

Simulation Methods for Signal Integrity of Automotive Bus Systems

Harald Günther^{#1}, Stephan Frei^{#2}, Thomas Wenzel^{*3}

[#]Arbeitsgebiet Bordsysteme, Technische Universität Dortmund
Friedrich-Wöhler-Weg 4, 44227 Dortmund, Germany

¹harald.guenther@tu-dortmund.de

²stephan.frei@tu-dortmund.de

^{*}TÜV Nord IFM, Elektronik & IT
Adlerstr.7, 45307 Essen, Germany

³twenzel@tuev-nord.de

Abstract— Automotive bus systems like FlexRay or CAN have to provide correct functionality for safety critical applications under various circumstances. In addition many parameters can influence signal integrity. To ensure correct behaviour under all given conditions, simulation based analyses are performed. In this article it is presented how simulation models have been developed, automated workflow and signal analysis have been implemented and parameter search methodologies have been chosen and adapted to provide tools for validation of bus system topologies.

I. INTRODUCTION

Automotive bus systems are used to connect control units or intelligent sensors and actors in vehicles. From economical point of view large cable networks are desirable. Systems are often operated close to specification limits. To operate safety critical applications under these circumstances, the functionality of the bus system must be ensured with sophisticated methods.

An approach to detect problematic behaviour and its root causes is the computational investigation of signal integrity of the physical layer of the bus system. Models for any component of a bus system have to be developed. Accuracy of models and methods has to be ensured by measurements with realistic systems.

However, many parameters at that level are not fixed, e.g. tolerances of devices, variations in the topology, external electromagnetic influences etc., so that there is a nearly unmanageable number of combinations. Validation of safe functionality becomes difficult. By simulation with parameterized models powerful search methodologies can be applied to find the most critical parameter combinations in the operation of the bus and to validate a system design this way.

Tasks and challenges in creating appropriate simulation models and to develop well suited search and optimization methodologies are presented in this article.

II. SIMULATION MODELS

For execution of complete bus system simulations models of each component of the bus systems were created and linked together. Figure 1 gives an overview of typical components of a FlexRay bus system.

Models for bus transceiver, common mode choke, termination and bus transmission line were developed.

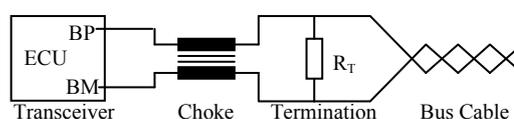


Figure 1: Typical Components of a Bus System

A. FlexRay Bus Transceiver

For signal integrity investigations the most important part of the bus transceiver model is the output driver. The model is based on a physical approach which is shown schematically in Figure 2.

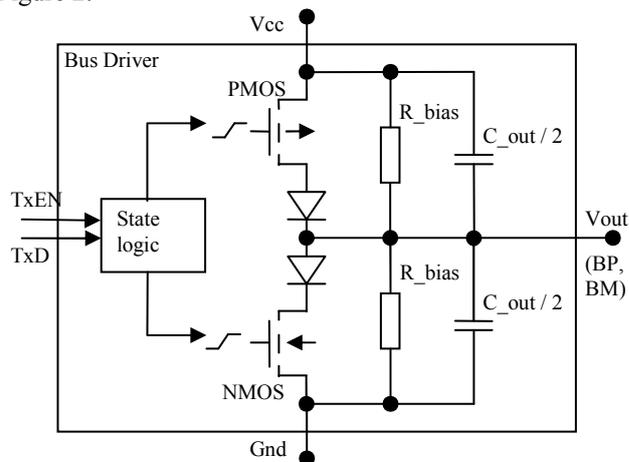


Figure 2: Schematic Structure of Output driver of FlexRay Transceiver Model

The three possible bus levels belonging to the internal transceiver states *idle*, *active low* and *active high* are realized by interconnection of two MOSFET transistors. They work as controlled switches based on the MOSFET equations and connect the bus output pin with ground or supply voltage, depending on the state of the transceiver. The adaption of the switching behaviour and of the bus levels is done with a differentiable control function and the series connection of two diodes. When *idle*, both transistors are in high impedance mode and the transceiver is ready for signal reception. An additional ohmic voltage divider is used to model the correct

impedance behaviour in this case. To ensure correct behaviour in different load conditions, capacitive effects of the transceiver device are modelled using output capacitors.

