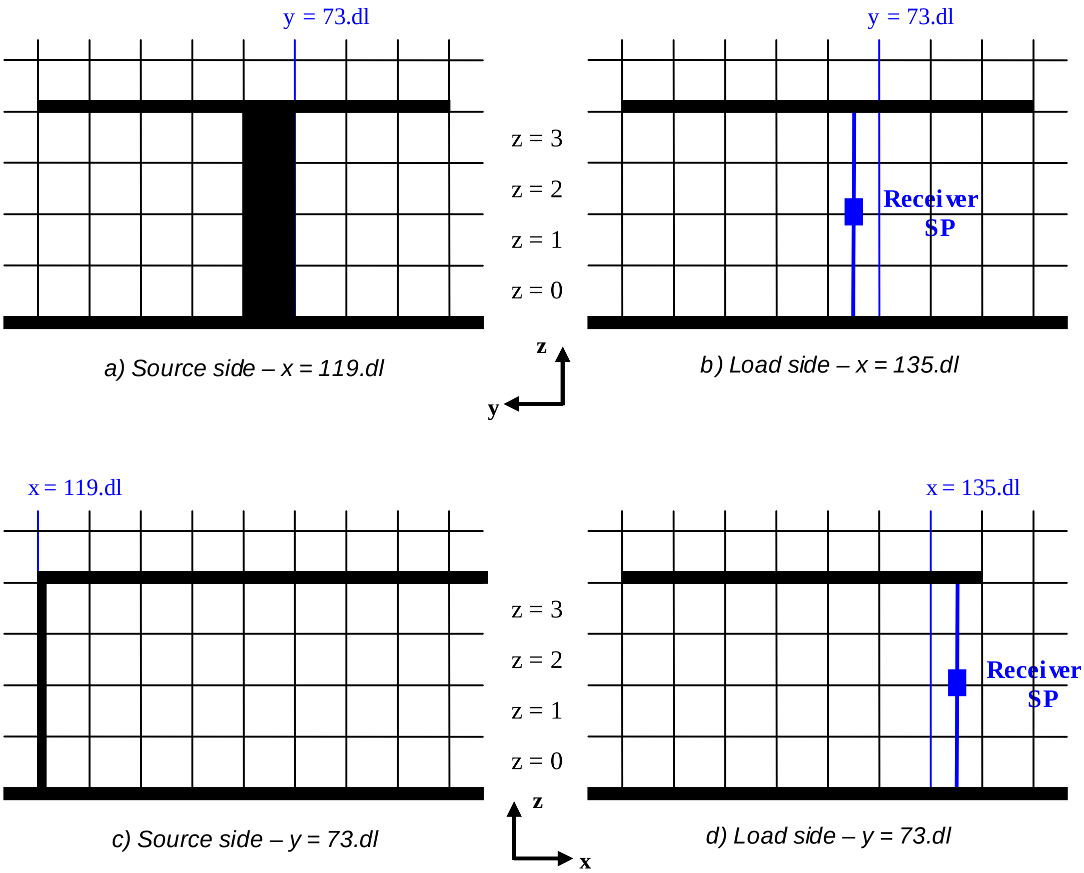

Figure 3: Supply strip

We recall that the external informations on the cell boundaries are the incident voltages $V_z^r = 2\sum_{j=8}^{11} V^j$ and the past event S_{ez}.

II. HYPOTHESIS I:

Only inject the dynamic part of the supply port in the TLM mesh.

"SearchVI" function

At the first time step (N = 0),

$$\begin{cases} V_{IP}[N] = 0 \\ \mathbf{V_{SP}[N]} = \mathbf{V_{dd}} + \mathbf{V_{SP\ dynamic}} = \mathbf{V_{dd}} \end{cases} \quad (1)$$

$$\begin{cases} I_{IP}[N] = I_{IP\ static} = f_{IP}(V_{IP}[N]) \\ \mathbf{I_{SP}[N]} = \mathbf{I_{dd}} + \mathbf{I_{SP\ dynamic}} = \mathbf{f_{SP}(V_{IP}[N])} + \mathbf{I_{SP\ dynamic}} = \mathbf{I_{dd}} \end{cases} \quad (2)$$

and the state space variables are:

$$\begin{cases} X_{IP}[N] = (I - A_{IP})^{-1} B_{IP} [V_{SP}[N] \quad V_{IP}[N]]^{T} \\ X_{SP}[N] = (I - A_{SP})^{-1} B_{SP} [V_{SP}[N] \quad V_{IP}[N]]^{T} \end{cases} \quad (3)$$

where V_{dd} and I_{dd} are the dc components of the supply port, and $V_{sp\ dynamic}$ and $I_{sp\ dynamic}$ the perturbations.

