Analysis of noise immunity at common circuits of the front end parts of high-speed transceivers

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Abstract. Method of analyzing the impact of interference (noise) from power and ground circuits on the interface part of high-speed transceivers is presented. The method is based on the construction of special macro models of the studied devices with selected nodes of interest, analysis and calculation of the parameters of these macro models in the frequency domain. The comparison of different types of drivers as part of the transmitters it has been performed and the advantages of pseudo-LVDS drivers in terms of noise immunity has been shown, confirmed by calculations in the time domain.

1. Introduction
Data collection and processing systems of different purposes (in particular, systems of physics experiments) with their performance increasing require the use of more and more high-speed components, including serial channel transceivers. In recent years, progress was achieved in the speed of transceivers located on the periphery of the system-on-chip. As the authors own experience shows [1-3], at speeds of several hundred Mb/s or higher a serious problem is the influence of high frequency noise from the connections, supplying power and ground to the corresponded busses within the crystal and the package. Such, for example, is the influence of parasitic inductances of pins and connecting wires inside the package. This influence can not be mitigated by the use of an external filter circuit on the PCB (Printed Circuit Board). In the drivers of transmitters the presence of these parasitic inductances leads to the transmission of high-frequency noise from common circuits to outputs with merely a little attenuation. That results in a blurring levels and narrowing horizontally the eye diagram for a differential output driver within the unit interval. In other words, the integrity of signals in the transmitter-receiver path is deteriorating and the number of errors in the received data is increasing.

The literature review showed that among the most commonly used criteria for the comparison of interface units of high-speed transceivers the speed, power consumption and absolute levels of processed signals (the later- to assess the compatibility with the alternative variants) dominates. As noted in the conclusion of the author’s report on the last year's conference CPPA-2015 [1], “LVDS transceivers, commonly used in on-board systems of data collection and processing, may be modified to substantially increase the transmission speed while maintaining their main advantages”. Thus, it is advisable to perform a comparison of alternative variants for studied devices with additional criterion - the noise immunity at common circuits. The severity of the problem of the effect of noise on a common substrate depends largely on the used technology. Unlike previous the influence of the parasitic elements of package and connecting wires on the DUT (device under test) immunity bound with the supply and ground lines has a universal character and can not be fully eliminated. The main purpose of this work is the analysis and comparison of noise immunity bound with the supply and ground lines of drivers with different types of interfaces.
2. Method of analysis of noise immunity

To characterize the noise immunity bound with the supply and ground lines of the DUT a specialized macro model with selected nodes of interest is proposed (figure 1). The system of macro model parameters is given in table 1.

![Figure 1. Proposed specialized macro model (with example of a driver)](image)

Table 1. The proposed system of noise immunity parameters as to common circuits.

| Input nodes | 1 | 2 | 3 | 4 | 3-4 |
|-------------|---|---|---|---|-----|
| Z_{11}      | - | K_{13} | K_{14} | K_{1,3-4} |
| Input impedance | - | TC for a single signal | TC for a single signal | TC for a differential signal |
| Z_{22}      | K_{23} | K_{24} | K_{2,3-4} |
| Output impedance | TC for a single signal | TC for a single signal | TC for a differential signal |

Note. TC – transfer coefficient.

The standard for OpAmp parameter PSRR (Power Supply Rejection Ratio) is similar to K_{1,3-4} coefficient, but in general the proposed system of parameters more fully and accurately describes the noise immunity of the DUT as to supply and ground lines. You can directly compare the parameters Z_{ii}, K_{ij} of the studied devices to choose between them in terms of noise immunity as to common circuits. In particular, due to the inductive reaction of ground and power terminals, the devices with relatively large (in absolute value) values of impedances Z_{11}, Z_{22} will have the advantage for noise immunity. The proposed parameters can be calculated and measured in the frequency domain, which often simplifies and accelerates the acquisition of informative results.

3. Compared types of drivers and the comparison results

By operating principle the various drivers can be divided into two types depending on what a reference value (voltage or current) they translate to a load (figure 2). The pseudo-LVDS driver is considered because, unlike the classical LVDS-driver, it may provide operation at a speed of several Gb/s, as the rest viewed drivers [1].

![Figure 2. Types of compared drivers.](image)
Analytical expressions for the parameters $Z_{ij}$, $K_{ij}$ of the compared drivers can be obtained, but they are mostly difficult to analyze even without taking into account the frequency dependencies. It should be only noted that in the general case these parameters include both passive and active components, associated with the switches or output resistances of transistors and their transconductances. In order to make a valid comparison of the calculated parameters of the drivers, the following conditions of equivalence have been adopted:

- identical dimensions of the transistors in the output stages (for pseudo-LVDS driver - after scaling)
- the same load impedance of 100 ohms
- identical own output resistance equal to or close to 100 ohm and achieved, if necessary, by connecting in series or parallel the matching resistors at the outputs
- technology - CMOS 0.18 micron
- output swing of 800 mV for drivers operating in the current mode, and vdd/2 for the drivers operating in the voltage mode
- identical parasitic elements (parasitic capacitances at the terminals 5 pF to ground).