With several parameters like switching voltages of the MOSFETs and diodes and parameters of the control function it is possible to match details of signal integrity behaviour of the model with the behaviour of the real transceiver device. Datasheet information and measurement data is used for this. An advantage of this behavioural modelling approach compared to behavioural modelling approaches using measured characteristic curves ([1]) is the possibility to integrate for example temperature and supply voltage dependencies of the transceiver device into the model quite easily. By using basic physical equations the influences of several quantities can be integrated directly.

B. Further Bus System Components

To represent the bus transmission line the model presented in [2] is used.

Models for common mode chokes are provided by the suppliers to some extent. Here a model of Epcos B82789C0104H001 is used.

Terminations of bus lines are modelled with lumped resistor and capacitor elements according to [5].

C. Comparison of Simulation and Measurement Results

The models for the bus system component were verified with measurement results for each component individually. The signal integrity behaviour was validated at several load conditions. Good agreement between simulation and measurement data could be achieved.

Below the simulation results of two FlexRay bus system topologies shown in Figure 3 are presented as example and compared with measurement data. It is shown that with the help of simulation based investigation conclusions about real world behaviour of bus systems can be drawn.

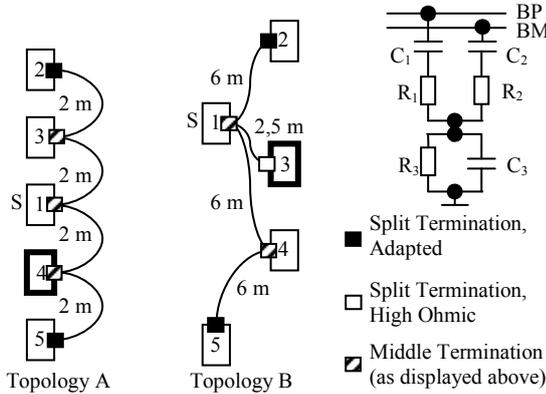


Figure 3: Structure of FlexRay Topologies

Topology A is a chain connection of 5 bus nodes connected with bus lines with a length of 2 meters each. Node 1 is sending. Figure 4 shows the comparison between simulation and measurement data at node 4.

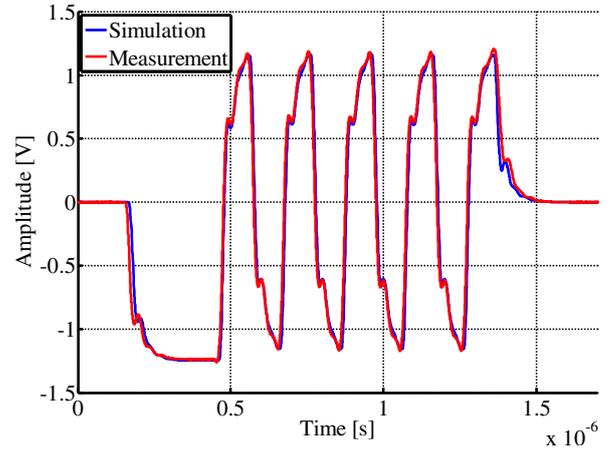


Figure 4: Simulation and Measurement Results for Topology A

The agreement between model behaviour and measurement values is very good.

Topology B also includes 5 bus nodes connected with a network containing different line lengths. Node 1 is sending data onto the bus. Figure 5 shows the signal traces of simulation and measurement at node 3.

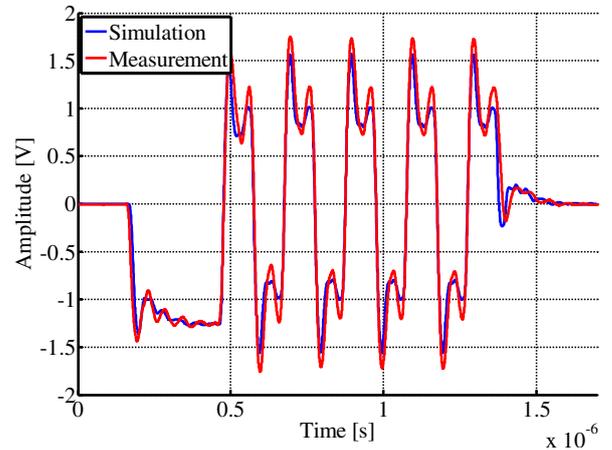


Figure 5: Simulation and Measurement Results for Topology B

Again very good agreement between simulation and measurement data can be seen.

III. AUTOMATED BUS SYSTEM ANALYSIS

To process a great number of simulation runs easily simulation flow has to be automated. The usage of parameterized models then allows automated investigation of influences of several parameters.