Then at the next time steps, call of the "SecantMethodSP" function.

"SecantMethodSP" function

It consists in solving simultaneously the following equation set with the multivariate secant method:

$$\begin{cases} \sum_{k=1}^{m} \left(2\sum_{j=8}^{11} V_{jk}^{i} + z^{-1} S_{ez\,k} \right)_{IP} - \left(V_{IP}/T_{e0} + m\,\eta_0\, I_{IP} \right) < 1.10^{-10} \\ \sum_{k=1}^{m} \left(2\sum_{j=8}^{11} V_{jk}^{i} + z^{-1} S_{ez\,k} \right)_{SP} - \left(V_{SP}/T_{e0} + m\,\eta_0\, I_{SP} \right) < 1.10^{-10} \end{cases} \quad (4)$$

either, with developed V_{SP} (1) and I_{SP} (2):

$$\begin{cases} \sum_{k=1}^{m} \left(2\sum_{j=8}^{11} V_{jk}^{i} + z^{-1} S_{ez\,k} \right)_{IP} - \left(V_{IP}/T_{e0} + m\,\eta_0\, I_{IP} \right) < 1.10^{-10} \\ \sum_{k=1}^{m} \left(2\sum_{j=8}^{11} V_{jk}^{i} + z^{-1} S_{ez\,k} \right)_{SP} - \left(\left(V_{dd} + V_{SP\ dynamic} \right)/T_{e0} + m\,\eta_0 \left(I_{dd} + I_{SP\ dynamic} \right) \right) < 1.10^{-10} \end{cases} \quad (5)$$

where *m* is the cell number on which the macromodels spread.

According to the current hypothesis, only the dynamic components (supply port) are injected within the TLM mesh. Also, the **dc components must be transparent for the network**. Consequently, we modify (4) by (6):

$$\begin{cases} \sum_{k=1}^{m}\left(2\sum_{j=8}^{11} V_{jk}^{i} + z^{-1} S_{ez\,k}\right)_{IP} - \left(V_{IP}/T_{e0} + m\,\eta_0\, I_{IP}\right) < 1.10^{-10} \\ \sum_{k=1}^{m}\left(2\sum_{j=8}^{11} V_{jk}^{i} + z^{-1} S_{ez\,k}\right)_{SP} - \left(V_{SP}/T_{e0} + m\,\eta_0\, I_{SP}\right) + \left(V_{dd}/T_{e0} + m\,\eta_0\, I_{dd}\right) < 1.10^{-10} \end{cases} \quad (6)$$

The multivariate secant method begins with the three initial points (V_{IP}; V_{SP}):

$(0; \mathbf{V_{dd}})_0$ $(0; \mathbf{V_{dd}} + \Delta V)_1$ $(\Delta V; \mathbf{V_{dd}})_2$

For each (V_{IP}; V_{SP}) couple we calculate the associated currents with:

$$\begin{cases} X_{IP}[N] = A_{IP}\, X_{IP}[N-1] + B_{IP}\left[V_{SP}[N-1] \;\; V_{IP}[N-1]\right]^{T} \\ I_{IP\,dynamic}[N] = C_{IP}\, X_{IP}[N] + D_{IP}\left[V_{SP}[N] \;\; V_{IP}[N]\right]^{T} \\ I_{IP}[N] = f_{IP}\left(V_{IP}[N]\right) + I_{IP\,dynamic}[N] \end{cases} \text{, for the IP} \quad (7)$$

$$\begin{cases} X_{SP}[N] = A_{SP}\, X_{SP}[N-1] + B_{SP}\left[V_{SP}[N-1] \;\; V_{IP}[N-1]\right]^{T} \\ I_{SP\,dynamic}[N] = C_{SP}\, X_{SP}[N] + D_{SP}\left[V_{SP}[N] \;\; V_{IP}[N]\right]^{T} \\ I_{SP}[N] = f_{SP}\left(V_{IP}[N]\right) + I_{SP\,dynamic}[N] \end{cases} \text{, for the SP} \quad (8)$$

and the solution search begins.