The calculation results are shown in table 2.

| Driver type  | Input nodes | Output nodes | 1       | 2       | 3       | 4       | @ph=0;0,7GHz | @ph=180;0,7GHz |
|--------------|-------------|--------------|---------|---------|---------|---------|--------------|----------------|
| Pseudo-LVDS  | 1 260 Ohm   | -            | 0,49    | 0,30    | 0,19    | @ph=0;0,7GHz |
|              | 2 -         | 260 Ohm      | 0,51    | 0,70    | 0,21    | @ph=180;0,7GHz |
| nVML         | 1 4,2 kOhm  | -            | 0,01    | 0,03    | 0,02    | @ph=180;2,4GHz |
|              | 2 -         | 260 Ohm      | 0,34    | 0,81    | 0,47    | @ph=180;1,4GHz |
| CML          | 1 43 Ohm    | -            | 0,44    | 0,79    | 0,35    | @ph=180;1,3GHz |
|              | 2 -         | 43 Ohm       | 0,18    | 0,53    | 0,35    | @ph=180;0,76GHz |
| VML          | 1 213 Ohm   | -            | 0,70    | 0,23    | 0,47    | @ph=0;0,87 GHz |
|              | 2 -         | 200 Ohm      | 0,28    | 0,78    | 0,50    | @ph=180;1,3GHz |

Notes. Arrows indicate the change of single signal transmission coefficients by changing the vector of the input digital signal “vin” from {1,0} to {0,1}. For differential signal transmission coefficients the absolute value, phase in degrees and cut-off frequency are listed.

Analysis of driver circuits and the obtained for them computational results allow us to make the following conclusions:

- Comparing the circuits we find that only in the LVDS-driver the levels of both output signals are not attached to common bus potentials, that increases the noise immunity. LVDS - and VML - drivers have circuits, internally symmetric with respect to the power and ground busses (at condition of an equal contribution of the upper and lower parts of circuits built with the p- and n-channel transistors). This creates the preconditions for the suppression of interferences coming
Comparing the output impedance relative to the power and ground nodes we find that in the CML-drivers these impedances are the lowest (43 Ohms), that potentially increases the sensitivity to noise of the driver as to the common circuits because on the predominant inductive reaction of power and ground pins.

Comparison of differential transmission coefficients shows that they are minimal for the pseudo-LVDS drivers and maximum for VML-driver.

Only the pseudo-LDS drivers (and LVDS-driver at lower operating transmission speeds) provides the conditions for a significant suppression of high frequency noise from power and ground circuits. For other types of compared drivers the cut-off frequencies for differential noise transmission coefficients $K_{1,3-4}$, $K_{2,3-4}$ are noticeably greater (up to 3.5 times) than for the pseudo-LDS driver.

Complex relations on frequency of the given in table 2 absolute values and phases of impedances and transmission coefficients can affect the results of comparison of drivers at high transmission speeds.

4. Simulation results for TX-RX paths considering parasitic elements of the package

In order to check the results of comparing various drivers by the results of calculations in the frequency domain the simulating of TX-RX paths in the time domain was performed at the following conditions:

- at input - random digital 8b10b encoded signal at speeds of 1.25 or 2.5 Gbit/s
- normal process-voltage-temperature (PVT) conditions
- for CML, VML and nVML drivers there were used the same types of receivers, and for pseudo-LVDS driver – a receiver with increased power 2.5V in the input stage.
- account was taken of the typical parasitic elements of TQFP-208 package [4].

The simulated scheme and the configuration of parasitic RLC-circuit for transmitter output and receiver input terminals are shown in figure 3.

![Figure 3](image)

**Figure 3**. The simulated scheme and the configuration of parasitic RLC-circuit.

Calculations at the speed of 1.25 Gbit/s have shown that all TX-RX pairs operate successfully. But by the quality of eye diagrams of the output signals of transmitter and receiver the pseudo-LVDS driver is preferable. At a speed of 2.5 Gb/s distinction of drivers is more significant (figure 4), the pseudo-LVDS driver is, as before, at the foreground and CML-driver is the worst of the compared
drivers. This finding is consistent with the results of comparing the drivers on the basis of analyzing the parameters of their macro models in the frequency domain (part 3).

Figure 4. The eye diagrams at the transmitter and receiver outputs in the TX-RX paths, different by types of drivers as part of the transmitters.

5. Conclusion
To evaluate the noise immunity of the DUT as for the general supply and ground lines there was proposed a method, based on the construction of special macro models of these devices with selected nodes of interest, with the following an analysis and comparison of the parameters of these macro models. The proposed system includes the standard parameter PSRR, but on the whole it describes more fully and accurately the noise immunity of the devices taking into account the parasitic components.

In contrast to the widely used IBIS-models the proposed macro models is less formalized, that is suitable not only for numerical calculations, but also for the generalized comparison of alternative solutions. In addition, the parameters of such macro models can be defined in the frequency domain, that is, more simply and quickly.

Comparison of macro models parameters for four types of drivers showed an advantage of pseudo-LVDS drivers for noise immunity (except previously established [1] their advantages for power consumption). This conclusion was confirmed by simulating in the time domain the transmitter-receiver paths designed in CMOS 0.18 micron technology, considering parasitic elements of the TQFP-208 package at speeds up to 2.5 Gb/s.

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