A. Functionality and Application Workflow

A single simulation run with subsequent signal analysis involves the following steps which have to be processed in the given order:

- Creation of complete model for bus topology under investigation
- Application of parameter value into the model
- Execution of simulation
- Analysis of results

These steps have been automated and thus enable automated analyses of different parameter values of the bus system. The workflow is shown in Figure 6 schematically.

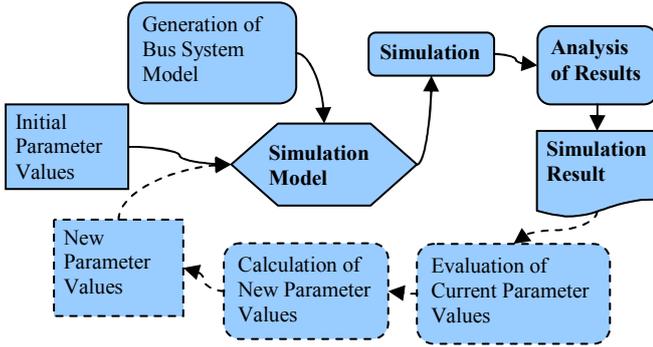


Figure 6: Workflow of Automated Simulation with Optimization

First the several bus system component models are connected to a complete bus system model according to structural information about the topology from a text file. Next, to the different parameters of each model their initial values are assigned. The bus system model which is ready for simulation now, is passed on to the simulation program, which executes the simulation and exports the results. Those are imported after successful completion for evaluation. From the results of the analysed signals an evaluation of the complete bus system topology is evolved.

For investigation of different parameter values new values are generated and the simulation process is iterated.

B. Automated Analysis with Eye Diagram

For analysis of results obtained from bus system simulation criteria are needed. In practice the eye diagram is a widespread method which also can be used here. To determine the opening level of the eye a mask is defined which specifies limits of signal traces [4]. If the mask is subtended by some parts of the signals, then the size of overlapping is taken as value for the error. For this the differences between signal and mask are determined and integrated up over the complete trace of the signal. This value is taken as quantity for overlapping of signals and eye diagram mask.

Figure 7 shows examples of eye diagrams.

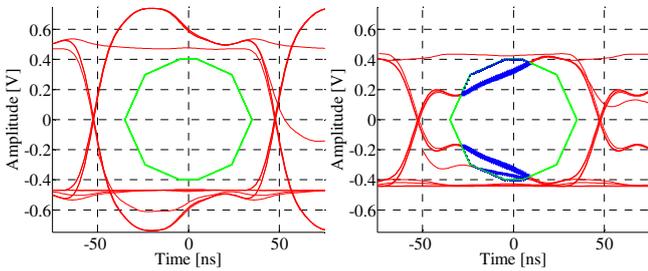


Figure 7: Examples of Eye Diagrams

In the left part of Figure 7 an eye diagram with a non violated mask is shown. Here the error value using the above described method with overlapping is zero. In this case other methods to determine an error value must be used, for

example calculating a weighted mean squared error to some reference signal. In the right part of Figure 7 the eye diagram mask is subtended by the signal traces, the area of coverage is marked. This area is calculated and used as error value.

C. Optimization of Bus Systems

With the help of automated bus system simulations, parameter optimizations can be processed easily. Safety critical applications are very important and it is necessary to know, under which circumstances a bus system still provides correct functionality and when correct message transmission probably is no longer possible. Thus an interesting question is the influence of different parameters on the signal integrity of the bus system. But only few parameters left to change already result in very many combinations so that a calculation of each combination mostly is not possible in practice. Optimization methods can be used to determine corner cases and to find parameter combination providing the maximum signal error value.

Methods commonly used in circuit analysis produce good results in general ([6],[7],[8]). But in the last years plenty of other optimization techniques were developed which have the potential to achieve better results in less optimization steps ([9],[10]). Thus the possibility to use several modern methods within the field of signal integrity and interference immunity of bus systems is investigated. The following methodologies are examined more closely: Tabu Search, Simulated Annealing (SA), Genetic Algorithms (GA) and Particle Swarm Optimization (PSO). For details about these methods and possibilities to adapt and extend them see [11].

D. Comparison of Methodologies

Tabu Search works very locally, the search takes place most often on a very limited section of the search space. Thus there is a high probability that the most interesting sections of the search space are not reached and only results that do not come close to the global optimum are found [11]. For this reason, Tabu Search is not examined more closely.

Table 1 shows results of the three other methodologies for two bus system topologies: Topology 1 is of minor complexity with 5 bus nodes and 16 parameters for variation, topology 2 is of higher complexity with 11 bus nodes and 41 parameters for variation.