<u>“ScatterRegularNodeMacro” function</u>

For each cell on which the SP macromodel is spread over, the voltage at the node center and the event are:

$$\begin{cases} V_z = T_{e0}\left(2\sum_{j=8}^{11} V_j^{i} + z^{-1} S_{ez} - \eta_0\, I_{SP} + \eta_0\, I_{dd}\right) \\ S_{ez} = 2\sum_{j=8}^{11} V_j^{i} + \Gamma_{e0}\, V_z - \eta_0\, I_{SP} + \eta_0\, I_{dd} \end{cases} \quad (9)$$

and for the input port,

$$\begin{cases} V_z = T_{e0}\left(2\sum_{j=8}^{11} V_j^{i} + z^{-1} S_{ez} - \eta_0\, I_{IP}\right) \\ S_{ez} = 2\sum_{j=8}^{11} V_j^{i} + \Gamma_{e0}\, V_z - \eta_0\, I_{IP} \end{cases} \quad (10)$$

The scattered voltages have not been modified.

Fig. 4 shows the TLM voltages as well as those ones of HSPICE. (V_{SP} TLM) and (V_{SP} x=134 TLM) respectively indicate the voltage at the macromodel location and one cell before. The SP voltages are zoomed Fig. 5.
It appears that:

- good tendency of the input port of the receiver and the driver,
- the problem of early ripple observed in the supply port (conf. Fig. 4 in “Update1 IP+SP” – ripple before launching the driver voltage) has been solved,

- the HSPICE SP curve present two peaks at 1.95 and 2.17ns. They are not visible in the SP TLM curve but two trend inversions are noticed and happen around the same time. The compensation of the static current I_{dd} in the code may be the cause. The check of the DDR static curves, reported in Fig. 6, seems to confirm it. Indeed, at the difference of the IP, the SP static current varies and this variation is cancelled under our hypothesis. On the other hand, the two peaks come from that component,
- the difference between the SP TLM voltages observed in Fig. 5 let suggest the scattered information is not well done yet.

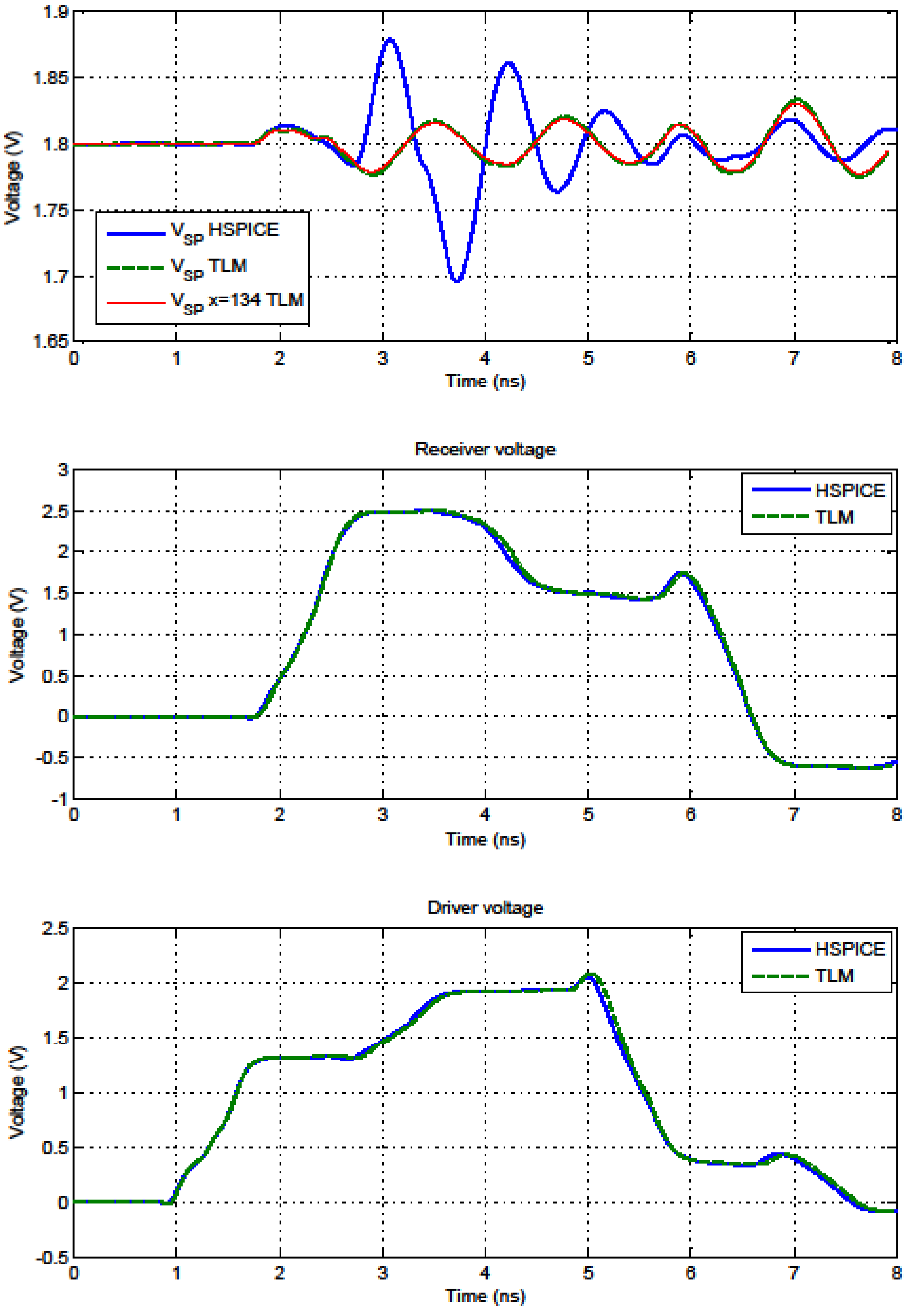

Figure 4: Driver, IP and SP receiver voltages got under hypothesis I – comparison with HSPICE

Hence, we should:

- modify the static current compensation,
- look at the scatter process.