TABLE 1: RESULTS OF OPTIMIZATION FOR TOPOLOGIES 1 AND 2

	Topology 1			Topology 2		
	SA	GA	PSO	SA	GA	PSO
Initial Error	0.514			0.112		
Method	SA	GA	PSO	SA	GA	PSO
Maximum Error	0.753	0.741	0.749	0.158	0.141	0.157
Average Simulations	269	2020	1486	744	2020	1864

The maximum error values found with SA and PSO are comparable, at topology 1 PSO is a little off compared to SA. But the results of GA are worse than those of the other two methodologies at both topologies. At topology 2 there is a considerable difference. The difference between the results of

GA and the other two methodologies seems to grow with increasing amount of parameters for variation. A possible reason for this behaviour can be found within the complexity of the methodology. GA contains several operations, like selection, mutation and crossing of individuals, which need to be adapted to the current optimization problem. Though detailed research about adaption possibilities has been done in advance, GA produces worse results here. SA and PSO need much less effort for adaption, which can be seen in the quality of the results. Thus these two methodologies are more suitable for application in practice.

Because GA and PSO are based on populations they need more simulation runs to calculate the maximum error value than SA. At the minor complexity of topology 1 the population based algorithms cannot use their whole potential of the parallel approach. Here SA produces the best results within the shortest optimization time. But at the more complex topology 2 the amount of needed simulation runs for SA increases significantly, the increase for PSO is clearly less. Tendentiously it can be said, that with increasing amount of parameters for variation the run times of the population based, parallel search approach of PSO and the sequential search approach of SA obviously come closer.

For better comparison between SA and PSO the course of optimization is looked at in the following. Figure 8 shows the course of convergence of the two methodologies, after how many simulations which error value has been found. With topology 1 there is only little difference between the two curves, SA is faster only in the last part before reaching the final error value. A different image shows topology 2. Here it can be seen that in the beginning PSO makes much more progress than SA in searching for the best error value.

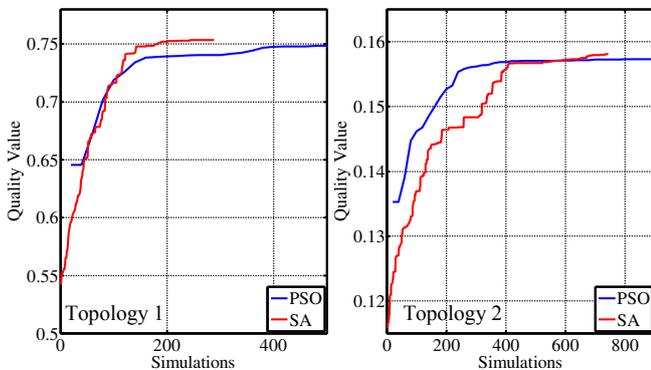


Figure 8: Progress of Optimization with SA and PSO for Topologies 1 and 2

With topologies with minor complexity the parallel search approach of PSO obviously is too complex. For each single step, the whole population containing p individuals has to be evaluated, thus only every p steps improvement in finding the maximum error value can be made. In this time, SA in total has p times the chance to find a better error value and to continue the search from this point. With more complex models the advantages of the population based methods can be seen. Due to the parallel search approach at PSO, the search spaced can be searched at different locations at once. By this the approximate location of the maximum error value

can be obtained faster. In comparison SA needs a certain amount of time until the search process has reached the region of maximum error value in search space, and thus with more complex topologies SA spends comparatively much time in not that interesting regions of the search space. It can be assumed that with topologies with a high amount of parameters for variation, PSO will find critical configurations in bus system operation faster than SA.

In addition the general approach of the population based, parallel search space coverage of Particle Swarm Optimization can easily gain speed up by using multi threaded program execution on parallel calculation units. This enables investigation about very complex topologies at acceptable run times.

IV. CONCLUSIONS

Many bus systems operate at limits of their specification. Under these circumstances validation of safety critical function is of high importance. Because many parameters influence the signal integrity of bus systems, a verification by measurement is not possible any more. In this article methods for automated, simulation based validation of bus systems are presented. The models used for simulation are described and it is shown, that results about real bus system topologies can be derived from simulation. Further an automated environment for bus system analysis using signal analysis based on eye diagram violation is presented that helps finding critical parameter combinations. Several search methodologies are examined and compared. The methodology of Particle Swarm Optimization seems to be particularly suitable for the analysis of complex bus system topologies.

Based on the results presented here, simulation and optimization times can be decreased using multi threaded execution und thus practical conclusion about signal integrity and electromagnetic immunity even of very complex bus systems can be drawn within short time.

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