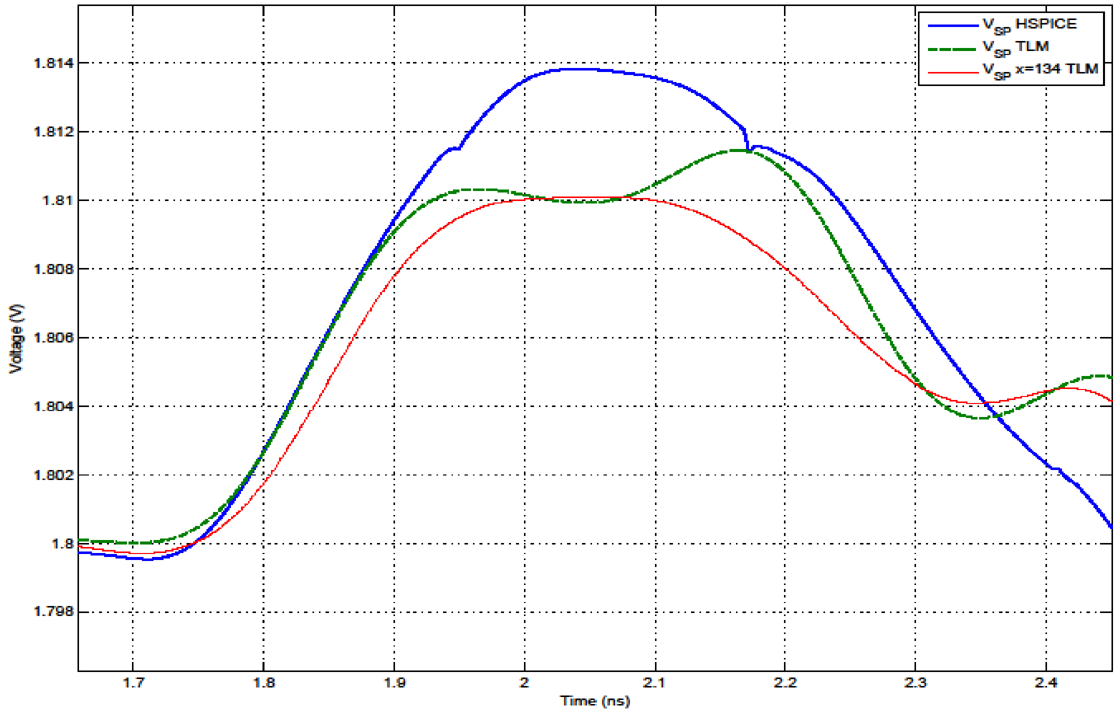

Figure 5: Zoom of the SP voltage under hypothesis I

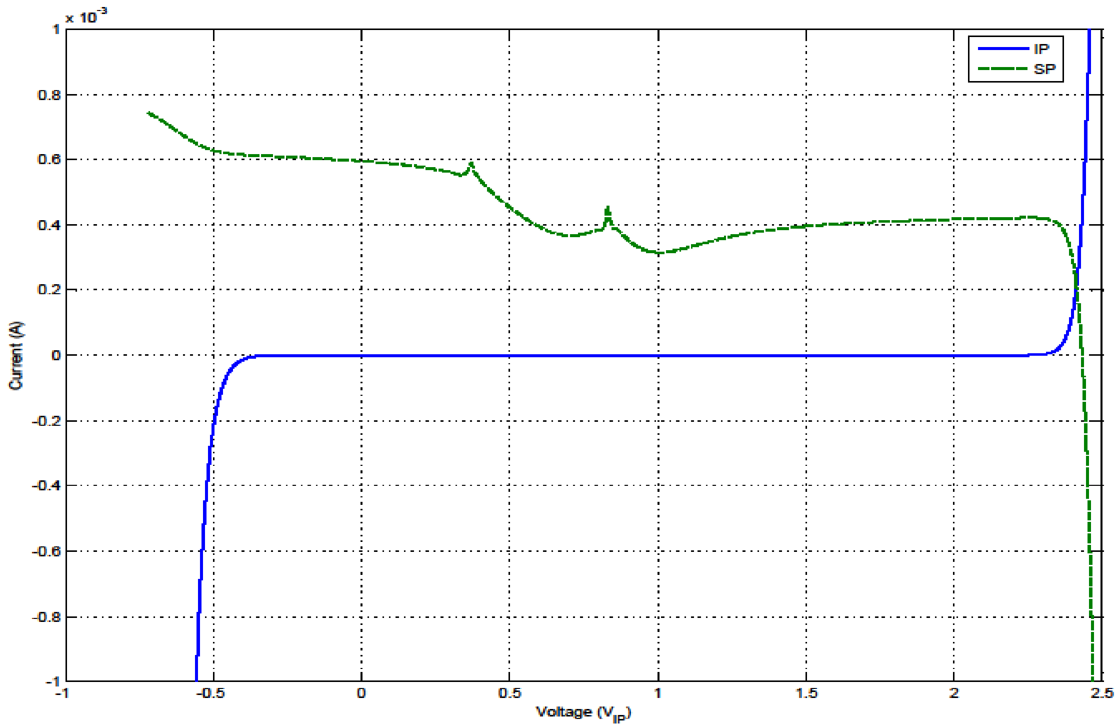

Figure 6: Static characteristics of the DDR receiver

III. HYPOTHESIS II:

We compensate partially the supply port static current.

In hypothesis I, the static component variation of the supply port $I_{dd} = f(V_{IP})$ is not seen as it is fully compensated. We now consider that the fluctuations around $I_{dd0} = f(V_{IP} = 0)$ is also sent to the TLM mesh. The equation (6), (7) are then modified by (9), (10).

$$\begin{cases} \sum_{k=1}^{m} \left(2\sum_{j=8}^{11} V_{jk}^{i} + z^{-1} S_{ezk} \right)_{IP} - \left(V_{IP} / T_{e0} + m\,\eta_0 I_{IP} \right) < 1.10^{-10} \\ \sum_{k=1}^{m} \left(2\sum_{j=8}^{11} V_{jk}^{i} + z^{-1} S_{ezk} \right)_{SP} - \left(V_{SP} / T_{e0} + m\,\eta_0 I_{SP} \right) + \left(V_{dd} / T_{e0} + m\,\eta_0 I_{dd0} \right) < 1.10^{-10} \end{cases} \quad (11)$$

$$\begin{cases} V_z = T_{e0} \left(2\sum_{j=8}^{11} V_j^{i} + z^{-1} S_{ez} - \eta_0 I_{SP} + \eta_0 I_{dd0} \right) \\ S_{ez} = 2\sum_{j=8}^{11} V_j^{i} + \Gamma_{e0} V_z - \eta_0 I_{SP} + \eta_0 I_{dd0} \end{cases} \quad (12)$$

Fig. 5 shows the TLM voltages as well as those ones of HSPICE. The SP voltages are zoomed in Fig. 6.
It appears that:

- good tendency of the input port of the receiver and the driver,
- the inversion of trend in the TLM SP voltage is not anymore noticed and the peaks are observables, the ripple magnitude are larger.

We should:

- look at the static current compensation around I_{dd0}. Indeed, $I_{dd0} > I_{SP}$ (= $I_{dd} + I_{SP\ dynamic}$) if its dynamic part is small. That entails a **driver behaviour** instead of a receiver one,
- look at the scatter process.

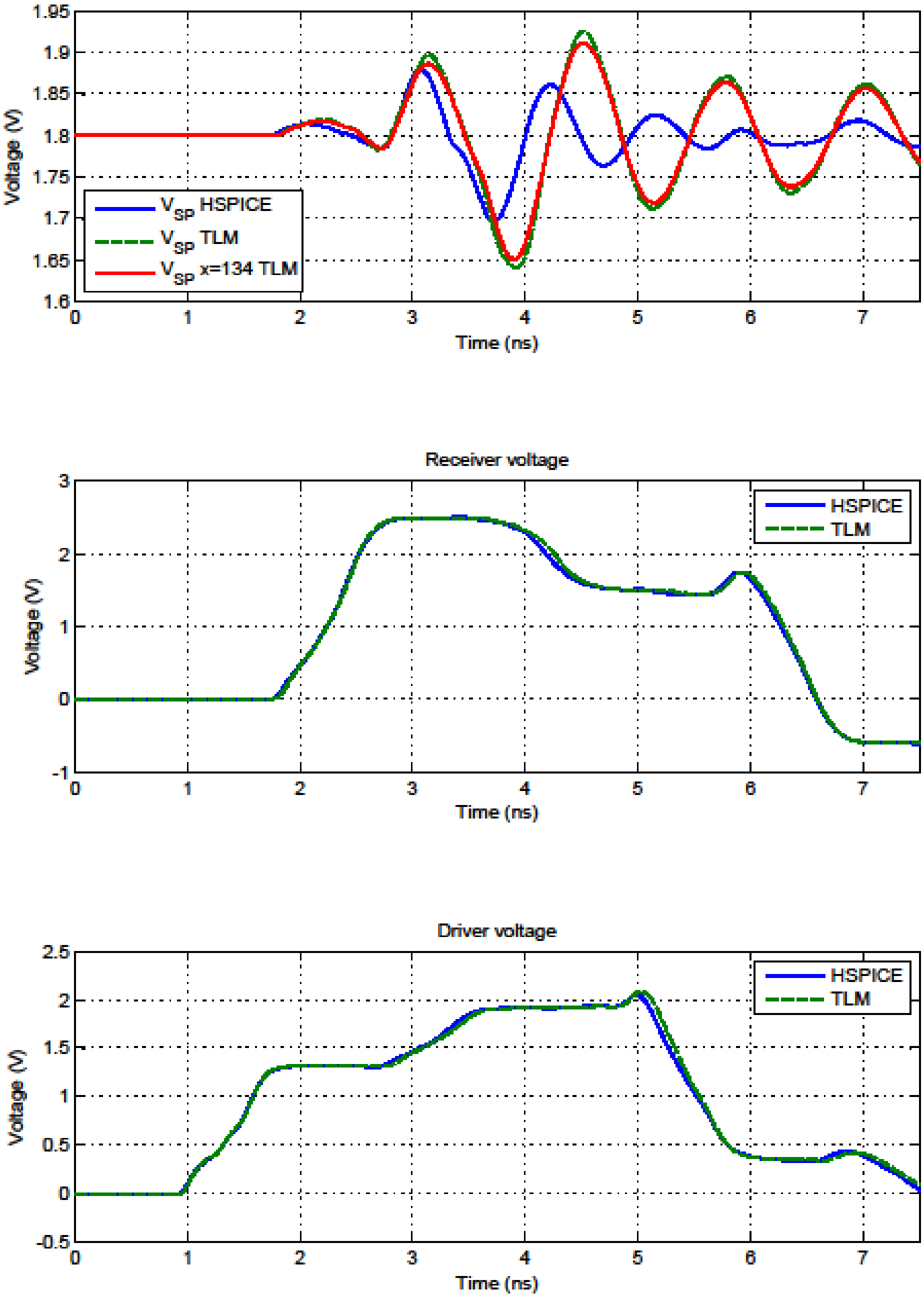

Figure 7: Driver, IP and SP receiver voltages got under hypothesis II – comparison with HSPICE

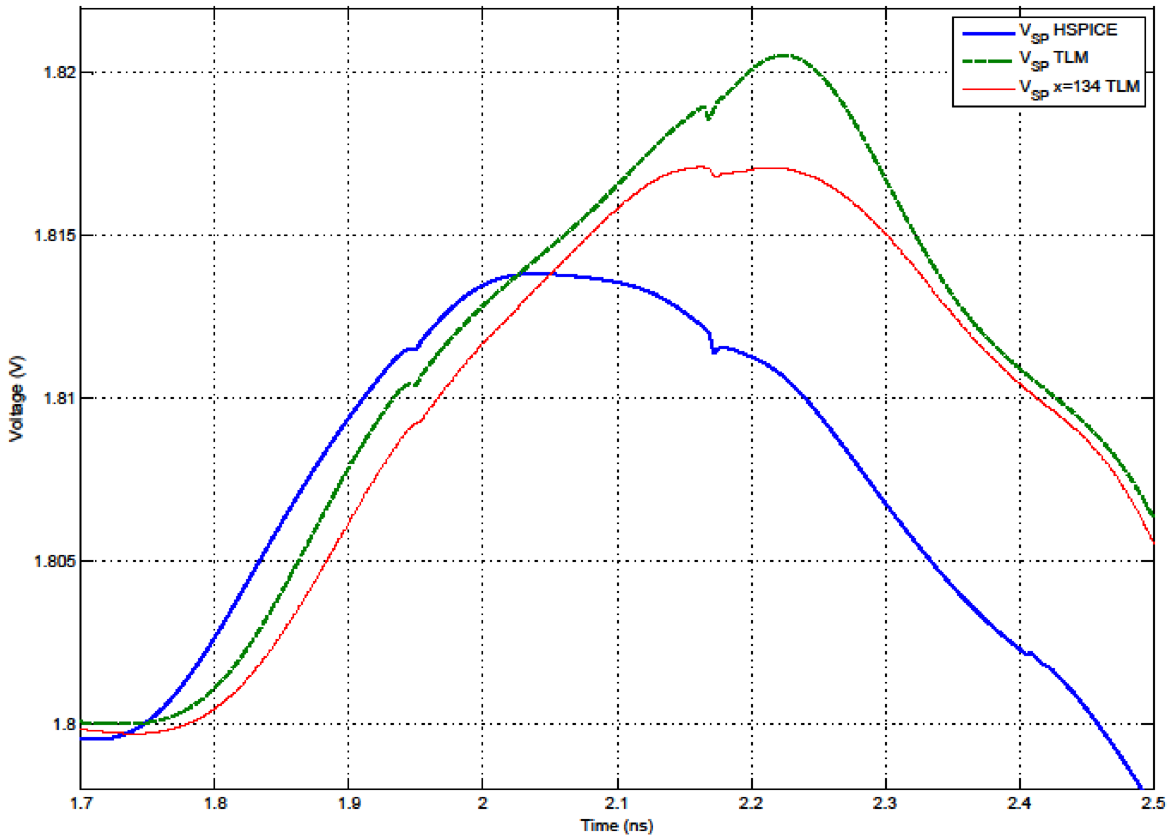

Figure 8: Zoom of the SP voltage under hypothesis II